The AMSAT® Journal

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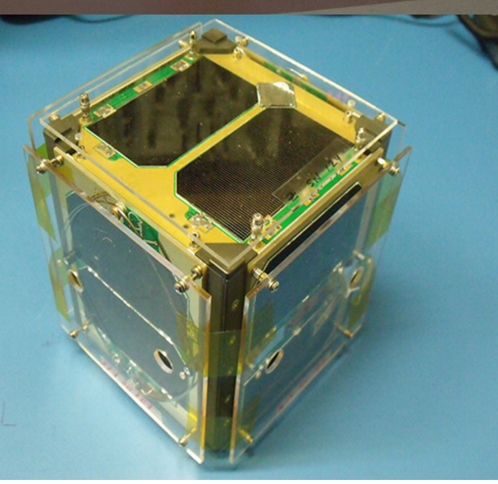
Symposium Ahoy!



in this issue ...

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AMSAT Announcements

2016 AMSAT Board of Directors Election Results

As a result of the 2016 Board of Directors Election, Tom Clark, K3IO, Mark Hammond, N8MH; and Bruce Paige, KK5DO, will serve on the board for two years.

The First Alternate is Paul Stoetzer, N8HM, and the Second Alternate is Clayton Coleman, W5PFG. Both will serve for a term of one year.

The results of the voting with 697 ballots cast are as follows:

Tom Clark, K3IO...............................547
Mark Hammond, N8MH..................504
Bruce Paige, KK5DO.........................396
Paul Stoetzer, N8HM........................362
Clayton Coleman, W5PFG...............200

Submitted by:
Martha Saragovitz, Manager
Paul Stoetzer, Secretary

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

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

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The AMSAT Journal staff is always interested in article submissions. Whenever possible, submissions should be sent via e-mail to journal@amsat.org using plain text or word processor files; photos or figures in TIF, GIF or JPG formats. Kindly do not embed graphics or photos in your manuscript. We prefer receiving those as separate files. AMSAT-NA reserves the right to select material for The AMSAT Journal based on suitability of content and space considerations.

Apogee View

Barry Baines, WD4ASW
President

Labor Day has passed, and we're now into fall. This time of year brings several annual events that are important to AMSAT.

First, the results of the Board of Directors election were announced on September 15. You'll recall that Lou McFadin, W5DID, and JoAnne Maenpaa, K9JKM, decided to step down from the board, and did not stand for re-election, while Tom Clark, K3IO, was up for re-election. Consequently, two openings were available on the board for new people to become involved with determining AMSAT's strategic direction.

The election results: Tom Clark, K3IO (Clarksville, MD), was re-elected and Mark Hammond, N8MH (Coats, NC), and Bruce Paige, KK5DO (Houston, TX) were elected to replace Lou and JoAnne for two-year terms. Both individuals served as board alternates for the past year, but just as noteworthy is that both had previously served as voting board members. The end result is that the AMSAT Board will continue with experienced personnel who know the workings of AMSAT and work well within the board structure. AMSAT is fortunate to have two capable individuals ready to step up and help guide the future of AMSAT. Mark and Bruce assumed their new roles immediately upon announcement of the election results.

But Wait, There's More…

Paul Stoetzer, N8HM (Washington, DC), was elected First Alternate, and Clayton Coleman, W5PFG (Palestine, TX), as Second Alternate, for one-year terms. Paul currently serves as the AMSAT Corporate Secretary and is a very active satellite operator while Clayton is the Chair of the 2016 AMSAT Space Symposium Committee and is also a very active satellite operator. They'll bring their passion to the board for amateur radio in space as well as a willingness to deal with the challenges that AMSAT faces.

Board alternates are fully engaged in the board's deliberations, fully participating in the activities of the board. We've encouraged board alternates to be involved because they do bring a perspective to the discussions, and should they assume a voting seat in the event a sitting member is no longer able to participate, they're already briefed and fully engaged in preparation for their new role. This approach has worked well in the past when in 2014 both alternates assumed voting positions, first when Gould Smith, WA4SXM, resigned for health issues, and later, Tony Monteiro, AA2TX, succumbed to cancer.

That said, there is another reason why I'm excited to have Paul and Clayton join the board as alternates. I see this as the extension of a process where we're bringing the next generation into AMSAT leadership positions.Differences in perspectives and life experiences exist between what most members of the current leadership have seen and been influenced by versus younger members who see things somewhat differently. Organizations thrive by being able to adapt to new environments and opportunities.

A key concern is whether AMSAT can recognize new ways of keeping amateur radio in space, while also recognizing and adapting to evolving expectations of our membership and the Amateur Radio community in general. Bringing in new blood is critically important, not only in terms of bringing new perspectives, but infusing new energy and enthusiasm as well, preventing the organization from atrophying as a result of potential leadership burnout. Hopefully, we'll continue to succeed in encouraging AMSAT members to become actively involved in the activities and leadership of AMSAT

So, welcome aboard to Paul and Clayton! We also must thank JoAnne and Lou for their service to the board and to AMSAT in general. Their participation in the board and insight have been very beneficial to AMSAT. Both have made a huge difference for AMSAT. Fortunately for AMSAT, Lou will continue to be engaged with ARISS and JoAnne will be assisting behind the scenes in the User Services area, as she is able. While their roles and responsibilities are evolving, AMSAT still will be able to take advantage of their considerable skills and interest in what AMSAT and ARISS are accomplishing.

Symposium @ Sea

The other major fall event is the AMSAT Space Symposium and Annual Meeting. This year's event is the 34th edition and is taking place in an entirely new venue: on board a cruise ship! The Carnival Liberty will be departing Galveston, Texas, on Thursday, November 10 for Cozumel, returning to Galveston on Monday, November 14. During our time at sea, we'll conduct the symposium using the ship's meeting facilities. For those of you who have participated in prior symposia, the schedule will be somewhat the same, with presentation of papers, an AMSAT banquet with a keynote speaker, and the formal Annual Meeting, as well as taking time to recognize key AMSAT volunteers who have done so much in the past 12 months to make this organization a success.

One change worth noting is that I had announced in the previous Apogee View that we had identified our banquet speaker. Unfortunately, circumstances have changed, and that individual is unable to join us for the symposium. We are now in the process of securing a keynote speaker and expect to announce that shortly.

I'm writing about the symposium for inclusion in this issue of *The AMSAT Journal* because, even though we've highlighted the Symposium @ Sea since January, it isn't too late to book your reservation NOW with Carnival Cruise Lines. This year's symposium promises to be both an educational and fun-filled opportunity for AMSAT members and their families. If you've been procrastinating about going, now is the time to make your reservation. Details were provided in the envelope that was mailed to the AMSAT membership in July, as well as is the AMSAT website: **amsat.org/?page_id=3667**.

Please note that booking your cabin with Carnival Cruise Lines covers your cabin and food. However, you still need to REGISTER for the AMSAT Space Symposium with AMSAT. The registration fee is $40.00 and includes the Proceedings of the 34th AMSAT Space Symposium and Annual Meeting. No additional costs are required for participating in the symposium and banquet, and other meals are included with your cabin. We do ask, however, that you notify us of the number of individuals in your party, and how many will be attending the banquet and/or the Field Ops Breakfast. You may register for the symposium on the website at the AMSAT Store, or mail the completed registration form (included in the 2016 Election Ballot that you received in July) with payment to the AMSAT office, or call Martha at the AMSAT office (301-822-4376).

Certainly one of the unique opportunities of attending Symposium @ Sea is being able to operate through the amateur satellites as a maritime mobile station. Carnival Cruise Line's policy is to allow amateur radio operations aboard their vessels. However, a licensed amateur radio operator intending to operate from Carnival Liberty must seek an International Amateur Radio Permit (IARP) that permits U.S. amateur licensees to operate in certain countries of the Americas. As Carnival Liberty is a Panamanian-flagged ship, an IARP is required while operating at sea on board that ship. The IARP is available through the ARRL with a 30-day lead-time expected. For details on applying for an IARP through the ARRL, as well as to download the IARP application, please see: www.arrl.org/iarp.

Mexico is not a signatory to the CITEL agreement that is the basis for IARP, which means the IARP is not an authorization to operate while the ship is in Mexican waters. An amateur seeking to operate within Mexico must seek a reciprocal license. If you intend to seek a reciprocal license in order to operate from Mexico while on the cruise, here's a starting point to better understand the application process: **xe-permit.wd9ewk.net/**.

Lastly, the Senior Leadership Team has discussed the idea of offering an award certificate to amateur satellite operators who work an amateur radio station on board the Carnival Liberty in the Gulf of Mexico during Symposium @ Sea. AMSAT Awards Manager Bruce Paige, KK5DO, has agreed to develop the details, so please keep an eye on AMSAT News Service (ANS) and the AMSAT website for specifics about working the AMSAT Symposium @ Sea.
See ya at Symposium!

Fox-1 Program Status

By now you've probably heard that SpaceX had a major failure occur on September 1 with one of its Falon-9 launch vehicles during tests at Cape Kennedy. The destruction of the rocket and mated satellites is currently under investigation.

AMSAT signed a contract with Spaceflight in July 2014 to have Fox-1Cliff (amended later to include Fox-1D) be placed in the initial flight of the SHERPA payload adapter and dispenser system that will fly on a SpaceX Falcon-9 rocket. Following the incident, AMSAT released the following statement that was carried via the AMSAT New Service on September 3:

"As a consequence of the anomaly during the static fire test of the SpaceX Falcon 9 on September 1, 2016, the planned integration of Fox-1Cliff and Fox-1D on the Spaceflight SHERPA has been postponed. AMSAT will provide updates regarding the schedule for Fox-1Cliff and Fox-1D activities when further information is available."

As of September 20, AMSAT has not received any additional information concerning an updated launch schedule or when Spaceflight will require delivery of our two CubeSats. Presumably the failure will have an impact on SpaceX's launch schedule. We can say that both satellites have been built, their environmental and performance testing completed, and are ready for launch. AMSAT VP of Engineering, Jerry Buxton, N0JY, will deliver both satellites to Spaceflight, Inc., whenever Spaceflight is in position to integrate them into the SHERPA. In the meantime, Jerry is 'babysitting' both satellites to ensure they're at peak performance for launch. Stay tuned!

Meanwhile, work proceeds on RadFXSat/Fox-1B, which has been assigned to NASA's Educational Launch of Nanosatellite program (ELaNa-XIV) mission from Vandenberg AFB. The current launch date is March 16, subject to change. Our CubeSat is expected to be ready in October for environmental testing required by NASA. At this point, we're confident that RadFxSat/Fox-1B will meet the integration schedule.

Vanderbilt University submitted its CubeSat Launch Initiative Proposal in November 2015 to fly RadFxSat-2/Fox-1E. Its proposal was accepted into the ELaNa program this past February. At this point, we're anticipating a launch opportunity currently being scheduled for late 2017. Fox-1E will feature a linear transponder, the first Fox-1 class satellite not using FM. Development work on the linear transponder is proceeding, and we look forward to seeing this new communications package design flying in the next 15 months or so.

Looking Forward…

The AMSAT Board of Directors meeting will take place prior to the AMSAT Space Symposium @ Sea. We're meeting at the DoubleTree by Hilton at Galveston Beach all day and into the evening on Wednesday, November 9, and Thursday morning, November 10. The board meeting is open for members and guests to attend, though there likely will be at least one closed session on Thursday morning. AMSAT has a small block of rooms available at the DoubleTree, but the October 21 cutoff is quickly approaching. If you're planning to attend the board meeting and would like to stay at the hotel, contact Martha at the AMSAT office immediately and get the group code.

The board meeting is a day and a half of intense conversation and exchange of information. First, the board elects the senior officers for the coming year. Next, the various department heads present their reports to the board. The board will review the 2016 financial picture of the corporation and discuss a draft 2017 budget.

During the November meeting, I expect the board will look at establishing a strategic planning process to take place in 2017. As the board is responsible for the strategic direction of AMSAT (while the President and Senior Leadership Team handle day-to-day tactical affairs), the board needs to step back for a serious and reflective look at the future using a strategic planning process that encompasses a variety of areas. The AMSAT organization that exists today is not the same organization that existed in 2008 when I became President. Indeed, most of the board members and Senior Leadership Team that serve today were not in those positions back in 2008.

Adding to the need for such a process is that the Fox-1 program will complete the last of the series (as currently planned) in late 2017 or early 2018. While Engineering is working towards creating the "five and dime" ground terminal that has potential application in a variety of uses — including Phase-4B, CubeQuest Challenge with Ragnarok Industries, and a HEO 6U CubeSat concept, it is certainly appropriate for the board to take time in the coming year to establish a multi-year plan. The plan should build on our accomplishments, encourage the organization to push the envelope, subject to AMSAT's existing resources, and capabilities, and recognize the perceived impact of externalities that influence the organization. The last thorough strategic plan was established in 2004 with an update in 2009, when the board made the decision to accept the recommendations of the Engineering Task Force (led by VP of Engineering Tony Monteiro, AA2TX) to establish the Fox-1 program. Given that it has been seven years since the board took the time to think through a strategic plan, it is time to focus on it again.

In summary, the upcoming board meeting offers an opportunity to not only acknowledge and celebrate the variety of successes of the past year and to note areas of focus for 2017, but also to initiate a critically important conversation that will presumably focus on "where do we go from here?" This conversation will likely continue through 2017, as we continue our relentless efforts towards "keeping amateur radio in space."

Lastly, we will conduct the AMSAT Annual Meeting (required by the by-laws to be conducted in October or November each year) on board Carnival Liberty. Although the annual meeting will take place at sea on the Carnival Liberty, as in past years, we'll utilize EchoLink to allow AMSAT members not at the symposium to participate in the annual meeting. The meeting will include an AMSAT Status Report given by the President, as well as a Q&A session for members to ask questions and provide input in a public meeting. Please note that our ability to provide an EchoLink connection is contingent upon the availability of internet access through the ship's satellite link. Technical issues could preclude making EchoLink available.

Please keep an eye on the AMSAT website and AMSAT News Service (ANS) for specific information about the day and time of the annual meeting and how to access the EchoLink connection. In the past, the annual meeting has taken place late on Saturday afternoon of Symposium weekend. However, as the cruise ship will be at Cozumel on Saturday, November 12, the annual meeting likely will take place on Sunday the 13th. I expect that the President's presentation to those attending the annual meeting subsequently will be placed on the AMSAT website, and that a summary of the annual meeting will be provided through AMSAT media. So, for anyone unable to join us for the annual meeting either in person or via Echolink, we will make the presented materials available.

eBay Sellers Donate to AMSAT

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

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

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

When your item sells and the winning bidder pays, eBay will deduct the percentage from your take and forward it to AMSAT.

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

AMSAT CW Activity Day

Ray Soifer, W2RS

Thanks to all who participated in AMSAT's Straight Key Night 2016, held in memory of Ben Stevenson, W2BXA. For 25 years, AMSAT has sponsored SKN on OSCAR, and it's been my pleasure to conduct this event.

While Morse as a license qualification has gone the way of the spark gap, I am pleased to see that amateur CW activity is as popular as ever. Straight keys and "bugs", however, have found a niche primarily with the boat anchor crowd, and AMSAT's insistence on their use in OSCAR SKN has held down participation. Similar considerations have led ARRL to broaden its annual HF event to include all forms of CW, even computer-generated. The idea is to encourage everyone to enjoy CW operation, no matter how they choose to do it.

We agree 100%. So, in with the new: AMSAT CW Activity Day.

As with the old SKN, it will be a fun event, not a contest, and will run for 24 hours on January 1, 2017 (UTC). All forms of CW are welcome. Since it is not a contest, there is no required exchange. A QSO is a QSO. Working the same station on more than one satellite is permitted.

Instead of submitting Best Fist nominations, all participants are asked to post their results, including "Soapbox" comments, to AMSAT-BB. Please include the satellites you used, and the number of CW QSOs you had on each. While it is not necessary to post your full log, you may do so if you wish.
CU on CW!

ARISS Update

Frank Bauer, KA3HDO
Vice President, Human Spaceflight
ka3hdo@amsat.org

Our ARISS international team of volunteers is simply amazing! A simple thanks is not enough for all they do every day. Directly or indirectly they inspire, engage and educate our youth and the general public about amateur radio, human spaceflight, satellites and radio technology. As a result, countless students and adults learn, first hand, about our collective hobby and the vast opportunities that AMSAT opens up through satellite development and operations, on-board the ISS and on-board our Fox CubeSats.

It will be hard to convey all we have accomplished in ARISS since our last ARISS Update. In this article and accompanying photos, we will just touch the surface of what we have done. To gain even deeper insight, I encourage you to volunteer! And don't forget the ARISS donation button on the AMSAT Home Page. The road to complete our desperately needed hardware upgrade is still long and expensive. We still have plenty of ARISS Challenge Coins for those willing to donate $100 or more. So, here is the ARISS update.

Meeting with NASA Benefactor SCaN

On Friday July 22, the ARISS-US Executive team (Frank Bauer, Debra Johnson, Kenneth Ransom, Dave Taylor, Rosalie White) traveled to NASA Headquarters to meet with leaders from NASA SCaN (Space Communication and Navigation). SCaN is ARISS' primary NASA benefactor, funding about half of our payload operations support costs — about $70K per year. CASIS (Center for the Advancement of Science in Space) funds the other half of our payload operations support costs. Discussion topics with SCaN included ARISS program objectives and successes. The SCaN team led brainstorming sessions throughout the day on ways to improve program outcomes, especially through potential new partnerships, and how to more formalize ARISS back-up communications strategies. SCaN is especially interested in ARISS' back-up communications support as SCaN is responsible for the primary communications and navigation capability on ISS. Some of the ideas leveraged from our meeting with SCaN dovetailed into the U.S. team strategic planning that ARISS executives conducted following the SCaN meeting.

The ARISS team at Escape Velocity.

U.S. Team Strategic Plan and Comprehensive Budget

While in Washington, D.C. for the SCaN meeting, the ARISS Executive Team carved out part of the weekend for a strategy planning retreat. Mark Steiner, K3MS, was able to rejoin the team after a brief hiatus from ARISS and support our U.S. team retreat. We thoroughly discussed multiple topics to further develop our team vision, mission, goals, strategies, and 3- and 5-year plans. Over the next two weeks, we employed the retreat material to develop a U.S. team strategic plan and 2017 budget. While the strategic plan and budget could be viewed as aggressive or far-reaching, the ARISS-US executive team felt it was important to reach far. After all, how can we reach for the stars if we remain grounded to the Earth. AMSAT President Barry Baines and ARRL CEO Tom Gallagher are currently reviewing the strategic plan and budget before we publicly release it. We also plan to employ the U.S. plan as a data-point to develop an ARISS International Strategic Plan.

ARISS Outreach at Benefactor-sponsored Venues

The year continues to be transformative for ARISS as we learn to better work and adapt to our major benefactors' (SCaN and CASIS) needs and requests. Our newest initiative is supporting conferences and event venues per the request of our benefactors. Our approach to these are to augment team members that have done this before, such as those that have supported our Air and Space Museum events, with new team members, especially team members local to the venue. To date, we have supported the following: in April, U.S. Science & Engineering Festival (SciFest) in D.C. for CASIS; in early July, Escape Velocity in Maryland for SCaN; and, in mid-July, ISS Research and Development Conference (ISS R&D) in San Diego for

CASIS. Two of these events, SciFest and ISS R&D, included an ARISS contact.

Highlights of the July events follow.

Escape Velocity

NASA's participation in Escape Velocity was billed as science fact meets science fiction as the included photos of the event can attest! ARISS set up and staffed it's display as part of the NASA booth. Escape Velocity was held at National Harbor, Maryland, July 1-3. SCaN retirees Ken Perko, WA3WHE, and Bill Watson, KB3USC, and ARISS summer intern Alex Siegel supported the booth. Paul Stoetzer, N8HM, demonstrated satellite QSOs just outside the auditorium. Youth and the general public listened on headsets to a recorded ARISS contact and explored the specially developed ARISS antennas and slow scan TV system. As you can see from the photos, frequent visits from "alien life forms" were the norm.

ISS R&D

CASIS asked the ARISS team to promote STEM education and outreach at the ISS Research and Development Conference, which was held July 12-14, in San Diego, CA. This event was pretty comprehensive as it included substantial equipment shipment logistics, setup of a booth, an ARISS contact and the presentation of an ARISS paper on Ham TV. Five ARISS volunteers set up and staffed the ARISS booth in the CASIS Space Station Explorers area of exhibits. ARISS California residents Kerry Banke, N6IZW, and Tim Bosma, W6MU, were our "local" team supporting this venue. An ARISS contact was conducted on July 14 between Jeff Williams and students from six area schools and one Florida school.

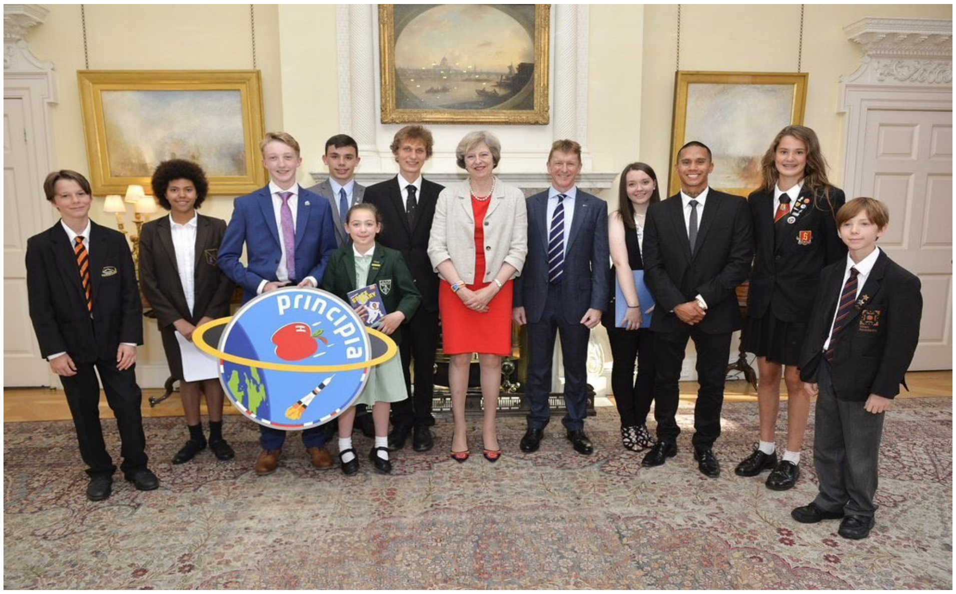
ARISS closely collaborated with local Space Station Explorers colleague Liam Kennedy to engage the local school community with ARISS. Liam Kennedy's ISS engagement hardware/software system, called ISS Above, uses the Raspberry Pi as a hardware platform. ISS Above is in several ARISS ground stations and has been employed during several ARISS contacts, including this contact. Prior to the contact, Astronauts Carl Walz and Josh Cassada energized students and parents with stories about their experiences as astronauts, with Carl describing his efforts installing the ARISS antennas on ISS and Josh describing his training as a new NASA astronaut. Also, I presented a paper on the ARISS Ham TV capability as part of the conference session on STEM outreach.

Interoperable Radio and Power Supply System Status

The ARISS hardware team is making great progress on the design of the interoperable radio system. A brass board version of the multi-voltage power supply was developed by Kerry Banke, N6IZW, and was presented at the ISS R&D conference. Many human spaceflight experts attend the ISS R&D conference. One of the NASA avionics

Frank Bauer with student at ISS R&D conference.

experts did a thorough review of the power supply and was impressed with the design. Kudos to Kerry and Lou, W5DID! In addition, Lou, Kenneth Ransom, N5VHO, Graham Shirville, G3VZV, and I traveled to Moscow where we presented the interoperable radio system design to Sergey Samburov and his team at RSC Energia. The meeting went well with additional presentations planned via telecon with the Russian subject matter experts. Our next step is to conduct our first design



review of the hardware system, which is tentatively planned for the week of October 20. A NASA-held Phase 0 safety review is expected a month later.

Meeting the Prime Minister

Tim Peake's outstanding Principia STEM education mission is now complete, and he is safely back on Earth. Peake's amazing support of ARISS was unprecedented. Not only did he conduct the first-ever Ham TV downlink during an ARISS contact, he deeply inspired a large student population in the UK and around the world to pursue STEM careers. His reach into schools and the general public was the largest ever for ARISS, with school audiences above 44,000, social media posts greater than 100,000 and general public outreach via media greater than 20 million.

But wait! There's more!! After returning from ISS, Peake took several of the UK students with him on July 18 to meet with the new UK Prime Minister Theresa May at 10 Downing Street. Among them was Jessica Leigh, M6LPJ, who obtained her ham license for Tim's mission and was the first student to talk to Tim Peake on-orbit. And at the AMSAT-UK International Space Colloquium the Ron Broadbent, G3AAJ, Award for 2016 was presented to the ARISS UK team. The award was for their outstanding work during January - May 2016 on the demanding series of ARISS contacts with the 10 Principia schools. It is fitting that Ciaran Morgan, M0XTD, and his team received this award because G3AAJ, now SK, was one of the founders of ARISS and worked diligently to develop ARISS as a model team to inspire our next generation to pursue amateur radio as a hobby and STEM/ space careers.

Closing

In November, ARISS celebrates its 20th anniversary. To commemorate our anniversary, we will be holding our ARISS International meeting in Houston, Texas, November 15-18 (right after the AMSAT Symposium Cruise). On November 14, we are planning special tours of NASA Johnson Space Center for those interested. It is not too late to sign up, so contact us if you are interested.

As we close in on our 20th anniversary, I continue to be awed by our international team. I have communicated to you just a small segment of the tremendous efforts that occur every day as part of ARISS. And I thank AMSAT and YOU for your help and support to make our program such a tremendous success.

73, Ad Astra — To the Stars

Smile for AMSAT at Amazon.com

Select smile.amazon.com when making your Amazon purchases and default to Radio Amateur Satellite Corporation as your chosen charity.

Want to put a smile on a satellite? When you make your purchases from Amazon, you can select a charity and Amazon will donate .5% of a qualified purchase towards your selected charity. AMSAT (Radio Amateur Satellite Corporation) is registered with Amazon Smile and you can select it as your preferred charity, which in turn will put a smile on our satellite efforts.

Once you have selected your Amazon Smile charity, when you go to amazon.com, it will remind you to go to smile.amazon.com. However, you can put everything you want in your cart at the original amazon.com site, then leave the site and go to smile.amazon.com and all your items will still be in your cart and make the purchase there. Or, just go to smile.amazon.com all the time. Your choice, only thing is if you forgot to pay at smile.amazon.com, AMSAT gets a goose egg instead of help towards a new satellite.

Remember, go to smile.amazon.com and select Radio Amateur Satellite Corporation.

Chirps

Predicting mutual satellite windows between two stations

Question by Andrew Glasbrenner (glasbrenner at mindspring.com) on August 20, 2016:

Is anyone aware of a tracking program that will predict mutual windows between two points on all satellites in a group rather than just one satellite at a time? I am aware of and use SatPC32's excellent WinListen, but as far as I can tell it only predicts mutual windows for one satellite at a time.

Answer by Alex Diaz (xe1mex at yahoo.com) on August 20, 2016:

Nova for Windows has a utility named "Listing Data for Two Observers." Specifically, what you want is named "Two Observers, Multiple Satellites Mutual."

Operating on Satellites from a Cruise Ship: Lessons Learned on Nine Cruises

Allen F. Mattis, N5AFV, n5afv@amsat.org

Operating on satellites from a cruise ship is something many satellite operators have wanted to do. Operating aboard ship requires the operator to obtain both permission to operate amateur radio on the ship and the proper amateur radio license. Someone who operates amateur radio on a ship without fulfilling these requirements could face serious consequences. Advance planning and preparation are needed to both fulfill these requirements and to select and become familiar with the radio equipment to be used.

Requirements for Maritime Amateur Radio Operation

Part 97 of the rules of the Federal Communications Commission is quite clear:

> 97.11 Stations aboard ships or aircraft
>
> (a) The installation and operation of an amateur station on a ship or aircraft must be approved by the master of the ship or pilot in command of the aircraft.
>
> (b) The station must be separate from and independent of all other radio apparatus installed on the ship or aircraft, except a common antenna may be shared with a voluntary ship radio installation. The station's transmissions must not cause interference to any other apparatus installed on the ship or aircraft."
>
> In addition, the information available on the ARRL website regarding maritime operation by US amateur radio operators (http://www.arrl.org/maritime-mobile-operation-in-international-waters) states "When an FCC licensed amateur is operating an amateur rig aboard a US-registered vessel in international waters, he or she must follow Part 97 of the FCC rules, particularly Section 97.11…. If the ship is of foreign registry, (he or she) must obtain a reciprocal operating authorization for the country of registry in addition to being in compliance with Section 97.11.

Obtaining Permission to Operate

Some cruise lines have had bad experience with amateur radio operators in the past, and as a result, they may not allow amateur radio operation on their ships. There are documented cases of ham radio operators putting up vertical or wire antennas on ships and operating without permission. Due to safety considerations, cruise ships will not allow antennas to be attached to the ship, and runs of coaxial cable are also considered to be a safety hazard. A small number of cruises organized by groups such as the Quarter Century Wireless Association (QCWA) have put together ham radio cruises with HF operation permitted but individual operators have little to no chance of obtaining permission to operate on HF with large antennas. Fortunately, the UHF/VHF bands employed by satellites lend themselves to the use of low power and handheld antennas, and seldom result in RFI.

In 1999, the international regulation requiring all ships at sea to monitor the international CW distress frequency of 500 kHz was dropped, and many cruise lines no longer have radio officers. Instead, they have communications officers whose responsibility includes maintaining both the information technology (IT) network and the radio systems on board the ship. The communications officers on many ships are very computer oriented and know little about radio communications.

With the tighter security imposed post-9/11, speaking with the communications officer is often no longer possible. It used to be possible to meet with the radio officer on a cruise ship[1], and this often made it easier to obtain permission to operate. I have been successful submitting written requests to operate amateur radio on ships.

My written requests to operate amateur radio on a cruise ship are submitted to the purser's desk for forwarding to the communications officer. It is better to write a letter requesting permission to operate before leaving home, and to print out several copies to take along on the cruise. A neat legible typed letter that has been carefully worded has a better chance of obtaining approval to operate than a letter written by hand while standing at the purser's desk with little advance thought given to the wording.

The primary concern when deciding whether or not to allow amateur radio operation on board a ship is that of safety and preventing possible interference to any apparatus or systems installed on the ship. We all know that operation of radio transmitters sometimes causes RFI, and that is why some cruise lines forbid passengers to operate any kind of two-way radio on board their ships.

Given that many of today's communication officers do not have the in depth knowledge of radio theory possessed by the radio officers of the past, when requesting permission to operate, operators need to address any negative perceptions regarding amateur radio that radio officers may have in their mind. Several points clearly should be made in the written request to operate. The letter I have developed after several cruises requests permission to operate a small low-power handheld amateur radio on board during the cruise. I state that the radio is very similar to the Family Radio Service (FRS) radios used by many passengers, but operates on the 145 MHz VHF and 435 MHz UHF amateur radio bands. I tell them that I typically operate for very short periods of time, usually 10 to 15 minutes three or four times a day. I do not tell them that I will operate through a satellite or give them any details they do not need to know. The cruise line does not want any passenger to do anything that will disturb other passengers, so I state that I use a small headset with a microphone when I operate the radio so that I do not disturb other people. I usually end my letter by stating that I have operated this equipment on cruises in the past and that it did not cause any problems. If it is a cruise line I have sailed on in the past, I name the ships that I have operated on.

The time it takes to receive a response after a request to operate amateur radio has been submitted varies with both the cruise line and the ship. On one cruise with Princess Cruises, written approval to operate amateur radio was delivered to my stateroom eight hours after I submitted my request at the purser's desk. On a later cruise with Princess, I turned in my written request at 5 p.m. and received a telephone call from the communications officer at 7 a.m. the next morning giving me verbal approval to operate. Princess Cruises is one of the more amateur radio-friendly cruise lines. Other amateur radio operators have reported having a good experience operating from ships of the Holland America Line and the Norwegian Cruise Line.

Some amateur radio operators who sailed on Carnival Cruise Lines have reported that they did not receive a reply to their written requests to operate amateur radio while on the ship. What most amateur radio operators do in this situation is to assume that if, after reading the request, the communications officer hasn't notified them that it is not permitted, they are allowed to do it. I experienced a similar situation on a cruise with Royal Caribbean International. My written request was returned to my stateroom the next day by ship's mail with no comments or markings on it. Since the communications officer knew I wanted to operate amateur radio, and he didn't notify me that I couldn't operate, I assumed it was permitted.

The Celebrity Cruise line reportedly has a policy of not allowing passengers to operate amateur radio on their ships. Even though the promotional material that Celebrity sends to passengers and prospective passengers does not mention the policy, a Celebrity representative told my travel agent that they would confiscate any amateur radio equipment they found on board one of their ships.

Sometimes approval is given to operate amateur radio on a cruise ship, but with restrictions. For example, one radio officer approved my request to operate, but not at a full power of five watts. He was concerned about possible interference to the ship's radios on the 156 MHz VHF marine band. During that cruise I was careful not to transmit near any antenna on the ship that looked like it was used for VHF. Now that future satellites will be using UHF uplinks, we should also avoid transmitting near any UHF antennas.

In some instances, radio amateurs are asked not to transmit during critical periods such as when the ship is entering or leaving a harbor, or docking.[2] On one cruise, I chose not to transmit while passing through the Panama Canal. There were so many different simultaneous radio transmissions that I heard almost constant intermod on my HT. If I had transmitted at that time, I likely would have contributed to the intermod and been heard by other radio operators along the canal and on the ship. It is very important that amateur radio operators on board ships be careful not to do anything that may result in the denial of future requests by amateur radio operators for permission to operate on the ship.

In some ways, obtaining permission to operate is probably the single largest obstacle facing those who wish to operate amateur radio on cruise ships. There is always the possibility that once you have obtained the necessary licensing and boarded the ship you will not be able to operate.

Licensing on Foreign Flagged Vessels

The basic rule regarding licensing for amateur radio on a ship is that operation in international waters requires the operator to have an amateur radio license from the country in which the vessel is flagged. If the vessel is not in international waters, but in the territorial waters of a nation, it is necessary to have an amateur radio license from that nation in order to operate amateur radio from the ship. Fortunately, a number of international treaties and conventions make foreign licensing relatively easy for US amateur radio operators. The American Radio Relay League (ARRL) web page (http://www.arrl.org/international-operating) has a great deal of information on these international agreements, as well as on reciprocal licensing [3].

European Conference of Postal and Telecommunications Administration (CEPT)

The European Conference of Postal and Telecommunications Administration (CEPT) agreement T/R 61-01 gives US radio amateurs operating privileges in most European nations. All that is necessary is to have in your possession proof of U.S. citizenship, your original FCC amateur radio license (Technician class or higher) and a copy of the FCC public notice entitled "Amateur Service Operation in CEPT Countries" (DA 11-221, dated February 7, 2011), which is available on the ARRL web page. I have used CEPT operating privileges to operate on ships flagged in the United Kingdom and Norway, and to operate from land in Curacao, St. Bartholomew, Italy, France, Spain, Portugal, Azores, and Denmark.

International Amateur Radio Permit (IARP)

The Inter-American Telecommunication Commission (CITEL) has adopted an agreement for an International Amateur Radio Permit (IARP) that is valid in eleven countries in North and South America. The participating countries are Argentina, Brazil, Canada, El Salvador, Panama, Peru, Trinidad and Tobago, United States of America, Uruguay, and Venezuela. The IARP is issued to U.S. amateur radio operators by the ARRL and detailed information including an application form is available on the ARRL website (www.arrl.org/files/file/Regulatory/iarp-app.pdf). Operators must provide a passport photo and a copy of their FCC license (Technician class or higher) when applying for an IARP. The processing fee for an IARP is $10 and it is valid for one year. I have received reports in the past year that processing at ARRL headquarters may take several months. I have used an IARP to operate from Panama and Venezuela.

Reciprocal Licensing

In addition to CEPT and IARP, the United States has a large number of reciprocal agreements with other nations regarding amateur radio. These agreements make it possible for FCC licensed radio amateurs to obtain a foreign amateur radio license without having to take an examination. In the course of my nine cruises, I have operated from 21 different ARRL DXCC entities. Reciprocal licenses have made it possible for me to operate while the ships were docked in foreign ports or while I was onshore in ports of call. In some nations such as the Bahamas, Bermuda and the British Virgin Islands reciprocal operators use their home call sign appended with the amateur radio prefix for the reciprocal country (for example, N5AFV/C6A, N5AFV/VP9 and VP2V/N5AFV). Some of the reciprocal licenses I have received issued a foreign call sign to me such as Dominica (V79AFM), Cayman Islands (ZF2FA) and Belize (V31FV).

One downside of reciprocal licensing is that most of the permits cost $20 or $25 a year, and sometimes personnel checks or cash are not accepted for payment. U.S. Postal Service money orders are accepted in most, but not all, nations. The Cayman Islands is an example of a nation that does not accept U.S. Postal Service money orders; however, the Cayman Islands will accept a cashier's check from a U.S. bank.

Another drawback to reciprocal licensing is that some nations take a long time to process an application. My application for a reciprocal permit in Belize took six months to process, and I did not receive it in time to use on my first visit there. It has been my experience that most countries take at least six weeks to process an application. Those who are planning to operate on a cruise should begin their application procedure at least three months in advance, and as I found out with my application to Belize, it sometimes takes even longer.

Many ships are flagged in Bermuda, and a four-month reciprocal license is available from Bermuda by mail at no cost. Information is available on the Radio Society of Bermuda website (http://www.bermudashorts.bm/rsb/visitors.htm). Most of my cruises have been with Princess Cruise Lines whose ships are flagged in Bermuda.

The ARRL web page does a good job of providing information on reciprocal licensing; however, the information that is posted on the ARRL web page is not always up to date. For example, the name of the agency that issues amateur radio licenses and permits in the Cayman Islands had changed since the information was posted on the ARRL web page, and the cashier's check I sent with my application was returned with a request for a check made out in the new name of the agency. Also, my application for a reciprocal permit in Jamaica was returned to me six weeks after I mailed it with notations on the envelope stating "No such box number" and "Returned for better address." Not enough time was left before my cruise to re-apply for a reciprocal license in Jamaica, even if I could find the correct address. One possible solution to out of date information is to attempt to verify the information on the ARRL web page by either contacting the licensing agency in the foreign country if an e-mail address is given, or by contacting another amateur radio operator who has recently operated from that country. Verifying the information on the web page takes additional time, and I found out that the three months I had allowed for obtaining licenses in Jamaica and Belize was too short.

Finally, some DXCC entities visited by cruise ships permit operating with a U.S. amateur radio license. Examples are Puerto Rico, US Virgin Islands, Alaska and Hawaii. U.S. operators also have instant operating privileges in Canada. However, cruise ships seldom spend more than six to eight hours in a port, and most radio amateurs who operate on a cruise do the majority of their operating while the ship is underway and spend the time in port seeing the sights and enjoying the things that tourists do.

The Operating Environment on a Cruise Ship

When most people think about operating amateur radio on a cruise ship, they visualize someone sitting in a comfortable deck chair in the warm sun sipping a cool drink between or even during contacts. Only a small percentage of amateur radio satellite contacts made from a ship resemble that mental image. The fact is that the operating conditions on the open deck of a ship at sea are often hostile in nature. First of all, a strong wind usually is present. If the ship is moving at approximately twenty knots into a twenty-five knot wind, there will be a fifty mile per hour wind blowing across the deck. Use of a headset allows me to hear my radio under such conditions. If you have ten to fifteen foot seas, the ship will be rocking significantly. Also, the deck may be wet from ocean spray, and it could even be raining. It may be cold. I have experienced temperatures in the 40°- 45° F. range on ships in the northern Gulf of Mexico during December and January. As we know, some satellite passes occur in darkness. If all of these conditions occurred at the same time, the operating conditions could be extremely hostile, and care must be taken not be fall overboard while operating.

Keep these operating conditions in mind when selecting the equipment to be used for operating the amateur radio satellites on a cruise. The equipment should be lightweight, water resistant, and operate on self-contained batteries. I also take the approach that the equipment should not draw undue attention to the operator. If just one other passenger makes a negative comment to the ship's crew about the amateur radio operation, it is possible that the communications officer or captain would shut down the operation. On one of my cruises another passenger watched me operating a satellite pass and asked me what I was doing. I thought it would be a good opportunity to talk up ham radio and AMSAT, so I explained what I was doing. The passenger's first comment after I finished my explanation was to ask about people's right to privacy on the satellite. There was no way he would believe that I had authority to talk over a satellite, and he was convinced that I was illegally listening to telephone calls. If he had reported the incident to the ship's crew my maritime mobile amateur radio operation would possibly have been shut down.

Given the importance of keeping a low profile and not attracting attention, I no longer use an Arrow antenna on cruise ships. I used an Arrow antenna one cruise and learned that an assembled Arrow antenna is too large to carry in congested tight passageways. It is also very time consuming to assemble and disassemble an Arrow antenna before and after each satellite pass. My use of the Arrow antenna on that cruise was restricted to the veranda of my stateroom. On another cruise I packed my Arrow antenna without testing it, and when I assembled it on the ship and tried to work an SO-50 pass I could hear the satellite, but I could not get into the bird. The duplexer in the Arrow handle was defective on the two meter side, and the Premier (Pryme) AL800 I had packed as a backup antenna became my primary antenna for the cruise.

Other satellite operators such as Lee Devlin, K0LEE[4], and John Sheets, N8QGC[5], have used the Arrow antenna on cruises. Andy MacAllister, W5ACM, has also used an Arrow antenna on cruises[6]. Whether or not to use an Arrow antenna is up to the personal choice of the individual operator.

My preferred choice of equipment radio to use on a cruise ship consists of my out-of-production Icom W32A HT with a telescoping Premier (Pryme) AL800 antenna. The AL800 antenna fits in your pocket and only takes a couple of seconds to attach to your HT and be ready for use.

However, the AL800 is heavy and comes with a BNC connector. Unfortunately, today's mini-HTs have SMA connectors. Adapters from BNC to SMA are available but the SMA connector and small case on a mini-HT may not support the weight of an AL800. Fortunately, lighter antennas are available. Ray Soifer has had success using the MFJ-1717 16-inch rubber-coated dual-band antenna for working satellites, and Andy MacAllister used the similar Diamond RH77 15-inch rubber-coated dual band antenna on his cruise.[7,1] Both of these antennas originally came with BNC connectors, but SMA versions are now available. On one cruise, I was able to switch back and forth between the Premier (Pryme) AL800 and MFJ-1717 antennas while making contacts on SO-50 and AO-27. I found that both antennas performed acceptably, though the Premier (Pryme) AL800 appeared to provide better reception than the MFJ-1717. I usually take an MFJ-1717 along on my cruises as a backup antenna.

A number of satellite operators have used the Yaesu FT-817 with self-contained batteries for portable operation.[8] Gene

Andy MacAllister, W5ACM/C6A, using Arrow Antenna to make a ship-to-ship contact from the Gulf of Mexico to the Pacific Ocean. [W5ACM, photo]

Marcus, W3PM, operated on the amateur radio satellites from the Queen Elizabeth 2 in the North Atlantic in both 2002 and 2003 using an FT-817 with a home brew 2-element quad for receive and a 19-inch whip for transmit. Whether you plan to use an HT or a larger rig, you should take along extra rechargeable batteries and a battery charger. Staterooms on almost all cruise ships in North America are equipped with 120 volt AC power systems compatible with standard battery charging devices.

Besides the transceiver and antenna, other equipment is needed to efficiently operate on board a ship. A GPS unit is essential to know the maidenhead grid square in which the ship is located, as well as the direction the ship moving. It is necessary to know the direction the ship is moving to determine which side of ship to be on in order to work a low elevation satellite pass. I have already mentioned that I use a headset so my radio will not disturb other passengers. An inexpensive MFJ-288I headset has served me well. I have also found that a small, voice-activated tape recorder allows me to record the call signs of the stations I work. In order to keep the set up simple, the recorder does not record from the radio, but records only my voice. After the satellite pass, I transcribe the information on the tape recorder into a hard copy log. Other miscellaneous items to remember to take along include extra batteries for the GPS unit and tape recorder, and the user's manual for your radio. I sometimes take a few pieces of backup equipment along, such as a speaker microphone or extra headset, and few basic tools like black electrical tape, screwdrivers and pliers.

Each amateur radio operator on a cruise ship must decide the best way to obtain pass predications for the satellites. I try to travel light on cruises, so I do not take a laptop computer with me. Because I know the itinerary of the cruise ship before I leave home, I am able to print out pass predictions in advance for the entire cruise. Most cruise ships have Internet access available, and on the rare occasions when it appeared that my pass predictions were not correct or the ship deviated from the scheduled itinerary, I was able to go to the Heavens Above web site (www.heavens-above.com/) and obtain the information I needed.

I recommend having copies of the receipts showing when and where you purchased your radio and any other expensive pieces of gear. This documentation may be needed if you plan to take these items ashore at a stop or when you go through customs upon return. I generally put together a small three-ring binder containing these items along with a few maps, my amateur radio licenses and permits, the pass predictions, log sheets and any other related items I feel I may need.

Additionally, thoroughly inspect and check out each piece of equipment before you leave. If something needs repair, you will have time to do it or have it done. One way to check out the equipment is to make contacts with it before the cruise. My usual procedure consists of using my W32A HT and AL800 antenna to make 75 to 100 satellite contacts during the month prior to the cruise. On the final day of practice operation five days before my first cruise, I was working a satellite pass and received two reports of low audio. Testing indicated that the microphone in my MFJ-288I headset was not working properly, and I replaced the headset before leaving. Making practice contacts before the cruise also prepares you for operating on the ship. It is easier to make contacts in the dark or under hostile conditions when you are used to using the equipment. Also, it is essential that an amateur radio operator have experience operating on the satellites before attempting a cruise operation, and a "newbie" or new operator can gain that experience in a just few weeks of practice operation.

Summary

Operating on satellites from a cruise ship is relatively easy if advance planning and preparation are done. Obtaining the necessary amateur licenses usually takes at least several months, and a carefully worded written request prepared in advance increases the likelihood of receiving permission to operate. Selection and thorough testing of the equipment to be used should not be left to the last minute. An amateur radio operator attempting to operate on satellites during a cruise should have prior satellite operating experience. If these steps are followed, operating satellites from a cruise ship can be a very rewarding experience. Those who operate on the satellites from a cruise ship soon find out how much fun it is to be called by dozens of amateur radio operators pursuing new grid squares for the ARRL VUCC satellite award.

Notes

1. A. MacAllister, "Cruising for AO-27 on the Carnival Sensation," *73 Amateur Radio Today*, March 1997, p. 60.

2. A. MacAllister, "Cruising for Satellites," *73 Amateur Radio Today*, October 2000, pp. 22-28.

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6. A. MacAllister and A. Mattis, "Pacific Ocean to Gulf of Mexico Ship-to-Ship Satellite Contact," *The AMSAT Journal*, January/February 2007, pp. 11-12.

7. Soifer, Ray, "AO-27: An FM Repeater in the Sky," *The ARRL Satellite Anthology*, 1999, pp. 4.11-4.12.

8. A. Glasbrenner, "A Short Introduction to Using Your FT-817 and Arrow for SSB Satellite Demonstrations," *The AMSAT Journal*, January/February 2005, p. 8.

Gene Marcus, W3PM, used a Yaesu FT-817 with a home brew 2-element qual for receive and a 19-inch whip for transmit while sailing on the Queen Elizabeth 2. [W3PM, photo]

Amateur Radio and CubeSats - The Birth of a New Space Industry

Keith Baker, KB1SF / VA3KSF

[*Editor: Portions of this article first appeared in the February 2014 edition of* The Spectrum Monitor.]

The CubeSat concept began as a type of miniature satellite for space research and communications with a volume of exactly one liter (10 cm cube) and with a mass of usually no more than 1.33 kg (about 3 pounds). Beginning in 1999, students and staff at California Polytechnic State University (Cal Poly), under the direction of Engineering Professor Dr. Jordi Paug-Suari and Professor Dr. Robert (Bob) Twiggs, then at the Department of Aeronautics and Astronautics at Stanford University, developed the CubeSat specification. Their goal was to help universities worldwide perform space science and experiments without the high cost usually associated with such activity. Dr. Twiggs has since become a member of the space science faculty at Morehead State University in Kentucky. Bob is also a ham radio operator (KE6QMD), and a long-time friend of AMSAT.

As a result of their pioneering work, radio amateurs and others have built and launched a number of these satellites into earth orbit (over 100 at last count), and the design has since become a hit with both commercial and military interests — so much so that the National Aeronautics and Space Administration (NASA) is now seeking a booster designed specifically to launch CubeSats.

But the real story in all this is that the CubeSat concept actually evolved from the decades of work done by some amateur radio operators quite literally in their basements and garages.

Beginnings

Private groups of amateur radio operators around the globe have built and sent dozens of Amateur Radio communications and science satellites to orbit since the first, OSCAR-1, was launched on December 12, 1961. However, few are aware of the contributions those satellites have made to today's electronic way of life.

The OSCAR-1 satellite consisted of a small curved box that measured 9 inches by 12 inches by 6 inches and sported a single, spring-loaded, 2 meter whip antenna on its top surface. OSCAR-1 did not offer two-way communications. Rather, its non-rechargeable, battery-operated radio simply transmitted a Morse beacon with 140 mW of power on a frequency of 144.983 MHz. While 140 mW doesn't seem like much power by today's standards, OSCAR-1's transmitter still put out some fourteen times the power of the 10-mW radio carried in Explorer-1, America's very first satellite.

OSCAR-1 also holds the record for not only being the very first non-military satellite, but it was also the very first secondary payload ever to be launched from a rocket and then go into its own orbit. As OSCAR-1 was the first satellite to reach orbit as an auxiliary package ejected from a parent spacecraft, its ejection mechanism was of great interest to other scientific groups who also wished to place their own free flying satellites into orbit. When these groups approached the U.S. Air Force for such information, they were routinely advised to study the OSCAR-1 design.

What is even more amazing was that OSCAR-1's innovative ejection system (which was subjected to detailed stress analysis as well as careful mechanical and thermal balancing before launch) was all built around a $1.15 cent spring purchased off the shelf from a local Sears and Roebuck store. So, in that sense, OSCAR-1 ushered in the era of commercial off-the-shelf (COTS) space hardware as well.

Moreover, back in the "toddler" stage of space exploration, all satellites would be considered small by today's standards. And radio amateurs were then, as now, at the very forefront of this emerging space technology.

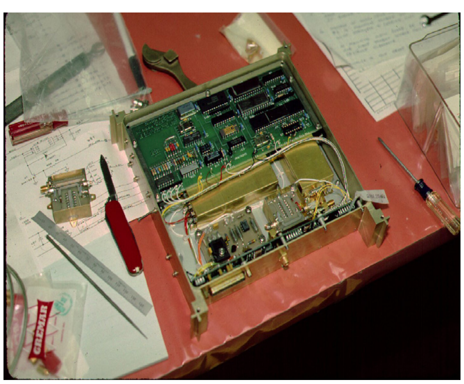
Bigger is Better

However, as with most other things American, and as rocket booster technology evolved, so did the size of satellites, to the point that, today, they range from small, lightweight nanosatellites to gargantuan behemoths that weigh several tons with volumes larger than an average size school bus.

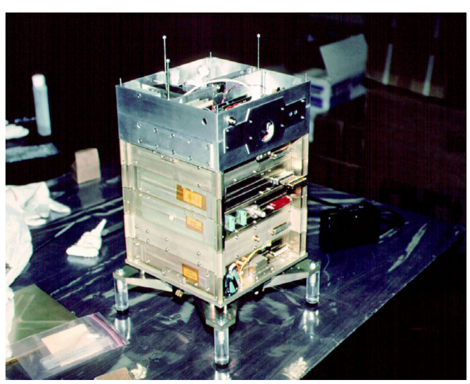
Unfortunately for radio amateurs, by the middle of the 1980s, the cost of launching even small satellites into orbit had grown to the point that organizations like the Radio Amateur Satellite Corporation (AMSAT) could no longer afford "piggyback" launches on military or commercial rockets. Indeed, by the late 1980s the commercial and military space business had grown so large that too many satellites were chasing too few launch opportunities. Clearly, if amateur radio operators were to continue putting communications satellites into space, something had to be done.

Microsats

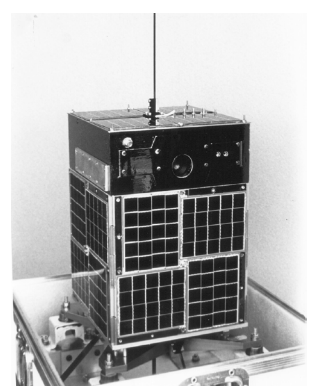
Faced with this do or die situation — and employing a number of innovative design



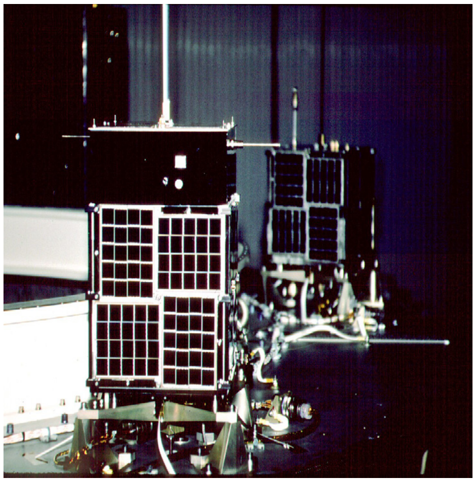
An early Microsat circuit tray. [Photo courtesy AMSAT]



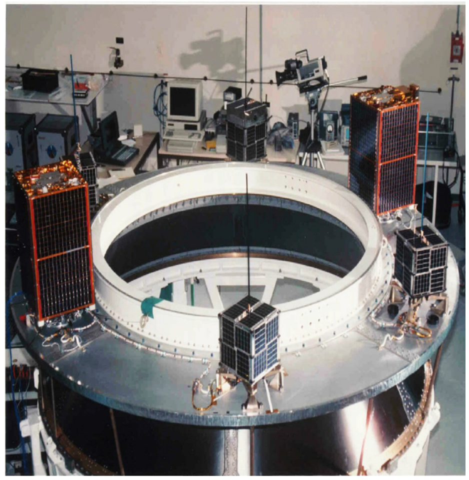
WEBERSAT undergoes final assembly in the Center For Aerospace Technology at Weber State University in Ogden, Utah. [Photo courtesy AMSAT]



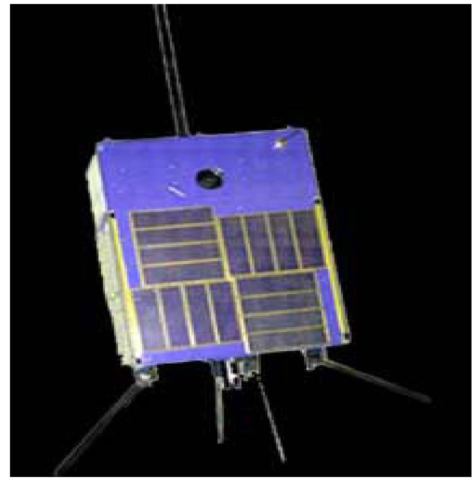
The flight model WEBERSAT satellite. Note the opening for the camera on the upper portion of the structure. [Photo courtesy AMSAT]



The WEBERSAT shares the launch structure with other Microsats. [Photo courtesy AMSAT]



Four Cubesats and two UoSats share the same launch structure, the Ariane Structure for Auxilliary Payloads [Photo courtesy AMSAT]



An artist's drawing of how WEBERSAT might look on orbit. [Photo courtesy AMSAT]

techniques that traded knowledge, skill and manufacturing capacity for a reduction (or outright waiver) of launch costs, AMSAT's experimenters helped create additional launch capabilities for commercial launch providers in return for significantly lower cost access to space. One of the most exciting examples of this concept is illustrated by a launch structure developed as a joint venture between the European Space Agency (ESA) and AMSAT.

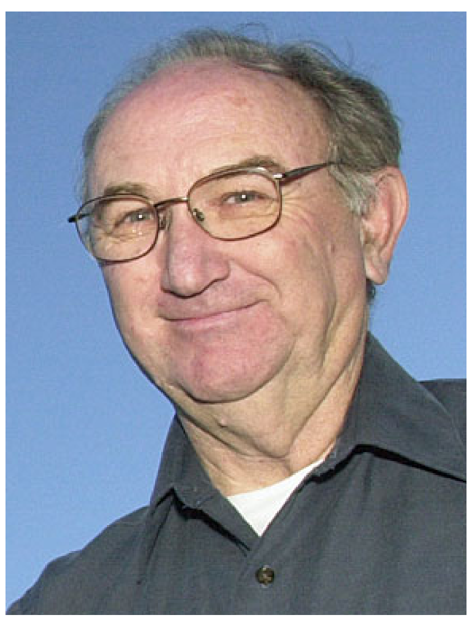
In the late 1980's, AMSAT was in the process of designing its latest series of satellites. Realizing they could no longer afford to launch full-sized satellites, and drawing (quite literally) on table napkins while sitting around a hotel room in suburban Detroit, AMSAT's experimenters came up with a significantly smaller spacecraft design they later dubbed a "microsat." The new design took advantage of the comparatively smaller size of electronic components of the day as well as the comparatively higher power solar cells of that time. The microsat design eventually evolved into a 9-inch-square cube that incorporated a series of stacked circuit boards with space for additional experimental TSFR ("This Space For Rent") experiments.

However, obtaining a launch opportunity for not one, but four of these planned satellites posed a rather daunting challenge. So, AMSAT volunteer engineers approached ESA with an idea of how they might exploit some of the then unused space on ESA's Ariane IV launch vehicle

To make a long story short, in partnership with ESA, AMSAT helped design and manufacture a very large carrying structure, called the Ariane Structure for Auxiliary Payloads (ASAP) for use in launching small satellites. The structure fit around the base of the Ariane IV rocket's upper stage and served as the platform from which all four of AMSAT's first microsats were placed into orbit by ESA in 1990. In return, AMSAT obtained a significant reduction in launch costs. ESA has since used the ASAP structure to launch similar, albeit mostly commercial, satellites into orbit.

Enter Bob Twiggs

One of the folks sitting around that table in Detroit that evening was Professor Dr. Robert (Bob) Twiggs. His contribution to AMSAT's microsat project eventually became Webersat-OSCAR 18 on orbit. The WEBERSAT (pronounced "Wee-Ber-Sat") was built and controlled by student hams and others at the Center for Aerospace Technology (CAST) at Weber State University in Ogden, Utah. At the time, Bob was the director of CAST.



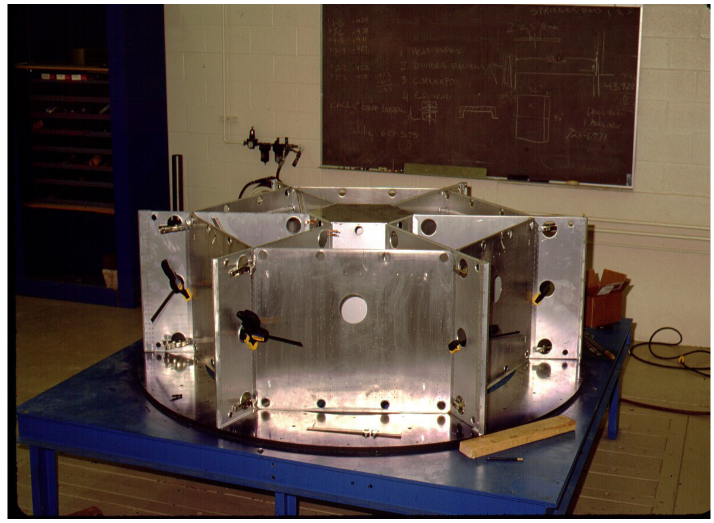
Professor Dr. Robert J. (Bob) Twiggs. [Photo courtesy Stanford University]

WEBERSAT carried an on-board CCD (Charge-Coupled Device) television camera with a resolution of 700 pixels and 400 lines that could snap a 350 x 350 kilometer Earth field of view. It then stored these pictures for later downloading. Some additional scientific experiments on board included a Micrometeorite Particle Impact Detector, a Visual Light Spectrometer and a Flux Gate Magnetometer. The onboard power budget averaged about 6 W from solar panels and onboard NiCad batteries. WO-18 also carried packet radio mailbox facilities, but these were never implemented other than for tests.

The satellite was both the largest and heaviest of the microsat series. That's because another TSFR section was added to the top of an otherwise stock Microsat frame during construction, primarily to house the camera and its associated equipment.

Soon after its launch in early 1990 (on the same Ariane vehicle that launched SPOT-2 from the Kourou Space Center in French Guiana along with three other microsats), Webersat began sending back images of both the Earth and the Moon. Some initial problems with the camera balance between light and dark were eventually resolved. The satellite digitized images from the onboard camera and then transmitted them on the downlink by way of an AX.25 serial data

Student members of Bob Twigg's CAST team pose with the fruits of their labors…the completed spaceframe and carrying structure for AMSAT's Phase 3-D satellite. [Photo courtesy CAST]



The completed flight model of AMSAT Phase 3-D Spaceframe sits on the leveling structure at CAST in Ogden, Utah. [Photo courtesy CAST]

stream.

CAST and Phase 3-D

The close relationship between Bob and his CAST team and AMSAT continued into the early 1990s. AMSAT selected CAST to manufacture the two space frames and the carrying structure (called the Specific Bearing Structure, SBS) for what would later become Amateur Radio's largest and most complex satellite, Phase 3-D.

The Phase-3 satellites were all designed to be launched into a type of high elliptical orbit called Molniya, thus giving users on the ground long periods of access. Phase 3-D was the fourth in this series and was designed to follow in the footsteps of two very successful (so-called "high altitude") AMSAT satellites, AO-10 and AO-13.

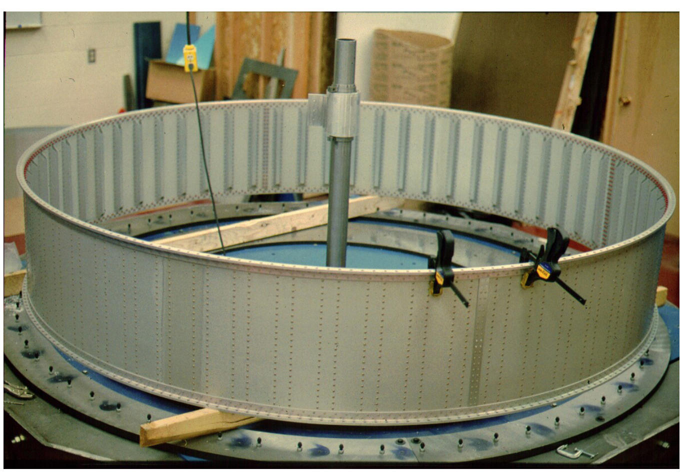
Throughout the early 1990s, Bob and his team at CAST worked closely with AMSAT's Phase-3D experimenters to construct and later perfect all of Phase 3-D's mechanical components, including, besides the SBS and space frame, much of the preparation work on the spacecraft's solar panels. Unfortunately, soon after launch, Phase 3-D (later re-named AMSAT-OSCAR 40) encountered propulsion problems, which most likely resulted in a near-catastrophic explosion that literally blew the bottom off the spacecraft.

At that point, all telemetry transmissions from the satellite ceased. Fortunately, the satellite was later located on orbit and partially restored to life. It gave several years of excellent service before its main batteries prematurely failed, most likely from damage caused by the earlier on-orbit explosion.

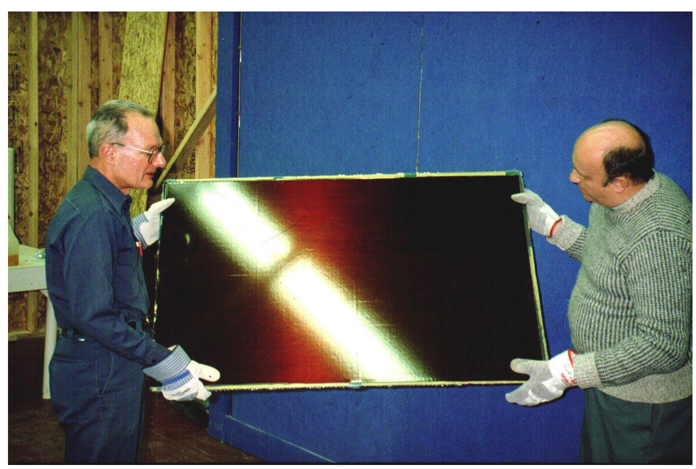
OPAL

By the time Phase 3-D was placed into orbit, Bob Twiggs had moved on from CAST to the Space System Development Laboratory (SSDL) in the Department of Aeronautics and Astronautics at Stanford University in California. The Laboratory had been established in 1994 to provide project-based learning programs for graduate and undergraduate engineering students to gain experience in systems engineering and space science.

One of Bob's first projects at the SSDL was to demonstrate a so-called "mother-



The completed AMSAT Phase 3-D carrying structure undergoes final assembly at CAST in Ogden, Utah. [Photo courtesy CAST]



Dick Jannson WD4FAB (Left) and the author display one of AMSAT Phase 3-D's rough solar panels in the CAST laboratory at Weber State University, Ogden, Utah. [Photo courtesy CAST]

daughter" satellite concept whereby a "mother" satellite would carry a number of smaller satellites internally and then, when in orbit, be commanded to release the much smaller "daughter" satellites into their own orbits. The mother satellite, the Orbiting Automated Picosat Launcher (OPAL), was designed to carry six small, hockey-puck-sized "picosatellites" and eject them once the mother satellite achieved orbit.

After several years of delays, OPAL launched as a secondary payload to JAWSAT on an Orbital Sciences Corporation launch vehicle (the maiden flight of its Minotaur launcher) on January 27, 2000, from Vandenberg AFB, California. OPAL was attached to the multi-payload adapter of JAWSAT, built by OSSS (One Stop Satellite Solutions) of Ogden, Utah. In addition to OPAL, three other free-flying satellites (ASUSat-1, OSCE, and FalconSat) attached to the adapter were deployed within minutes of reaching orbital altitude.

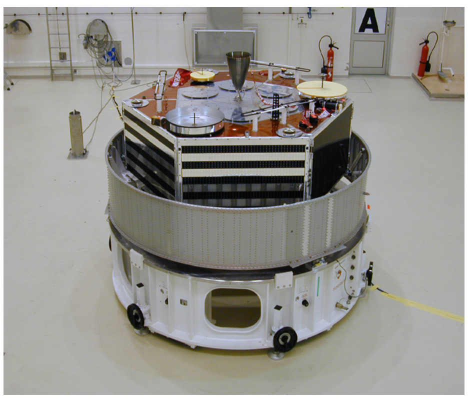
OPAL carried a total of six picosatellites — StenSat, PICOSAT1.0, Artemis and, from Santa Clara University, Thelma, Louise, and JAK. OPAL picosat launcher consisted of four launch tubes. Each was capable of holding two short (7.5 cm x 10 cm x 2.5 cm) or one long (7.5 cm x 20 cm x 2.5 cm) picosats. Six picosats flew on OPAL, four short and two long.

After launch and initial operation, OPAL was designated OPAL OSCAR-38 (OO-38) by AMSAT, and it remained fully operational on orbit for 29 months.

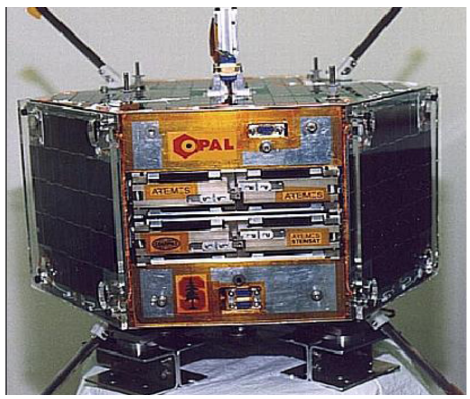
Lessons Learned

Clearly, Bob's pioneering work on OPAL successfully demonstrated the feasibility of the "mother-daughter" spacecraft idea. But, with the advances in surface mount technology and solar panel efficiency since he'd first worked on the Microsats with AMSAT in the late 1980s, the OPAL project also successfully demonstrated that small, lightweight satellites could be built and successfully placed on orbit. What's more, the success of the OPAL project at Stanford eventually led to the CubeSat program, a joint effort between Bob's team at Stanford and Dr. Jordi Paug-Suari's team at CalPoly.

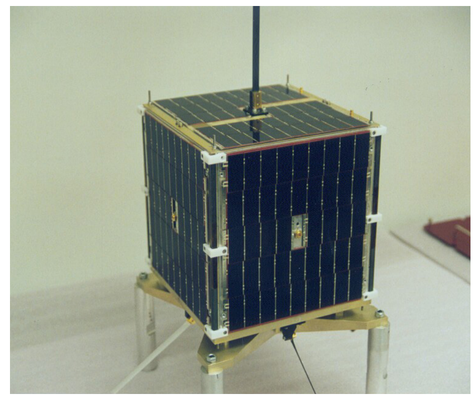
Together, they established what eventually came to be known as the CubeSat Standard. It consists of a 10 cm cube with an internal



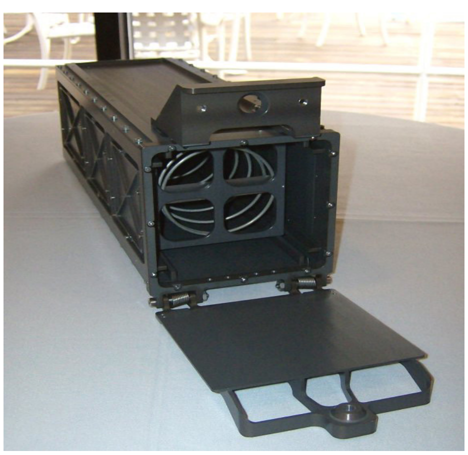
The completed AMSAT Phase 3-D satellite sits inside of its CAST constructed carrying structure just prior to launch from ESA's launch complex in Kourou, French Guyana. [Photo courtesy AMSAT]



The flight model OPAL satellite. [Photo courtesy SSDL]



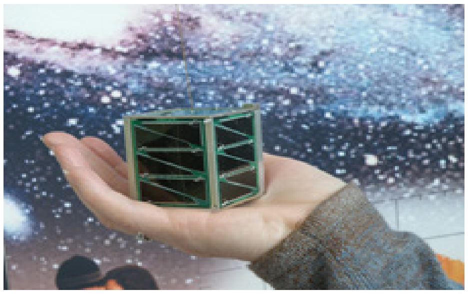
The EYESAT Microsat which later became AO-27 on orbit. [Photo courtesy AMSAT]



A "PeaPod" Cubesat launcher. Note the spring-loaded ejection mechanism. [Author, photo]

Lance Ginner, K6GSJ, primary builder of OSCAR-1, holds an engineering model of AMSAT's first CubeSat, (FOX-1A that later became AO-85 on orbit) at Space Symposium. [Author, photo]

Left to right: Barry Baines, WD4ASW, AMSAT-NA President; Dave Sumner, K1ZZ, former ARRL Chief Executive Officer with Fox-1A prototype; Tony Monteiro AA2TX (SK) then AMSAT-NA's VP of Engineering at the 2013 Dayton Hamvention®. [Author, photo]



A model of a smaller CubeSat — a "PocketSat." [Photo courtesy SSDL]

volume of about 1 Liter. Mass was initially established at around 1 kg, but that mass has since expanded to upwards of 1.33 kg.

Of CubeSats and "Pea Pods"

Establishment of a specific CubeSat standard — dimensional size, mass and electrical — also allowed for fabrication and flight qualification of a standard containment and ejection system at CalPoly called a P-POD (Poly Picosatellite Orbital Deployer). A P-POD holds three standard sized ("1-U") CubeSats, two "one-and-a half" sized CubeSats or a triple length ("3-U") CubeSat.

The P-POD operates very much like the jack-in-the-box toy that many of us played with as children. It consists of a 3-U box structure with a large ejection spring at the bottom. During final launch integration, the CubeSats are pushed inside the box, one on top of another, thus compressing the spring. Once they are all safely tucked inside, the "trap door" is closed and latched until deployment, at which time the latch is opened via radio command and the CubeSats spring out into their own orbits.

The P-POD minimizes potential interactions with the launcher's primary payload(s) by physically enclosing them into their own container and requiring that they be launched in a dormant (i.e., turned off) state. This makes paying customers far more likely to carry CubeSats along for the ride as they are reasonably assured that the CubeSats will not cause damage to their precious (sometimes multi-million dollar) primary satellite before they are ejected from the launch stack on orbit.

First CubeSat Launches

The first CubeSats were launched from the Plesetsk launch complex in northern Russia on June 30, 2003, with the Erorokot Launch Service's Multiple Orbit Mission. The CubeSats were put into a sun-synchronous orbit and included two Danish satellites (AAU Cubesat and DTUsat), the Japanese CubSat XI-IV and Cute-1 as well as the Canadian CAN-X1 and a 3U-sized CubeSat called Quakesat.

This historic launch was followed in October 2005 by a Kosmos-3M launch vehicle that carried three CubeSats into orbit on the ESA's Student Space Exploration and Technology Initiative mission. The CubeSats that successfully made it to orbit on this launch were the Neube satellite project from the Norwegan University of Science and Technology and the University of Tokyo's CubeSat XI-V.

A Concept Proven

What was to follow would turn out to be a string of successes. Increasingly, various organizations, from universities to government and military agencies soon got into the act, and the rest, as they say, is history. To date, the list of planned (or already launched) CubeSats now numbers well over 100, with many more to follow.

Another Launch Backlog

Unfortunately, the popularity of the new spacecraft design has also created a HUGE launch backlog, to the point that NASA has been soliciting bids for construction and launch of a dedicated booster to launch just CubeSats.

The NASA Launch Services Enabling eXploration & Technology (NEXT) contract will be a three-pronged experiment for the U.S. civil space agency, which is trying simultaneously to launch CubeSats without relying on ride-sharing arrangements, accelerate development of a new space rocket and build a framework for buying such rockets on a commercial basis, should its latest CubeSat launch experiment prove successful.

And AMSAT has now also hitched its wagon to the new CubeSat concept, having built its own series of CubeSats (called FOX) the first of which was successfully launched in late 2015 out of Vandenberg AFB, California, and has since become AMSAT-OSCAR 85 (AO-05) on orbit.

Full Circle

But, once again, it's important to remember that the entire CubeSat concept, which has since arguably spawned an entirely new space industry, sprang directly from the hands and brains of amateur radio operators. These people developed new, innovative ideas for building and launching spacecraft when it became clear that the odds of launching their own communications satellites were becoming increasingly cost-prohibitive.

Many people may scoff at a bunch of "amateurs" who work in their basements and garages to build space satellites. However, the past and present volunteers of AMSAT are amateurs only in the sense that the Wright Brothers, Marconi or Robert Goddard were amateurs.

Indeed, AMSAT's cadre of experimenters like Bob Twiggs (and those he worked with to develop the CubeSat concept) were pioneers who used available materials and creativity to design, build and operate devices that, over time, have spawned entire new industries (such as satellite-based telephones and direct-to-home satellite television) that the rest of us now take for granted. That same pioneering spirit has been a hallmark of AMSAT's technical and managerial approach since its founding back in 1969.

For nearly 45 years now, international AMSAT groups have played a key role in significantly advancing the state of the art in the space sciences, space education and space communications technology. Undoubtedly, the work now being done by AMSAT's volunteers throughout the world will continue to have far reaching (and very positive) effects on the very future of space communication, as well as other governmental, scientific and commercial activities in the final frontier.

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A Year of Science from AO-85

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On October 8, 2015, the Fox-1A (AO-85) satellite was launched into orbit carrying a science payload from Vanderbilt University. The Vulcan payload was the first of the RadFxSat platform, conceived to generate data for research on the effects of radiation on microelectronics. The telemetry values conveying the status of the spacecraft and payload are embedded in the sub-audible range of voice transmissions. Since launch, hundreds of ham radio operators have recorded and submitted hundreds of thousands of telemetry packets. These data can be retrieved using AMSAT's FoxTelem software and are being used by researchers to measure the effects of radiation on modern commercial electronics.

The radiation environment in space is fairly well known today. Balloon flight experiments performed by Victor Hess in 1912 demonstrated that radiation enters the Earth's upper atmosphere from outer space. These galactic cosmic rays are known to exist through interplanetary space. It wasn't until the dawn of the Space Age, when James Van Allen designed an experiment for the Explorer satellite, that data suggested the Earth is also surrounded by trapped radiation, primarily protons and electrons. Missions in the early 1970's studied the trapped radiation and developed models of the particle flux around the Earth. Even now missions such as the Van Allen Probes help to refine our understanding of the dynamics of this environment.

In the mid 1970's, a flurry of publications showed that cosmic radiation has deleterious effects on the electronics used in spacecraft. These effects mainly come in two forms — in either case, the sensitivity of electronics to radiation tends to be a function of the manufacturing technology. One is a result of the cumulative radiation dose. Over time, electronics will shift out of specification because of charges trapped near active regions within the integrated circuit (IC), potentially leading to functional failure of the device. Once a part has exceeded its total dose threshold, little can be done to return it to working order. Effects of the second form are transient in nature. These effects are a result of a single particle penetrating the spacecraft and its electronics and ionizing semiconductor materials along its path. The so-called "single event effects" that follow can be destructive or non-destructive. The result can ultimately lead to data corruption, e.g., bit errors, or even mission loss.

For certain portions of a digital IC, additional circuitry implementing error-correcting codes are often used to detect and correct errors within a data word. These codes are effective against occasional single bit errors but cannot easily be used for sparse sequential elements such as latches and flip-flops. The extra circuitry also introduces delays into read accesses. Satellites and exploration vehicles costing hundreds of millions of dollars are exposed to a wide range of ionizing particle species and energies in space. Certain systems such as data-collection systems may permit the occasional corruption of data; however, radiation-induced errors in critical systems, such as those for spacecraft control and life support, could result in mission failure.

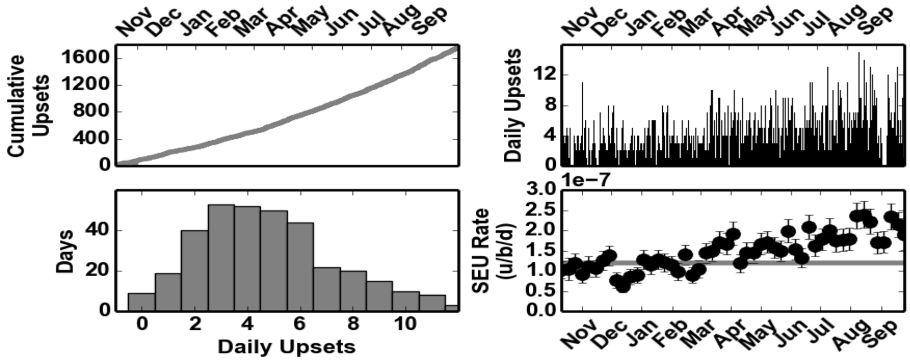
The aerospace community has developed ways to address these issues. One is the simple solution of radiation shielding. While this approach can be very effective for low-energy particles, it becomes less useful, or completely useless, for the higher energy environment and by necessity requires mass. To eliminate the remaining risk, the traditional approach has been to use electronic parts that are intentionally hardened to the space environment by design or technology selection. High-budget missions have the luxury of funding and using radiation hardened devices when required. This part selection can be very limited and costly for amateur or low-cost missions. As a result, commercial-off-the-shelf (COTS) electronics are appealing to designers as an avenue to reduce mass, volume, power, and ultimately the cost of launching and operating the satellite. In some cases, automotive or even commercial-grade electronics may prove sufficient.

Therefore, we are left with addressing the questions of the severity, frequency and likelihood of the effects. The radiation hardness assurance process must make predictions of on-orbit part performance based on information obtained on the ground. This typically involves the use of an irradiator or particle accelerator. However, both have limitations. For instance, transient effects can vary with incidence angle and beam energy. A handful of results from ground-based tests using a limited set of particle energies, ranges, and angles must be extrapolated to the full environment of space using models. Here we have the motivation for the RadFxSat platform.

The electronic component that is often the focus of study is a Static Random Access Memory (SRAM). The memory provides volatile storage of data, which can be individually addressed and written or read. These memories are ubiquitous and are extensively used by microcontrollers and microprocessors to operate on program data. Each SRAM cell stores a single bit of data in a bi-stable circuit. These memory arrays tend to be designed with the smallest available transistors, are highly integrated, and have large storage capacity. These three factors make them suitable for easily and quickly identifying single event effects.

The Vulcan payload contains an experiment aimed to identify radiation-induced memory errors, known as single event upsets, or SEUs. When an ion or proton passes through an electronic device it loses energy through un-countably large numbers of binary collisions with the electrons and nuclei of the material. Collectively, the collisions with these electrons are referred to as electronic stopping, or ionization. Energetic electrons set in motion in this way create transient currents in semiconductor circuits that are unrelated to the device's normal operation and that ordinarily interfere with it. These transients propagate through a circuit or, as in the case of bi-stable circuits like the SRAM, can cause devices to change logic states. From our point of view, that of circuit operation, this appears as a logic "0" changing to a logic "1" or conversely a "1" changing to a "0". These logic states depend on charge stored on specific nodes within the memory cell. Therefore, the SRAM memory cell has a threshold for the amount of charge that can cause an upset. So, while highly ionizing particles can easily cause upsets, lightly ionizing particles are much less likely, if capable at all. With technology scaling, this threshold has traditionally decreased.

On their own, protons are usually too weakly ionizing to cause single event upsets. However, if a proton displaces an atom in a collision or causes a nuclear interaction, the secondary particles themselves can be highly ionizing and easily capable of causing upsets. Sophisticated computer codes are used to calculate the probability that these interactions will occur and generate sufficient charge to upset a cell, thereby predicting a single event upset rate for a given proton environment. Frequently, this involves trips to particle accelerator facilities such as the TRIUMF laboratory in British Columbia, Canada, or the now closed Indiana University Cyclotron Facility in the United States. In these experiments, parts are placed and operated within a proton beam and the number of upsets is measured. This allows us to calculate a probability of upset in a specific environment. Similar techniques can be used for ions in the case of interplanetary galactic cosmic ray environments. This predicted error rate influences design decisions such as the suitability of a part or the effectiveness of error detection and correction algorithms.



High-reliability applications place stringent requirements on the frequency of SEU. Acceptable levels of risk often motivate these requirements and the cost of operating in an otherwise unprotected manner. Modern devices have increased packing density and speed, decreased power dissipation and capacitance, and are more cost effective than previous generations. The same trends in device scaling that these applications leverage are the cause of increased susceptibility to upset.

In the last 10 years, a number of investigators have discovered that very advanced memories are susceptible to the ionization from primary protons themselves. The possibility that on-orbit bit error rates might increase because of ionization from protons is disruptive to our reliability assurance techniques. The pressing questions are how much of the overall error rate this will account for, and whether we need to change the way that we assess the vulnerability of parts.

The Vulcan payload consists of a "brain" called the Vanderbilt University Controller (VUC) and a Low-Energy Proton (LEP) experiment. The VUC provides an interface between the experiment and the Fox satellite bus. Designed to be expandable to multiple experiments, the VUC provides power and command isolation of the experiments from the spacecraft. The VUC manages the state of individual experiments: OFF means an experiment is unpowered and may be run at the first opportunity; STANDBY means the experiment is powered and communicable but not yet allowed to conduct full operations; ACTIVE means that the experiment is conducting full operations; HALT means that the experiment operations are being shutdown; and DISABLED means that the experiment is not present or not allowed to operate. The VUC additionally monitors the current drawn by the experiments and removes power in the case of a fault.

The LEP hosts eight commercial memories for investigating the low-energy proton SEU mechanism. These memories are used only for testing, not for actual information storage. The LEP begins its routine by setting the entire memory space to a known data pattern. After five minutes, the experiment reads the memory and counts the number of bits that are in error. This is accumulated in a register. In addition, the length of the exposure time is accumulated as a "live" time. After evaluating the entire memory space, the LEP reinitializes the space for the next exposure. These values, upsets and live time, along with others, are a part of the experiment telemetry string sent through the Data Under Voice communications. The values taken together yield an upset rate that can be compared against predicted values.

The figure above represents the accumulation of data as well as post-processed analysis. The cumulative upsets have totaled over 1700 to date, as shown in the upper left corner. There has been a steady occurrence of events each day since launch. In the upper right corner, the cumulative number of upsets is broken down by day. It is clear that an average of 4 upsets is observed each day with variability up to 15 within a single day. This distribution is expected based on the random nature of events and follows the expected shape in the lower left corner. Overall, the payload has observed a mission average upset rate of 1.5 x 10^{-7} upsets per bit per day (u/b/d). Therefore, we could expect a similar memory to have the same probability for any single bit to become corrupted. The observed error rate is in good agreement with the predicted rate (grey line) suggesting that the established process of prediction is still effective for this generation of memories.

CubeSats offer unique opportunities to access space, but they have also been largely designed using commercially available parts. The benefits of using commercial parts are compelling — low cost, high volume, low power, and multichip solutions. However, they do not possess the reliability of space-grade microelectronics. They will always come with increased risk to a mission, but for some applications, even future NASA systems, the increased risk may be low enough to make the use of commercial parts acceptable. The key to successfully using commercial parts in future systems will be to understand how the advanced semiconductor technologies behave under radiation, and predicting the errors, degradation, and variability of radiation sensitivity from one part to the next.

Additional launches of the Fox architecture are planned. Fox-1C will carry the flight spare payload from Fox-1A (AO-85). This presents the possibility of observing data from two identical payloads in different orbits, but simultaneous in time. Fox-1B is preparing to launch under the ELaNa-14 program. It carries the Phoenix payload, which is a stack of three experiment boards, each with a CMOS memory fabricated in an advanced 28 nm technology. The memories are capable of running at a reduced power for data retention and will measure the occurrence of single event upsets according to supply voltage. Finally Fox-1E is under development under Elana-20 and will carry a memory fabricated in an advanced FinFET technology, as well as a board a copy of the Vulcan and Phoenix memory.

The Institute for Space and Defense Electronics at Vanderbilt University is home to faculty and full-time engineers dedicated to design, analysis, and testing of electronics for space and defense systems. The development of the Vulcan payload has presented unique opportunities to work with graduate and undergraduate students in developing flight boards. A larger outgrowth of the program has been the establishment of a student-led satellite club and amateur radio club, the latter motivating several students to receive their amateur licenses.

Our partnership with AMSAT has been a great benefit to us. The leverage brought by the Fox team and the incomparably extensive set of ground stations of the worldwide amateur radio community has enabled us to collect a vast amount of data and claim mission success!

Autonomous Satellite Tracker

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This paper describes a completely autonomous Earth satellite-tracking mount. This two-axis tracker needs no prior alignment with respect to the Earth's surface, and tracks satellites with high accuracy entirely by reference to built-in spatial sensors.

In conjunction with a 9-DOF (degrees of freedom) sensor attached to the antenna boom, and a GPS receiver, the 2-axis gimbal will track any Earth satellite within 2 degrees in real time without any orientation setup calibration of any kind. The tracker system includes a built-in web server and Wi Fi access point, which allows all monitoring, command and TLE (two-line element set) upload from any web browser, including a smart phone. All components are off-the-shelf, so no custom electronics, machining or other skills are required except that needed to attach an antenna boom to a flat plate. All electronics can be powered from a single dc supply from 7 to 18 V such as a LiPo battery pack or solar charging system. As of the time of this writing, total cost of the electronics and gimbal is approximately $350, not including antenna.

Introduction

Observers have been tracking Earth satellites with gimbal mounts since the beginning of the space age.[1] One of the challenges always has been to align these mounts so the theoretical calculations of satellite azimuth and elevation could be transformed to the mount coordinate system. After reading about the availability of low cost MEMS (Micro-Electronic Mechanical Systems) devices that directly measure spatial orientation, I wanted to build a mount that avoided the tedious calibration step by measuring directly the pointing direction of the payload.[2]

Going one step further, I also wanted to eliminate the need to have any prior knowledge of, or make assumptions about, the gimbal geometry, axis orthogonality, motor assignment and axis rotation angles. Doing so would simplify the mechanical requirements of the gimbal and wiring, and allow the use of simple off-the-shelf hobby servomotors and robot hardware for use with lightweight antennas.

The final goal was the ability to control and monitor the entire system from my smart phone without needing to first install an app. The most flexible way to accomplish this is by providing a web server, so I needed enough memory in the controller to accomplish this.

Achieving the Goals

The first goal is achieved by measuring the spatial orientation of the antenna directly using a combination of 3D magnetic, accelerometer and gyroscope sensors. When packaged together, these devices are referred to as having 9 Degrees-of-Freedom (9-DOF) sensors. The magnetic sensor provides the direction of the local magnetic field, including tilt. This is combined with knowledge of the local vertical gravity vector from the accelerometer to produce local elevation and azimuth with respect to magnetic north. To get a bearing from true north, the latitude and longitude from the GPS is combined with the World Magnetic Model to compute the local magnetic declination correction factor.[3] Information from the gyroscope provides additional stability and repeatability information. The final correction is to apply a simple model for atmospheric refraction to elevation based on nominal assumptions for air temperature and pressure. Although these, too, could be measured quite easily, the maximum effect at the horizon is about one-half degree, which I decided was not worth refining further. Taken together, these measurements provide an absolute measure of antenna direction in the local horizon coordinate system, which is exactly what is produced by the orbit propagator.

Now that we have the measured antenna direction and a computed predicted direction from the propagator in the same coordinate system, the second goal is to drive the gimbal motors in such as way as to reduce any difference between the two. Normally, this is done in closed-form by using a transformation matrix determined ahead of time that relates the gimbal axis coordinates to the local horizon coordinates. In order to eliminate the need for determining this matrix, my second goal is achieved by moving the motors by a small amount and just measuring whether the error increases or decreases. This is known as a gradient descent search.[4]

My first attempt at an error metric was to use the great circle distance between the measured and computed positions. However, this leads to a condition known as gimbal lock if the gimbal ends up pointing near the zenith, either intentionally because the satellite pass was high or unintentionally because zenith was reached during the search procedure.[5] This is avoided if the errors in azimuth and elevation are measured separately.

The final tracking algorithm can be summarized as follows:
Step 1 – choose one axis motor at random
Step 2 – measure error in azimuth and elevation separately
Step 3 – move the current motor a small amount and stop
Step 4 – measure the two errors again
Step 5 – if either error increased, reverse the last move and start using the other motor,
Step 6 – go to Step 3, repeating forever.

Note that this does not require any knowledge of the gimbal orientation or even what motor operates what axis. The effect is the antenna will make a few small random moves to get started, then one motor will march along steadily until it causes one or the other error measures to increase. Then the other motor will do the same and the process repeats until the antenna is pointing at the satellite. This process repeats forever. So, as the satellite moves, the errors creep up and the algorithm keeps working to reduce them. The smoothness of the motion depends on the time between moves and the angle commanded for each move. These are not critical during a large slew but some care is needed in order to maintain smooth tracking performance. A rigorous approach is not required. It is easy to set reasonable values using trial and error. The algorithm could be made more efficient by introducing control-loop equations for proportional gain, so large errors are reduced more quickly, and integral gain to maintain closer tracking tolerances, but in practice these refinements are not really necessary.

The Web Server

The web server turned out to be straight forward. I already know Javascript, HTML and the HTTP headers that are used between browser and server. So, I wrote my own server state machine from scratch on top of the basic Arduino Ethernet library. The main page is sent, in effect, as the default index.html for the server URL address. All state variables are updated and reported using a consistent NAME=VALUE syntax, where the NAME usually matches the HTML name of the corresponding DOM display element. Setting a new value is performed with a POST command and retrieving values is done by asking for getvalues.html. An XMLHttpRequest polls for values to keep the web page updated. More details about using the web interface are provided later.

Implementation Decisions

Figure 1 shows the Tracker gimbal attached to a tripod and supporting an Elk 2 m/70 cm LPDA antenna. Figure 2 shows the inside view of the tracker electronics box. Figure 3 is a block diagram showing how each electronic subsystem interconnects. Table 1 shows the major bill of materials.

Next, I elaborate the role of each component and share my experiences that lead to each choice. The main processor is the Arduino Mega 2560. I began with the model Uno but eventually I could no longer squeeze everything into its 32 KB flash memory and 4 KB RAM storage. The Mega has 8 times as much flash memory and twice as much RAM, which is plenty. The tracker uses about half of the flash on the Arduino Mega for code and constant strings, and about half of the RAM for mutable variables, leaving 4 KB of RAM for stack.

To control the two hobby servomotors, I initially used the Adafruit software servo library. However, the servos did not move smoothly. The cause turned out to be interference to the pulse timing by other libraries that lock out interrupts, even briefly. Servo position is directly related to pulse duration, which is sensitive to changes on the order of a few microseconds, so it doesn't take much timing change to cause unwanted motion. My solution was the 12-channel servo controller from Adafruit. This offloads all the timing from the Arduino and requires only a two-wire connection using the I2C bus to issue the desired pulse length for each channel. It also has the added benefit that the servos actively hold position until a new command is issued.

I chose the Bosch BNO055 9-DOF sensor. It is available on a convenient breakout board from Adafruit and is compatible with their Sensors library. The advantage of this sensor package is it includes an onboard processor that performs all the consolidation of the three sensors automatically and outputs directly its absolute spatial orientation as Euler angles interpreted here as azimuth, elevation and roll.[6] As anyone who has tried to manually fuse together these types of sensors knows, this saves quite a lot of tedious mathematics. This sensor also connects to the Arduino using the same I2C bus as the servo controller but does not interfere because they each have a separate bus address.

I chose the GPS module from Adafruit. It has a built in antenna, which works pretty well, but I also allowed for the connection of an external antenna if necessary. This module communicates with the Arduino using a UART, or serial connection. This revealed an additional advantage to using the Arduino Mega: it has four hardware serial ports available, allowing one to be dedicated to the GPS. The Uno only has one that already serves duty with the USB boot loader. A software serial library could be used with the Uno to use other pins but at the expense of higher overhead and a more limited bandwidth.

I wanted Wi-Fi ability so I could control the system from my smart phone. I tried several Wi-Fi modules and shields but found none to be reliable. Even the best one from Adafruit would work for a random time, anywhere from seconds to hours, and then just mysteriously stop. In stark contrast, all models I tried of wired Ethernet proved to

Figure 1 — Tracker gimbal is attached to a tripod and supports an Elk 2m/70cm LPDA antenna.

Figure 2 — Inside view of the tracker electronics box.

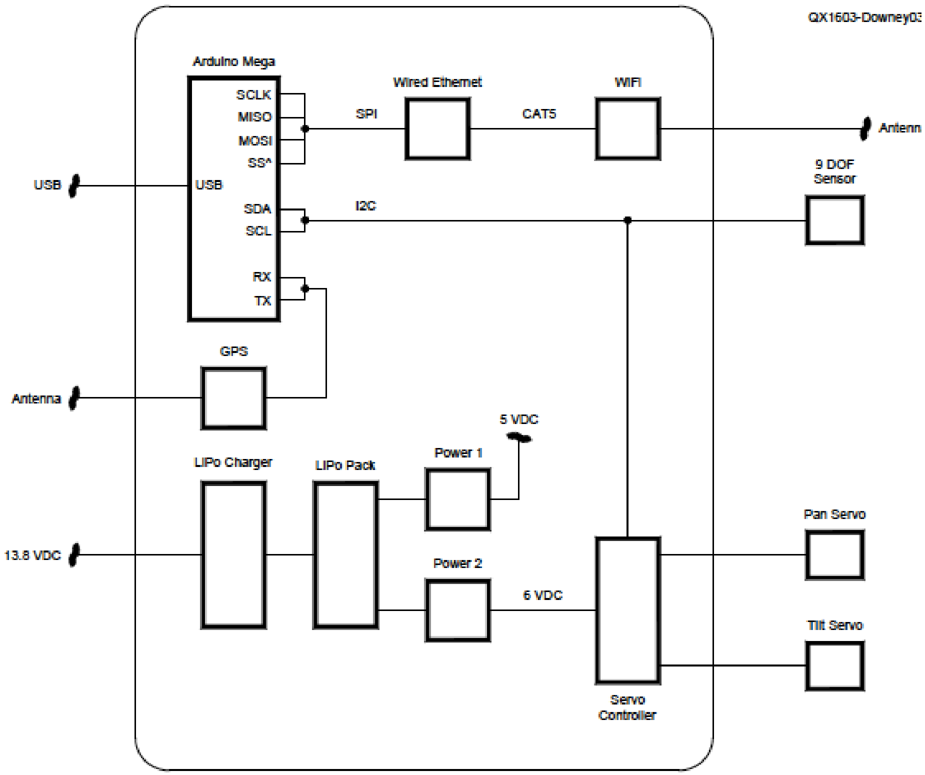

Figure 3 — Block diagram showing how each electronic subsystem interconnects. A partial bill of materials is in Table 1.

Table 1
Bill of Materials

Item	*Source*	*Approximate price*
Ardunio Mega 2560	Amazon: SunFounder Mega 2560 R3, stock number B00D9NA4CY	$18
Wired Ethernet shield	Amazon: SunFounder Ethernet Shield W5100 for Arduino, stock number B00HG82V1A	$16
Wi-Fi router	Amazon: TP-LINK TL-WR702N Wireless N150 Travel Router, stock number B007PTCFFW	$20
GPS module	Adafruit: Part ID 746	$40
Servo controller	Adafruit: Part ID 815	$15
Bosch 9 DOF sensor	Adafruit: Part ID 2472	$35
Pan platform	ServoCity: model SPG785A-CM, 5:1 ratio	$100
Tilt stage	ServoCity: model SPT400, 5:1 ratio	$95
	Total	*$339*

be 100% reliable, even including the oldest modules that use the WizNet W5100, so I ended up using a generic version made by Sunfounder. In order to accomplish my goal for Wi Fi, I just connected the wired Ethernet directly to a $20 Wi-Fi adaptor made by TP-Link. This combination works beautifully. I have not experienced a single wireless communication glitch. The adaptor I bought can be configured either as its own access point to broadcast a separate Wi-Fi network just for the tracker, or it can transparently bridge the Arduino to an existing Wi Fi network. The unit comes with a simple Windows utility to perform the required one-time setup. From then on, it comes up on its own every time.

I wanted everything to operate from one self-contained power source. I ended up using one LiPo battery and two separate power-conditioning modules. One supplies 5 V to the Arduino and its peripherals, and the other is dedicated to powering the servomotors. This approach provides clean power to the electronics and isolates the wide load swings and voltage spikes that occur from the motors. I currently use a 7.4 V 2000 mAh pack, which operates the tracker for several days of moderate use before needing a recharge. If desired, a solar pack could also easily be used.

The gimbal is one channel-mount pan platform (Figure 4) and one tilt platform (Figure 5) obtained from ServoCity.com. Together these provide about 400 degrees of azimuth motion and 135 degrees of elevation motion. Under the pan platform, I installed a short section of channel with ¼ 20 threaded screw plates for easy attachment to a common camera tripod. The pan platform has a hollow shaft that simplifies cabling to the 9-DOF sensor

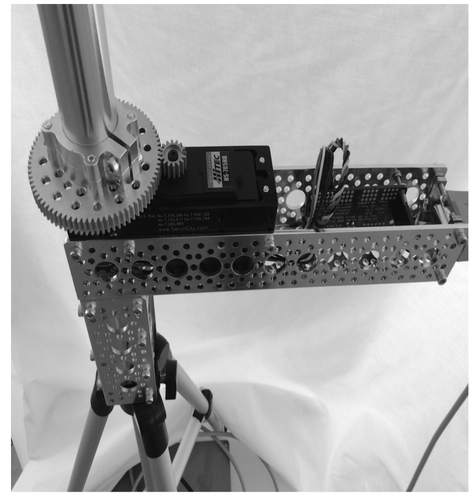

Figure 4 — The azimuth gimbal mounted on a tripod.

Figure 5 — The elevation gimbal shown with antenna attached.

and tilt motor, and reduces tangles during rotations. I discovered that the servos would make spontaneous and sporadic moves while I am transmitting on 2 m FM with the Elk LPDA antenna. I eliminated this interference by using shielded STP CAT5 cable, taking care that only the end of the shield nearest the Arduino was connected to ground.

Assuming the Bosch spatial sensor is accurately aligned with the antenna, the largest contribution to pointing error is the sensor itself, which claims a maximum magnetic heading error of ±2.5 degrees. The next largest source of error is the orbit propagator software. The code, available in the QEX files web page, used here is based on a very clean rendering by Mark VandeWettering, K6HX, of the James Miller, G3RUH, PLAN-13 code.[7,8,9] After the updates to the solar elements posted in 2014, the code produces topo-centric values within 0.2 degrees compared to a more rigorous SGP4 code within a few days of the TLE epoch.10

Installation

In a nutshell, assemble the electronics and the gimbal. Attach them to your support. Then attach your antenna and the Bosch sensor. Attach your antenna to the tilt platform so it points straight up when the tilt platform is run all the way over on its side such that the plane of the tilt platform is also vertical. I attached my Elk LPDA antenna using two U-bolts after drilling four holes in the tilt plate. Position your antenna of choice on the tilt plate so the antenna is roughly balanced to help reduce the load on the tilt servo. There's plenty of torque, so it should be fine to add a rear counter-weight to the boom if it allows you to balance the antenna better. Be aware that when the target is near zenith, the antenna will extend below the level of the gimbal. If you are using a tripod, add a vertical extension. Otherwise, when the antenna is pointed near zenith, it will hit the tripod legs.

Attach the Bosch sensor breakout board such that:
(1) the short dimension is parallel to the antenna boom
(2) the populated side of the board faces upwards, and
(3) the side with the control signals (SDA, SCL, etc.) points in the rear direction of the antenna pattern.

Take some care to make this accurate and secure because the overall pointing accuracy is entirely dependent on how parallel the sensor is to the antenna bore site. The position along the boom does not matter, but since one of the sensors is measuring magnetic fields, mount it as far as possible from anything containing iron, such as screws or U-bolts. It is not affected nearly as much by aluminum, but I would still stay at least an inch away from aluminum as well. Power up the tracker controller. Either connect with Wi Fi or attach a CAT5 cable to the wired Ethernet controller. The default IP address is 192.168.0.122. If your computer is on the same network, you can surf to that address and immediately see the main web page. If you want to change the IP of the tracker, you have two choices. One choice is to edit the source code file Webpage.cpp (on the QEXfiles web page) and load a new image into the Arduino. The other choice is temporarily to change your computer network to 192.168.0.0 so you can surf as above, then use the tracker web page itself to set a different IP address, reboot the Arduino, then change your computer network back to your desired setting.

Once your web page is accessible, use the Gimbal section at the bottom to experiment with the motion range of each axis. There is no predefined assignment of which servo axis is azimuth or elevation. When setting the minimum and maximum for the elevation servo, make sure to consider the full range of azimuth. The minimum and maximum values are stored in EEPROM so they will retain their values through a power cycle.

Web Page Description

Turn on the tracker controller and surf to its network address with your browser. You should see the web page shown in Figure 6. The page has two parts. The top part allows setting and inspecting the TLEs used to define the motion of the satellite of interest. The bottom part is a table showing detailed information for each of the tracker subsystems of Target, GPS, Sensor and Gimbal. Look through the table carefully because it provides a lot of information and control capability. Most fields are self-explanatory.

You will note that some of the data fields can be overwritten. This effectively turns off the automatic setting and allows you to enter your own values. Suggestions for how these can be used will be mentioned below.

Web Page in Detail

Across the very top is the title. Hovering over this title for a moment will display the software version. To the left is the network IP address of the tracker. If this value is edited and set, a new value will be stored in EEPROM and will be used the next time the tracker is powered up or rebooted. To the right is a button to Reboot Arduino,

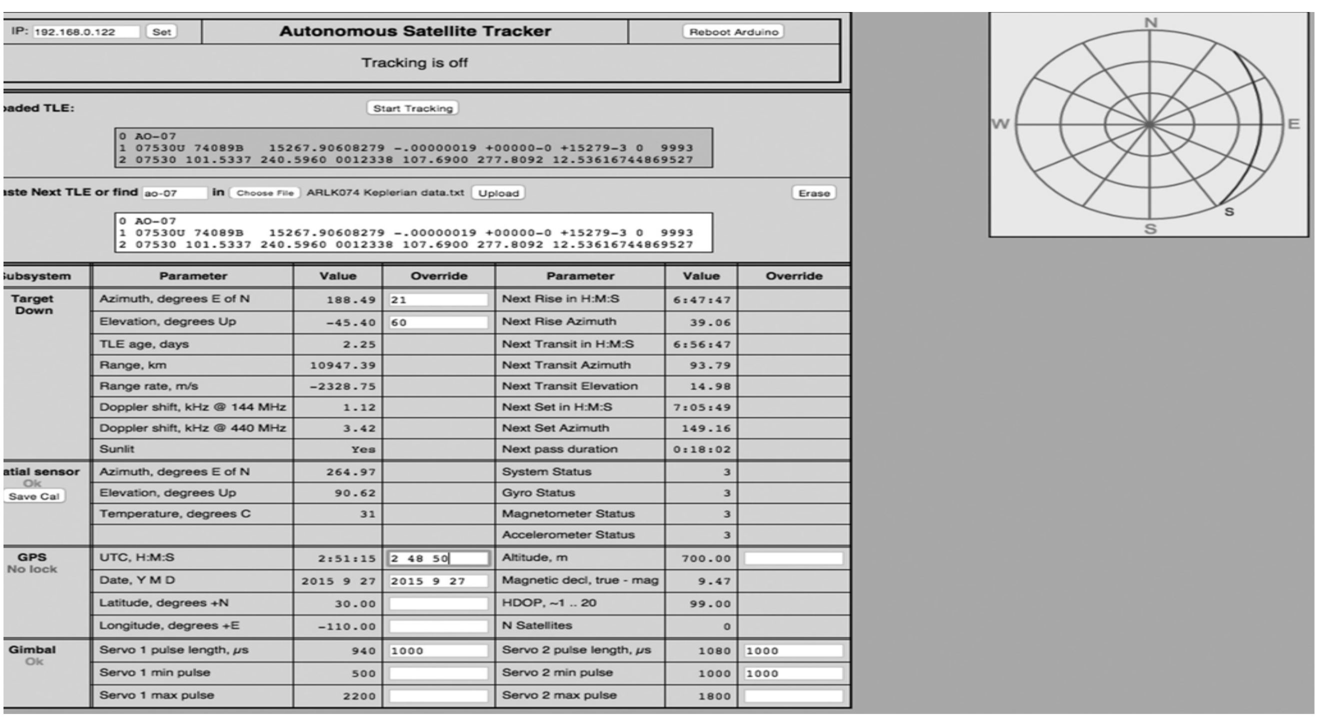

Figure 6 — The Autonomous Satellite Tracker web interface. Not the satellite track projection in the inset on the upper

mainly for this purpose. Below the title is the message line. Look here for confirmations, additional information and general messages as you use the page.

Aside from this bit of housekeeping, the top portion of the page mainly allows you to enter and Upload the TLE for the satellite you wish to track. There are two text areas for showing TLEs. The top-most text area, with the darker background, is read-only and displays the TLE currently loaded into the tracker, if any. The text area just beneath, with the white background, is writable. Here you can either copy/paste a TLE directly or you can type in the name of a satellite in the field provided and select a file that contains its TLE. The tracker will scan through the entire file for a name match. The name is not case sensitive. The tracker expects the file format to have the name on the line just before the TLE in typical fashion. If the satellite is found with a valid TLE, it will appear in the white text area. At this point the TLE is still just in your browser. To actually send it to the tracker, click Upload. After successfully uploading a valid TLE, it will appear in the darker text area. This is the TLE that the tracker will follow. You can change or erase the writeable text area all you want, and it won't matter unless you Upload it again.

Monitor and Control

Below the TLE section is the main table for monitor and control. The first table section is for the Target to be tracked. In the left column you will see observing details of the uploaded satellite elements at the time and location shown in the GPS section farther down. In the right column, you will see information about the next pass. Note that the tracker never computes information in the past, so if a pass is already underway (the satellite is currently above the horizon), then the Next Rise information will be for the subsequent complete pass, since that event has already occurred for a pass that is underway. You can override the computed azimuth and elevation. If tracking is enabled, this allows you to point your antenna at any desired fixed sky location.

Beside the table is an all-sky graph that shows the pass as it will look overhead. Again, if you override the time, and jump into the middle of a pass in progress, only the path from that moment onward will be drawn.

The Spatial Sensor

Below the Target Down section of the table is the section for the Spatial sensor. This displays the azimuth and elevation that it is measuring and reporting to the tracker. It also displays the current temperature and the status of the system processor and each of the individual sensors. These individual status values can range from 0 through 3, where 3 is the best. The tracker will not use the data unless all system status values report at least 1. Procedures for calibrating each sensor are provided in the Bosch manual. The sensor package will need to be moved around to different orientations to get all sensors at their best values. Use the pulse length override fields in the Gimbal section (see below) to perform these motions. Once all sensors report state 3, their associated internal calibration data can be stored to EEPROM by clicking the Save Cal button. Once saved, these values will be restored each time the tracker is powered up, and all sensors will usually immediately come up in state value 3. This button is available only when all sensors report status 3. The magnetic sensor is very sensitive to local magnetic fields and iron objects, so if you relocate the tracker, I recommend that you perform the calibration again and store a new set of values.

GPS

The GPS section shows the reported time and location, and also displays some quality metrics. HDOP is the Horizontal Dilution of Precision.[11] This is an indication of the accuracy of the latitude and longitude, the position values most important to the tracker. HDOP values range from less than 1, which indicates ideal conditions, up to 20 or more, indicating that location can be incorrect by 300 m or more. The number of satellites used in the fix is reported, where four or more is desirable. If you don't have a GPS connected, or it does not have lock, or you just want to experiment, you can override the time, date, latitude, longitude and altitude to see the effect on the passes. You don't need a GPS at all if you enter these data carefully.

Gimbal

At the bottom of the table is the Gimbal section. These data are in units of raw pulse duration. If you are aware of how hobby servomotors function, you will recall they are commanded to a given rotation angle determined by the length of a pulse issued on their control line. Pulse durations vary by manufacturer and even among devices of the same model. Roughly speaking, pulse lengths range from about 500 ms for one position extreme up to around 2400 ms for the other extreme. Normally pulse durations are set by the tracking algorithm, and bounded by the indicated minimum and maximum limit values. You can directly set specific pulse durations for each motor if you wish. Doing so will automatically disable tracking if it is enabled. This is fun, but also important to determine the safe as-built motion limits of each axis. The limits are stored in EEPROM and used by the tracker to avoid exceeding the limits of each servomotor.

The Gimbal section also allows you to tune each axis for best tracking performance. Recall from the tracking algorithm that a motor is moved a small amount, stops to allow a stable sensor reading, then moves again repeatedly to track the target. Fields are provided for you to set the stop period and the step size for each move. The stop period should be set to just long enough for the entire gimbal and antenna to stop shaking after a move. The step size should be set to the smallest value that results in a reliable change in reported sensor position.

Operation

After everything is set up and you are comfortable with the safe operation of the tracker motions, you are ready to track a satellite. Set the system up in a location with a good view of the sky. Turn it on, load the TLE into the white text area and click Upload. Click Start Tracking to begin tracking the satellite. That's all there is to it. Enjoy.

All photos courtesy of the author.
Elwood Downey, WBØOEW, has held the same call sign since he was first licensed in 1974. He is an ARRL Member. Elwood enjoys software, digital modes, antennas, and experimenting. He graduated with a BSEE cum laude in 1977 from Purdue University. Since then he has focused his career on telescope control systems and related astronomical instrumentation, which he finds very fulfilling. His career has taken him to many of the great observatories around the world.

Notes

1 siarchives.si.edu/collections/siris_sic_8335.
2 en.wikipedia.org/wiki/Microelectromechanical_systems.
3 www.ngdc.noaa.gov/geomag/WMM/DoDWMM.shtml.
4 en.wikipedia.org/wiki/Gradient_descent.
5 en.wikipedia.org/wiki/Gimbal_lock.
6 en.wikipedia.org/wiki/Euler_angles.
7 github.com/brainwagon/angst.
8 amsat.org/amsat/articles/g3ruh/111.html.
9 arrl.org/QEXfiles.
10 www.xephem.com.
11 en.wikipedia.org/wiki/Dilution_of_precision_(GPS).

Circularly Polarized Aimed Satellite Antennas

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Among steerable satellite antennas, we generally have two options. The axial-mode helical antenna has become a favorite among some satellite and other operators, especially at UHF (435 MHz and up). However, the crossed and turnstiled Yagi remains in favor among other operators. Let's explore these options, at least to a small extent.

The Axial-Mode Helical Antenna

The following notes on axial-mode helices summarize parts of my longer study "Notes on Axial-Mode Helical Antennas in Amateur Service," which appeared in the 2005 Proceedings of the Southeastern VHF Society. There I examined NEC-4 models of 5, 10 and 15 turn helices, both over perfect ground and over ground plane wire-grid screens. Figure 1 shows the general outline of the models, as well as their relative sizes, using a 1.2 lambda × 1.2 lambda screen that is 1 lambda above ground. The test frequency is 299.7925 MHz, where 1 meter = 1 lambda. You may scale the designs for other frequencies by using the ratio of 299.7925 to the new frequency times each of the critical dimensions, including the wire diameter but excluding the pitch angle. For uniformity, all models point straight up.

The need for such a study is a function of the classical literature on axial-mode helices. Researchers tend to treat the antenna as a broadband array and extrapolating data useful to amateur spot frequency use is somewhat daunting. (See the final notes for some references, especially VE3NPC's more recent empirical measurements.) Modeling this type of antenna also requires considerable care.

Perhaps the two most critical dimensions are the pitch angle and the circumference. In fact, basic helix theory tends to restrict axial-mode operation of the helix to pitch angles between 12° and 14°. The smaller the pitch angle (within limits), the higher will be the gain of a helix, given a fixed number of turns. As well, various texts restrict the circumference to ranges from either 0.8 lambda to 1.2 lambda (Kraus) or from 0.75 lambda to 1.33 lambda (Balanis). The number of turns in a helix is up to the builder, since gain (for any given pitch and circumference) rises with the number of turns. Furthermore, selection of a wire diameter is also a builder choice. Although not mentioned in any serious way in most literature, conductor size does make a difference to helix performance. The larger the wire diameter as a fraction of a wavelength, the higher the gain for an otherwise fixed helix size. The sample models that we shall explore use 2 mm diameter wire.

There are two major issues with modeling an axial-mode helix. The first issue arises from the fact that NEC must use straight wires to simulate a circle. The difference between the circumference of a circle and that of a polygon inscribed within the circle only reaches relative insignificance as the number of sides on the polygon passes about 16 or so. A 16 sided regular polygon inscribed within a circle has a circumference that is about 99.4% that of the circle. For a more rounded number in my NEC-4 helix models, I used 20 segments per turn. Using 2 mm diameter wire, the segment length-to-radius ratio remained well above modeling minimums.

The second major issue involves the reported vs the actual gain of the helix models. For both the perfect ground and the wire-grid plane models, I assigned the source to the first segment, the one in contact with the ground surface. Because this segment does not have equal length wire segments on either side of the source segment, the initial reports of gain and source resistance will be erroneous but correctable. By moving the source segment to other segments, I ascertained that applying standard Average Gain Test (AGT) adjustments to the gain values would yield very reasonable corrected reports.

Figure 2 shows the results of gradually increasing the circumference of 5, 10 and 15 turn helices (12° pitch, 2 mm diameter wire) over wire-grid planes that are 1.2 lambdaon a side and 1 lambda above average ground. The gain curves are similar to those produced by the NEC-2 models created by Paolo Antoniazzi, IW2ACD, and Marco Arecco, IK2WAQ, in "Measuring 2.4 GHz Helix Antennas," QEX, May/Jun, 2004. The major difference is that the ground beneath the helix in my models yields a moderate rise in gain below the generally accepted optimal circumference range. Both sets of curves show that as the helix grows longer, the optimum circumference for maximum gain decreases. Exceeding the optimal circumference results in a steep loss of gain potential. With a constant pitch angle (12°), the peak-gain circumference decreases by about 0.05 lambda with each 5 turn increase in helix length.

The dimensions for three sample axial-mode helical directive arrays appear in Table 1. The arrays correspond to 12° pitch 5, 10 and 15 turn antennas at 299.7925 MHz, where 1 meter = 1 lambda. The modeled performance data appears in Table 2. The gain values have been corrected for the average gain test (AGT) score, and the raw reports will be somewhat lower. The peak

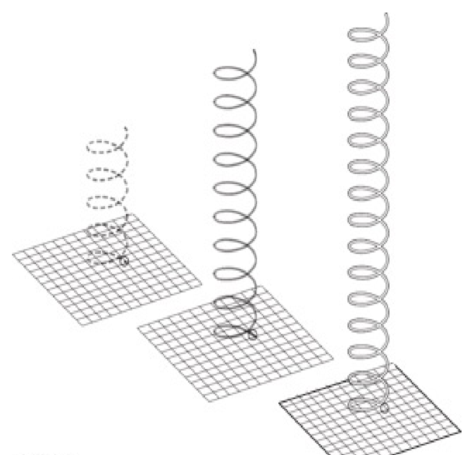

Figure 1 — Approximate proportions of 5, 10 and 15 turn helices over ground planes 1.2 lambda per side.

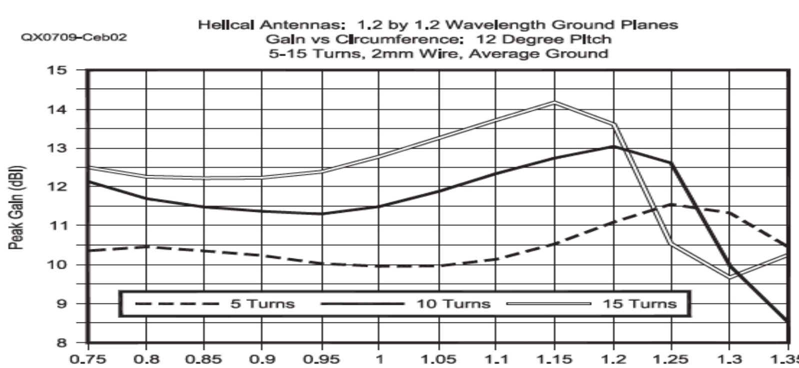

Figure 2 — Modeled gain of 5, 10 and 15 turn helices over ground planes 1.2 lambda per side.

Table 1
Dimensions of three sample axial-mode helical directional arrays for 299.7925 MHz. All dimension in meters or in wavelengths. Wire diameter = 2 mm. Helix pitch angle (α) 12°.

Number of turns	*Circumference λ*	*Total Length λ*
5	1.25	1.33
10	1.20	2.54
15	1.15	3.66

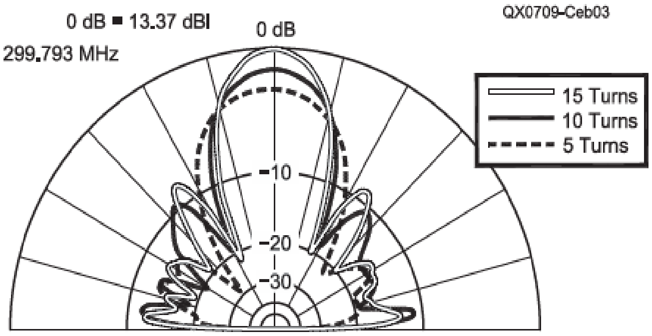

Figure 3 — Comparative elevation patterns of 5, 10 and 15 turn helices over ground planes 1.2 λ per side

Table 2
Modeled NEC-4 relative performance of the sample axial-mode helices. All gain values are corrected for the average gain test (AGT) score. Raw reports will be lower.

Number of Turns	*Gain (dBi)*	*Beamwidth (Degrees)*	*Sidelobe Ratio (dB)*	*R-H Gain (dBic)*	*L-H Gain (dBic)*	*Source Impedance Resistance (Ω)*
5	11.69	44	–10.5	11.53	–3.19	314
10	13.03	33	–8.0	13.02	–13.16	312
15	14.16	28	–7.8	14.16	–13.48	316

gain of the helices is about 11.7, 13.0, and 14.2 dBi for the 5, 10 and 15 turn antennas, respectively. Note that the gain increases almost linearly with the increase in the number of turns. This fact is important to keep in mind when comparing axial-mode helices with alternatives to them as circularly (or nearly circularly) polarized antennas.

Modeling the helix itself is simplified by the GH entry in NEC. However, the NEC-2 and the NEC-4 versions of that geometry command differ radically. Therefore, modelers need to consult the appropriate manual for guidance. (The commands are available in NEC-Win Pro and in GNEC, by Nittany-Scientific, with entry-formation assistance screens.) An alternative method of creating a helix appears in EZ-NEC Pro, which allows helix creation as a set of individual wires batch-created by entries similar to those used in the GH command. The termination of the helix on perfect ground is simple enough, but mating the lowest wire end to a wire-grid junction may call for the modeler to displace the wire end to meet the closest junction. The size of the elevated ground-plane surface for a given helix does make a difference in the performance of the antenna, although gain changes are small. There is an optimal size that varies with the length of the he-lix. The ground screens in the sample models are close to optimal.

An axial-mode helical antenna rarely yields perfect circular polarization. Instead, it yields elliptical polarization, with a major and a minor axis and a tilt angle. The antennas approach perfect circularity most closely along the axis of the helix. Applications needing something closer to circular perfection tend to work with quadrifilar designs, although they are impractical for amateur satellite service. The sample models improve their circularity with increased length. More pertinent to amateur use is the fact that an axial-mode helix does not produce a perfect single-lobe pattern. Figure 3 shows the total field patterns of the 5, 10 and 15 turn helices over an elevated ground screen. In each case, we can see a considerable collection of side lobes. Each model uses the circumference that produces the best gain, but that circumference does not yield the lowest level of side lobes. Reducing the circumference produces lower gain (from 1 to 2 dB, depending upon the length of the helix), but results in a cleaner pattern.

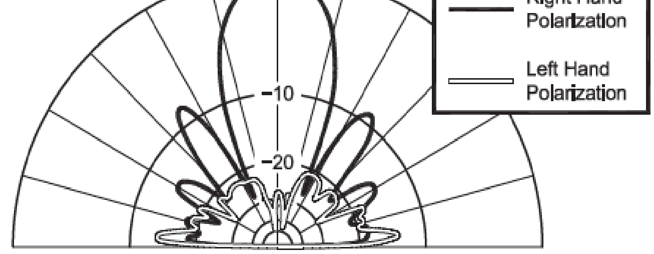

Figure 4 — Right-hand and left-hand polarized components of the elevation pattern of a 15 turn helix over a ground plane 1.2 λ per side.

Circumferences below about 0.85 lambda rarely have any sidelobes at all through the 15 turn limit in my investigation.

As well, there are remnants of opposite-direction polarization within the total field of the axial-mode helix. Figure 4 shows the dominant right-hand polarized component of a 15 turn helix over a ground-screen elevated above average ground. The left-hand compo-nent is down by 25 dB, with some of the lower lobes being composed mainly of left-hand components. All of these facets of axial-mode helix performance have a bearing on the sensitivity of such antennas to off-axis signals, whether at high or low angles relative to the axis that marks the centerline of the helix. How much side lobe and oppositely polarized lobe suppression is enough, of course, you must determine based on your application and your local circumstances.

These notes have not addressed the question of actually constructing a helical antenna. Chapter 19 of *The ARRL Antenna Book* provides some of the general schemes used. For UHF, the most common technique is to use a nonconductive central shaft with periodic side projections to support the helix turns at critical points. (Fowler also uses a conductive center support rod with no degradation of performance.) The number of supports per turn depends upon numerous factors, including the inherent stiffness of the wire or tubing used to form the helix. A central shaft has a mechanical advantage by allowing attachment to the ground-plane screen, cup or grid. Hence, the wire turns do not experience much stress, except for the inevitable attachment to a connector. Standard references give the impedance as 140 times the helix circumference in wavelengths. However, the impedance will vary with the helix structure at the terminating end and with the diameter in wavelengths of the element wire. As the impedance varies, so too will the matching method selected for use with the coaxial cable. In such applications, the coax used for the main feed line may be 50 Ω, or (for those using surplus solid sheath varieties) 75 Ω.

The dimensions for an axial-mode helical array are implicit in the set of design criteria to which we build. Hence, I have given only overall dimensions, although you may easily derive more specific dimensions from the graphs shown and the basic trigonometry for the design work. Table 3 gives dimensions — many of which are interdependent — that define a helix.

All dimensions refer to center-to-center distances relative to the wires. The last two items in the list are relevant to the physical planning of the helix design.

If these notes give the impression that the axial-mode helix is somewhat imperfect, the impression is correct. However, it is not so far from perfect to bar its effective use in satellite applications. The antenna originated as a broadband array and has been pressed — some-times uncritically — into spot-frequency or narrow-band uses. Understanding the fundamental properties of axial-mode helices in this context is an essential ingredient to producing an antenna that fulfills its promise.

Alternative Parasitic Arrays

An alternative to the axial-mode helical array is a parasitic array with turnstiled or quadrature fed drivers. Up to a point — but not necessarily beyond that point — such arrays offer some advantages over helical arrays. Not the least of these advantages is our famili-arity with the construction techniques involved in building them and matching them to standard coaxial cable feed lines.

Unlike the helix and its design equations, most parasitic arrays are designed by model or experiment — or both — for a certain level of performance at a given frequency, within some overall size constraint. Therefore, we shall offer some dimension tables for our samples without in the least claiming them as the best possible designs. The goal will be to note some significant differences between parasitic and helical arrays designed for circular polarization. The design models are for 299.7925 MHz to coincide with the helix designs that we have so briefly surveyed. Like the helices, the parasitic arrays can be scaled to other frequencies.

When most folks think of parasitic arrays with circular polarization (or an approximation thereof), the crossed Yagi comes to mind. Although that antenna is certainly one of our alternatives, it is not the only one. Neglected is the quad beam, which we may convert to circular polarization without adding any further elements beyond those needed for ordinary or linear polarization.

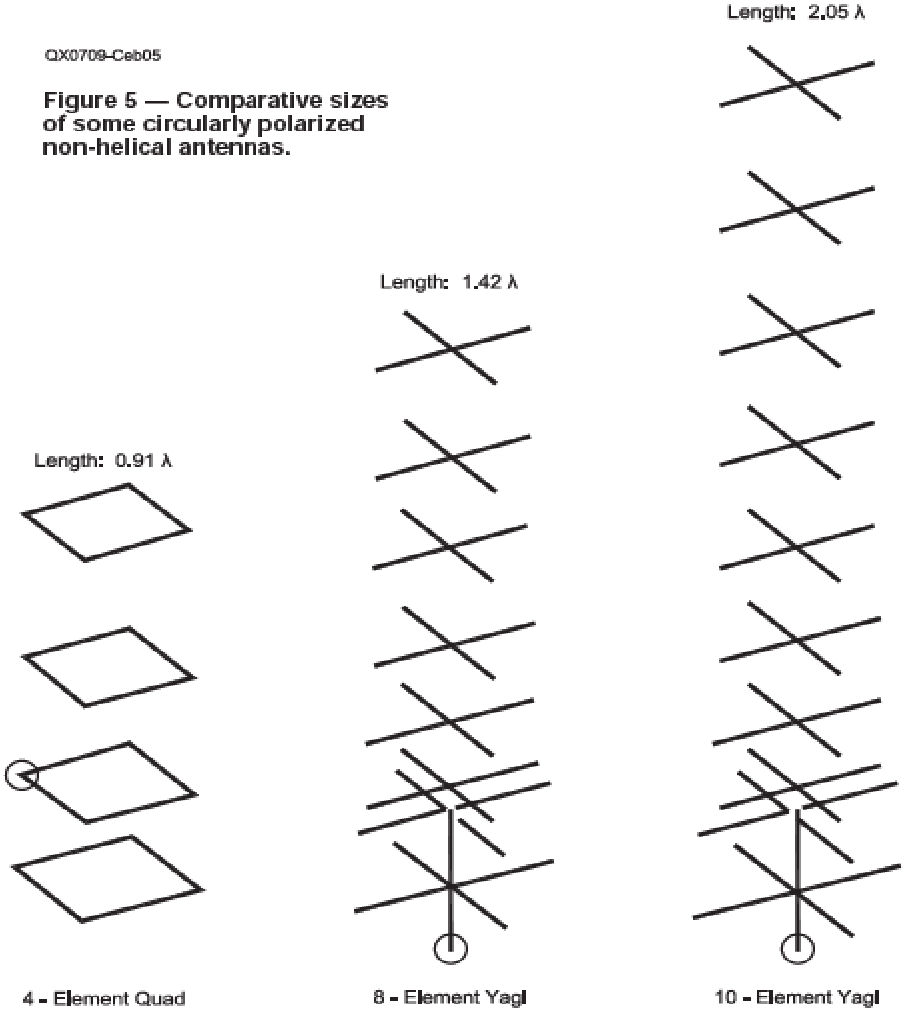

Figure 5 — Comparative sizes of some circularly polarized non-helical antennas.

Table 3
Dimensions Defining a Helix

R = radius of the helix, wire-center to wire-center	
C = circumference of the helix	$C = 2 \pi R$
S = spacing between turns	$S = C \tan \alpha$
α = pitch angle	$\alpha = \tan^{-1} (S/C)$
N (or n) = number of turns	
L = axial length of helix	$L = n S$
D = conductor diameter	
L′ = conductor length for a single turn	$L' = \text{SQRT}(C^2 + S^2) = C/\cos \alpha = S/\sin \alpha$

Figure 5 shows three of our samples to illustrate their comparative sizes. For moderate gain levels, the parasitic arrays have boom lengths that are much shorter than corresponding helical arrays. For example, a 10 turn helix with a gain of about 13 dBi is almost a half-wavelength longer than a 10-element Yagi with about a half dB higher gain. However, we have noted that helices tend to increase in gain almost (but not quite) linearly with added turns, while adding more directors to a parasitic array results in a decreasing gain-per-new-element value. Hence, there is a crossing point at which the helix shows more gain than a parasitic array of the same overall length. That crossover point most likely occurs when the arrays approach 5 lambda in overall length.

The first non-helical candidate is a 4-element quad, the dimensions for which appear in Table 4. The quad is only 0.91 lambda long from reflector to the last director. Using 1-mm diameter wire for the elements, it has a gain of 10.6 dBi when placed 1 lambda above average ground. The quad's beamwidth is 58°. The performance of the quad is more completely summarized in Table 5, along with the other sample candidates as alternatives to the helix. Two sets of values are especially significant. One is the high value of front-to-sidelobe ratio (listed as a negative value of dB below the main lobe gain value), when compared to the much smaller ratio shown by the helices. In fact, Figure 6 shows the elevation patterns for the quad overlaid with two of the Yagis for direct comparison with the helix patterns shown in Figure 3.

Because a quad allows some flexibility in the placement of the driver without undue adverse effects on the array gain, we may arrive at a single source impedance of about 95 Ω resistive. Hence, a lambda/4 section of 93 Ω cable forms a proper phase line run between successive corners of the driver. The result is a circularly polarized antenna. This technique first came to my attention in a sample model that Brian Beezley, K6STI, included in the model collection that accompanies his AO program. We should not run the phase-line coax parallel to the active element. Hence, it is likely that we would use a 3 lambda/4 section of line running from one corner to the center nonconductive boom and back to the adjacent corner. We may reverse the polarization simply by connecting the main feed line at one or the other end of the phase line. Higher isolation feeding methods have appeared from time to time. For this simple system, the result is a 50 Ω impedance for the main feed line. The 4-element quad in the outline sketch has a 2:1 50 Ω SWR bandwidth of more than 25 MHz, which eases the problems associated with construction variables. (Redesigning the antenna for fatter elements would yield an even larger bandwidth.) Obviously, longer versions are possible for the quad if you desire more gain. However, in our survey of alternatives, let's turn now to some Yagi designs.

Table 6 provides the dimensions of three sample Yagis, all derived indirectly from normal Yagis of DL6WU vintage. The short 8-element version is 1.42 lambda long, while the 10-element version has a boomlength of 2.05 lambda. The 12-element version is 2.60 lambda long. The last sample Yagi appears mostly to demonstrate that as we add new directors, the increase in gain dwindles per added element. Nevertheless, the 14.2 dBi gain of the 12-element Yagi compares well to the peak gain of the 15 turn helical antenna with a total length of over 3.6 lambda.

Since NEC uses only axial currents in calculating the antenna fields, you may model crossed Yagis with each crossed parasitic element pair joined at the center. If there are any interactions, they will not show in the model. In practice, it is likely that one will use a pair of independent linear elements. Since the drivers require separation, if only by a small distance, to establish their independence, it will not harm construction to use the same separation between parasitic elements. The modeled dimensions in Table 6 presume the use of a nonconductive boom.

Table 5 summarizes the potential performance of the Yagis. The total field patterns for the 8 and 10-element versions appear in Figure 6, along with the quad. I omitted the 12-element Yagi lest the morass of pattern lines become unreadable. Each Yagi shows close to the same front-to-sidelobe ratio — about 15 to 16 dB. As well, all of the Yagis show the same high ratio of right-hand gain to left-hand gain. Figure 7 shows the polarized components of the 10-element Yagi for illustration of the difference. You may wish to compare this pattern with Figure 4, the comparable pattern for a 15 turn helical design.

All of the Yagis use identical feed systems to establish quadrature and a match to a 50 Ω feed line. In this particular design, the single driver source impedance is 50 Ω. Hence, the turnstile phase-line is also 50 Ω. The resulting impedance presented to the main feed line is close to 25 Ω. A length of

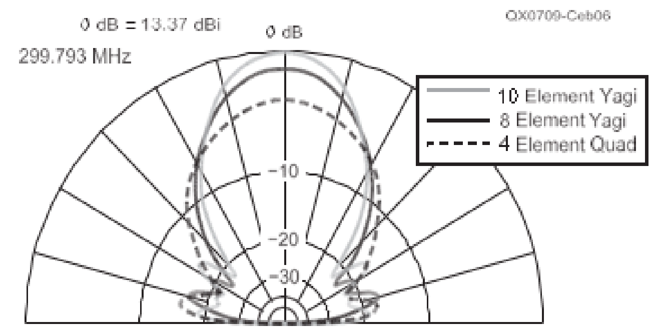

Figure 6 — Comparative elevation patterns of a circularly polarized quad and two circularly polarized Yagis: a 10-element Yagi, an 8-element Yagi and the

Table 4

Dimensions of a 4-element circularly polarized quad array. All dimension in meters at 299.7925 MHz or in wavelengths. Wire diameter = 1 mm.

Element	*Circumference*	*Side Length*	*Space from Reflector*
Reflector	1.084	0.271	—
Driver	1.028	0.257	0.240
Dir 1	0.964	0.241	0.540
Dir 2	0.948	0.237	0.910

Table 5

Modeled relative performance of the parasitic arrays at 300 MHz. Quad gain values are corrected for the AGT score. Raw reports will be lower.

Array	*Gain (dBi)*	*Beamwidth (Degrees)*	*Sidelobe Ratio (dB)*	*R-H Gain (dBic)*	*L-H Gain (dBic)*	*Source Impedance R ± j X Ω*
4-El Quad	10.58	58	−11.9	10.58	−18.21	49.7 – j 0.0
8-El Yagi	12.58	44	−14.9	12.57	−13.88	44.7 + j 7.7
10-El Yagi	13.57	40	−15.5	13.54	−9.04	44.7 + j 7.0
12-El Yagi	14.17	37	−14.9	14.15	−8.69	44.5 + j 7.0

35 Ω line (or a pair of 75 Ω lines in parallel) provides the required match for a 50 Ω main feed line. As with the quad, you may change polarization simply by swapping phase-line ends for the junction with the matching section and main feed line. Removing the phase-line altogether converts the array to linear polarization, with the unfed elements having little if any effect on operation in this mode.

To center the design frequency within the overall 2:1 50 Ω SWR passband, the line lengths for both the phase line and the matching line are not true quarter wavelengths electrically. The electrical length of the phase-line is a bit over 0.22 lambda, while the matching line is close to 0.215 lambda. The 2:1 SWR passband, as illustrated in Figure 8, runs between 270 and 330 MHz, a 60 MHz spread that should make home construction less critical. However, as with any antenna based upon turnstiled dipoles, the SWR bandwidth will be far wider than the operating bandwidth for which the patterns hold their desired shape. Hence, it remains good design practice to optimize the performance of the crossed Yagis for the desired range of operation. An SWR meter alone is not sufficient to optimize any circularly polarized antenna.

The physical implementation of a parasitic design will require considerable effort. Never assume, but actually measure the actual velocity factors of the lines. Construction will require close attention to line dress and to the potential effects of any connector installed. For UHF and upward, one should use certified connectors rather than hamfest specials and bargains. Even the solder lumps that close the wire loops of the quads can create detuning effects from 70 cm upwards. Whether you are building a helix or a Yagi, the casual and careless construction techniques that are harmless at HF become potential plagues to UHF antennas.

Conclusion

As always, we have looked at alternatives for antennas meeting a certain set of needs. In this case, we selected satellite communications, with its need for circular polarization — or as closely as we may approximate circular polarization using standard construction techniques. The key alternatives for antennas that we steer with respect to both azimuth and elevation are axial-mode helical arrays and turnstiled parasitic arrays.

Both techniques will produce able arrays. Our survey and samples do not exhaust the designs that we may bring to bear on the communications need. However, they should open the door to relevant considerations in making a choice between the two major routes to circularly polarized antennas and to some of the considerations when designing an antenna within either general category.

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There are a number of background sources for information on axial-mode helices. The following list is a start, with most of the items having extensive bibliographies.

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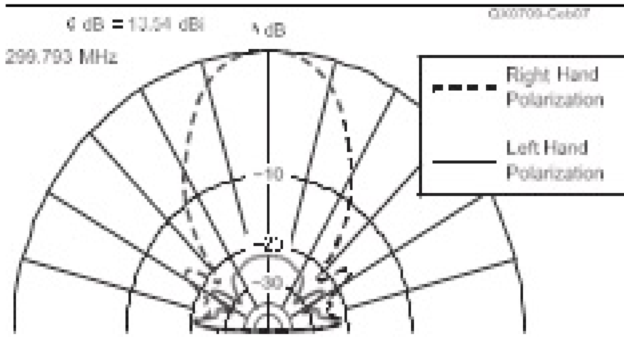

Figure 7 — Right-hand and left-hand components of the elevation pattern of a 10-element circularly polarized Yagi.

Table 6
Dimensions of three sample cross-element Yagis. All dimension in meters at 299.7925 MHz or in wavelengths. Wire diameter = 12.7 mm (0.5 inch or 0.0127 λ). Each element entry represents two elements at right angles to each other.

A. 8-Element Yagi

Element	*Element Length*	*Spacing from Reflector*
Reflector	0.469	—
Driver	0.452	0.205
Dir 1	0.404	0.267
Dir 2	0.398	0.437
Dir 3	0.392	0.640
Dir 4	0.386	0.876
Dir 5	0.382	1.141
Dir 6	0.367	1.424

B. 10-Element Yagi

Element	*Element Length*	*Spacing from Reflector*
Reflector	0.469	—
Driver	0.452	0.205
Dir 1	0.404	0.267
Dir 2	0.398	0.437
Dir 3	0.392	0.640
Dir 4	0.386	0.876
Dir 5	0.375	1.141
Dir 6	0.369	1.424
Dir 7	0.363	1.731
Dir 8	0.356	2.052

C. 12-Element Yagi

Element	*Element Length*	*Spacing from Reflector*
Reflector	0.469	—
Driver	0.452	0.205
Dir 1	0.404	0.267
Dir 2	0.398	0.437
Dir 3	0.392	0.640
Dir 4	0.386	0.876
Dir 5	0.375	1.141
Dir 6	0.369	1.424
Dir 7	0.363	1.731
Dir 8	0.356	2.052
Dir 9	0.350	2.347
Dir 10	0.350	2.607

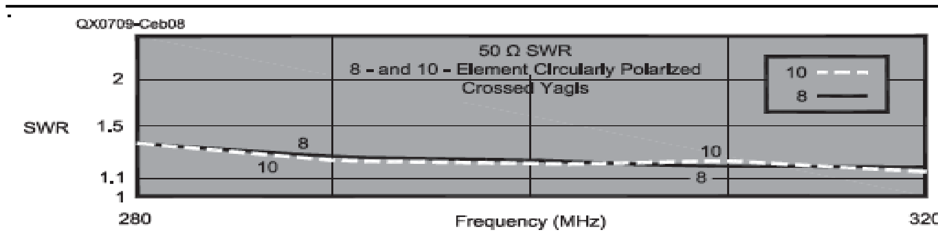

Figure 8 — 50-Ω SWR curves for the 8 and 10-element circularly polarized Yagis.

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[Editor: Originally published in the Sept/Oct 2007 issue of QEX.*]*

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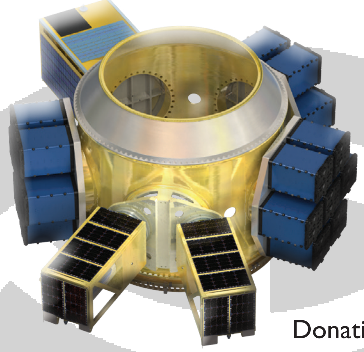

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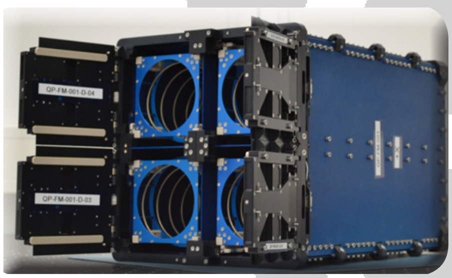

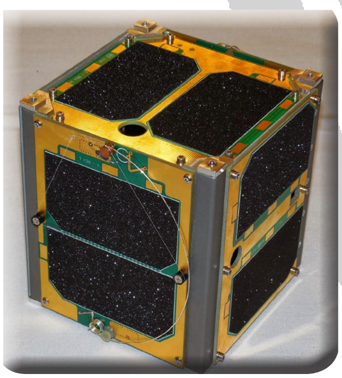

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