The AMSAT® Journal

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in this issue ...

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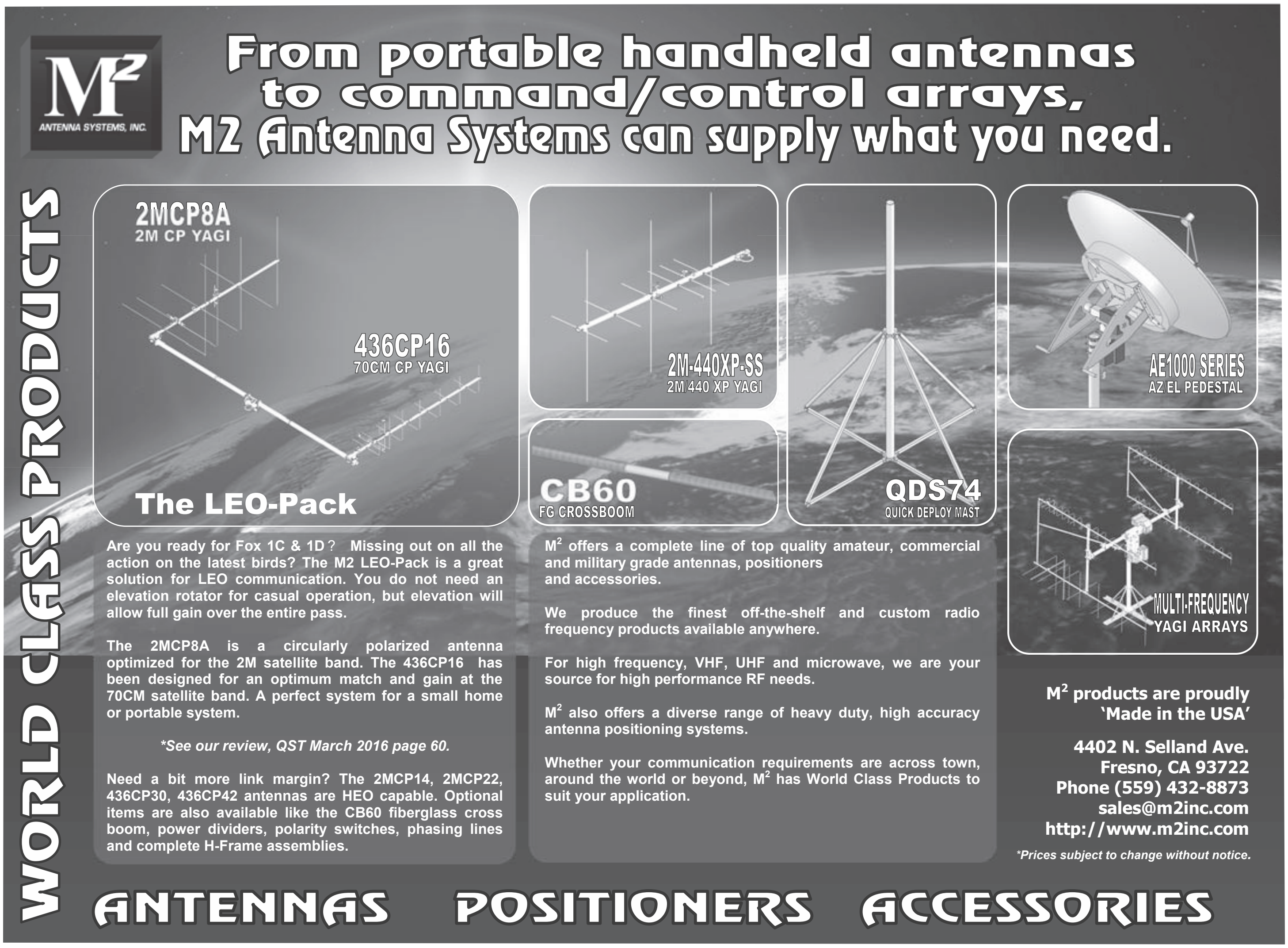

AMSAT Announcements

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

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

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

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

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

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

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

AMSAT's Mission

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

AMSAT's Vision

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

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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 reserves the right to select material for *The AMSAT Journal* based on suitability of content and space considerations.

Apogee View

Joe Spier, K6WAO
President

As I write this installment of Apogee View, I have just returned from Hamvention 2019. Before I report on all the AMSAT functions at Xenia, I'd like to take a moment to remind all AMSAT members of your importance to this organization. This is AMSAT's 50th Anniversary, and AMSAT has existed not only because of the hard work of all the volunteers over the years but in considerable measure from the support of the membership. The key support each and every member can provide is to vote in the annual Board of Directors election. I ask you to do your research. Cast your ballot for the director based upon their vision for AMSAT's future as reflected in the candidate's statements and whether their views represent where you want to see this organization moving in the future.

Before I get to our Hamvention activities, I have to thank the Dayton Amateur Radio Association (DARA) and the American Radio Relay League (ARRL). I arrived in Dayton a day early to help AMSAT Hamvention Chair, Phil Smith, W1EME, collect all the materials we had prepositioned to Dayton. AMSAT and DARA member Steve Coy, K8UD, allowed the use of his facilities, and this year, the space frames for the OSCAR Park display were delivered to his care. Phil and I delivered two van loads to Hamvention and met Steve Belter, N9IP, with a truckload of the 2019 Edition of Getting Started with Amateur Satellites (get yours at the AMSAT Store online).

Thursday was the official setup day for the AMSAT booth. While the setup crew unloaded the storage locker (another van load) and began the setup process led by Paul Stoetzer, N8HM, and Barry Baines, WD4ASW, I attended the opening of the AMSAT® Academy. The AMSAT® Academy was hosted by DARA at the DARA Clubhouse with support from Ed Collins, N8NUY, also an AMSAT and DARA member. The presenters were your El Presidente and AMSAT Vice-President for User Services, Robert Bankston, KE4AL. While I covered a bit of AMSAT history, Robert did the yeoman's work for the day with the 38 attendees. All were treated to a full day of instruction, designed for both beginners and advanced amateur radio satellite operators, as well as a digital copy of 2019 Edition Getting Started with Amateur Satellites, a one-year AMSAT Basic Membership or renewal, and a pizza buffet lunch.

This was a unique opportunity to learn all about amateur radio in space and working the FM, linear transponder, and digital satellites currently in orbit. Keith Baker, KB1SF, AMSAT Treasurer and a DARA member, introduced and escorted Japanese Amateur Radio League (JARL) and radio star, Kaori Mita, JI1BTL, who hosts the radio show "CQ ham for girls" in Japan. She sang one of her hit songs, the original of which may be found here: **www.fmpalulun.co.jp/sound/CQ1.mp3.** The next AMSAT® Academy will be held at the Albuquerque Duke City Hamfest and Convention in Albuquerque, New Mexico, September 20-22, 2019.

By the time I got back to the AMSAT booth, the crew had a lot of the preliminary setup completed. I headed over to the ARRL section and met with Bob Allison, WB1GCM. ARRL Test Engineer. After my many thanks to the League for the loan of OSCAR 1, we had a brief chain of custody ceremony, after which Bob and I walked OSCAR 1 to OSCAR Park. Other appearances at OSCAR Park included a full size model of AO-7 (thanks to Peter Portanova, W2JV), a full size Phase 3A space frame, 1/3 size models of AO-10 and AO-13, a full size working engineering space frame (everything but batteries and solar panels) of ARISSat-1 (thanks to Lou McFadin, W5DID), the Fox-1 Mechanical Mock-up (thanks to Alan Johnston, KU2Y), and the GOLF dimensional frame (thanks to Bob Davis, KF4KSS). After setup, everyone met at Tickets Pub in Fairborn. The turnout was incredible! Not only did AMSAT fill the space reserved, but we spilled over into the adjoining room.

As Friday opened at Hamvention, I made my way to the front gate where the Boy Scouts of America's Venturing Crew 73 members were getting donations for this year's Hamvention patch. The patch, which resembled the Hamvention "Mentoring the Next Generation" artwork, may be seen here: **crew-73.org/shop/**.

I returned to the AMSAT booth for the Hamvention 2019 opening, where booth traffic was heavy. I left at 1300 EDT to go to the ARISS Forum. The Amateur Radio on the International Space Station (ARISS) Forum was moderated by Frank Bauer, KA3HDO, AMSAT Vice President for Human Spaceflight and ARISS-I Chair, and Rosalie Wright, K1STO, ARISS-I Secretary and ARISS-US ARRL Delegate. Updates included ARISS basics, reports on the number of contacts to date, the contact proposal process, and a silent moment for Astronaut Owen Garriott, W5LFL (SK). ESA Astronaut Tim Peake, KG5BVI, appeared followed by ARISS introduction films, and the start of the guest panel talks. First up was Keith Brandt, WD9GET, NASA Flight Surgeon at Johnson Space Center, who spoke on crew health and perspectives. Next, Gordon West, WB6NOA, shared some audio clips of early crew contacts including one with W5LFL. Following Gordo, Diane Warner, KE8HLD spoke on STEM engagement. Several clubs were recognized for their ARISS outreach programs, including the Nashua ARC, DARA's 2019 Club of the Year.

Ninth grader Dhruv Rebba, KC9ZJX, spoke on what STEM choices he was considering after being Control Operator for the ARISS US394 contact (also my last contact as an ARISS mentor). A discussion followed on the NASA Deep Space Gateway (DSG) and the submitted ConOps plan, reflecting DSG's progress toward becoming a reality. Then Frank Bauer spoke about the Education Committee and its development. Lou McFadin, W5DID, provided an update on the ARISS hardware and the Inter Operable Radio System (IORS). Frank finished with the announcement that, for donations of any amount at **www.ariss.org/donate.html** after May 16 on FundRazr.com, an anonymous benefactor will match your contribution dollar for dollar, for which ARISS is very grateful. The donation match ends on July 17, 2019. I returned to OSCAR Park for the remainder of the day.

That evening, the TAPR/AMSAT banquet provided a great meal, social discourse, and a presentation by Philip Erickson, Ph.D., W1PJE, of the Atmospheric Sciences Group at MIT Haystack Observatory. His presentation, entitled "New Frontiers in Human Understanding of Geospace: Radio Explorations of Near-Earth Space from Top to Bottom Through Joint Amateur – Scientist Partnerships," focused on citizen science. Specifically, he described how the radio propagation data show how the space weather, ionospheric layers, lower atmosphere, and terrestrial weather patterns are all related.

Saturday seemed calmer at OSCAR Park and the AMSAT booth, or maybe we all just became immune to the crowds. The AMSAT Forum occurred midday. I updated attendees on AMSAT with the usual reports on membership, financials, and the expectation for the EAR Policy that should be ready the 3rd quarter this year. I was followed by Jerry Buxton, N0JY, AMSAT Vice President – Engineering, who talked about the Fox-1 series and Golf (Greater Orbit, Larger Footprint) Projects. Alan Johnston, KU2Y, AMSAT Vice President – Educational Relations, introduced the AMSAT CubeSat Simulator. Robert Bankston, KE4AL, AMSAT Vice President – User Services, discussed AMSAT's 50th Anniversary Operating Event and the new AMSAT Ambassadors Program.

Our major announcement at the AMSAT Forum concerned the 50th Anniversary Space Symposium. This year will be the 37th Annual AMSAT Space Symposium and General Meeting, to be held Friday through Sunday, Oct. 18-20, 2019, in Arlington, Virginia. The location will be The Hilton Arlington, 950 North Stafford Street, Arlington, Virginia, 22203, 703-528-6000.

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On Saturday, I was interviewed by one of the local Dayton television stations, but alas, I have a face for radio as most of the footage ended up on the cutting room floor. You can see parts of OSCAR Park in the report at: **fox45now.com/news/local/radio-lovers-from-across-the-world-go-to-hamvention-in-greene-county.**

Sunday was almost relaxing in comparison, with only half a day in the AMSAT booth, then breaking down and packing up materials, returning them to the storage locker, and then off to the Columbus airport for delayed flights until I got back to Reno about 0300 PDT the next day, in just a little over 24 hours.

I had the pleasure of attending the 16th Annual CubeSat Developer's Workshop at Cal Poly in San Luis Obispo, CA, April 23-25. This premier event brings together universities, K-12 educators, commercial vendors, commercial space opportunities, and the public from all over the globe. Traffic at the AMSAT table was steady, with significant interest generated by the Linear Transponder boards of AMSAT's Fox-1E. I must commend AMSAT's Vice-President, Engineering, Jerry Buxton, N0JY, and Drew Glasbrenner, KO4MA, who staffed the AMSAT booth and interacted with the CubeSat community. This left me free to attend many lectures and learn about cutting edge CubeSat developments. I learned about a great need for the development of thermal protection for CubeSats to operate in the lunar night temperatures that can plunge to less than minus 397 degrees Fahrenheit (minus 238 Celsius) — colder even than the surface of far away Pluto.

At the end of June, I'll attend the ARISS-I Face-to-Face Conference in Montreal, Quebec, Canada. I'm also interviewing a candidate for AMSAT Vice-President for Marketing. I have two volunteers with extensive grant writing skills, and I will announce that program once all the particulars are sorted out. For now, I ask that you continue your membership, help recruit new members, contribute what you can when you can, use the satellites, transition to the linear birds, and more importantly – have fun!

73-Joe, K6WAO

AMSAT CubeSat Simulator Part 3: Failure Simulations and Troubleshooting

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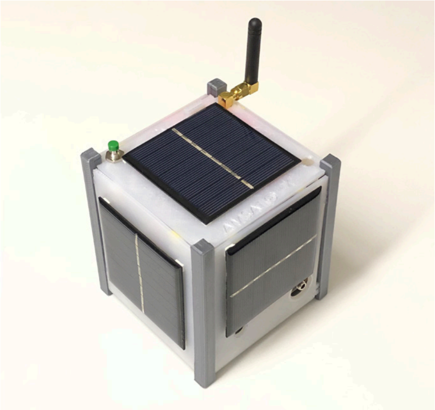


Figure 1—The AMSAT CubeSat Simulator proof of concept prototype.

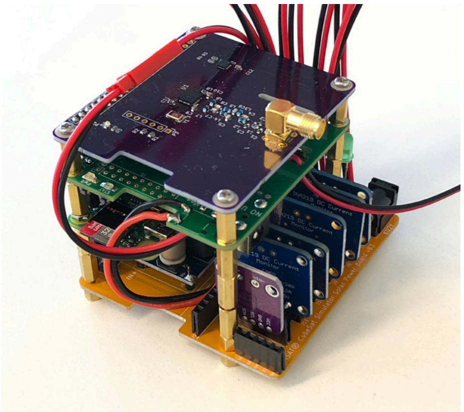


Figure 2 — The latest CubeSat Simulator board stack showing (from the top) the Digital Transceiver Board, MoPower UPS V2 Board, Raspberry Pi Zero W Board, and the custom AMSAT Solar Power Board.

Introduction

Last year, we introduced the new AMSAT CubeSat Simulator as a tool for satellite technology education and demonstrations. We described the proof-of-concept prototype that we built and demonstrated at the 2018 AMSAT Annual Meeting & Space Symposium in Huntsville, Alabama.

In the previous issue (*AMSAT Journal*, Part 2, Jan/Feb 2019), we described some educational activities that can be done with the CubeSat Simulator by looking at the activities of the original ARRL ETP CubeSat Simulator, as described by Mark Spencer, WA8SME, roughly ten years ago, as fully referenced in our earlier works.

In this article, we describe some new activities that we have developed with the new CubeSat Simulator. These include some interesting failure simulations, efficiency and maximum power point calculations, and using an Arduino platform as a payload for the Simulator.

Background

The new AMSAT CubeSat Simulator, shown in Figures 1 and 2, is a Raspberry Pi Zero W-based, 3D-printed frame structure, functional model of a "1U" CubeSat that is designed to act, as reasonably as possible, as one flying in Low Earth Orbit (LEO). Its purpose is to demystify to all how satellites work. Like typical LEO satellites, this simulator runs on rechargeable battery power and solar cell panels. Our model currently transmits telemetry on the UHF band using the AMSAT OSCAR 7 (AO-7) format using AFSK modulation. For details on the design and construction of the simulator, see our paper in the 2018 AMSAT Annual Meeting & Space Symposium proceedings (at **countingfromzero.net/amsat/CubeSatSimPaper.pdf**) or as updated and edited for the Nov/Dec 2018 issue of the *AMSAT Journal*.

The telemetry data graphs shown in this paper were generated by placing the CubeSat Simulator on a rotating turntable in front of a halogen work lamp, which simulates a spinning satellite in space, as shown in Figure 3.

The remainder of this article describes new activities for the CubeSat Simulator. They include some real-world simulated and actual failures, an ample number of plots to support troubleshooting, and also some efficiency calculations. Each of these simulator exercises to date provides the basis for valuable lessons in understanding satellite technology and in developing one's skills.

Failure Simulations

CubeSat missions on orbit do not always go according to plans. Functional issues stemming from CubeSat design, electrical and mechanical parts, assembly, rework, handling or the integration and test phase is a fact of life. The tension or strain from sources such as launch, the radiation environment, outgassing effects, loose conductive particles afloat and more can cause intermittent operations, degraded performance or even, unfortunately, a failure. Detecting and diagnosing impending failures is essential, as it can help develop workarounds or solutions, or at least aid in avoiding such issues in the future. A steely-eyed missile man once confided that the worst kind of failure is having launched a flying "brick," where no telemetry is received from a satellite after being deployed, and as a result, there are no clues -- and no recourse -- as to what kind of failure occurred.

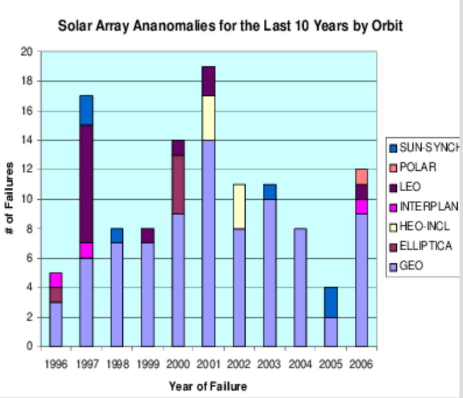
Figure 3 — The CubeSat Simulator on a rotating turntable under halogen work lamp illumination.

SATELLITE FAILURE

The literature in the small satellite community ranks the frequency of on-orbit failures by subsystem. Of the top ten major subsystems of every satellite (shown in Part 1 of this CubeSat Simulator series), it is the Electrical Power Subsystem (EPS) that seems to appear at or near the top of such lists.

The EPS includes the solar cell strings and panels, the batteries, charging controller, heaters, thermostats, and the power distribution circuits, among other components as well. Among these, the accompanying graphic by ResearchGate (Reference: W. Brandhorst Jr, Henry & A. Rodiek, Julie & O'Neill, Mark (2008), "Stretched lens array: The answer to improving solar array reliability", Conference Record of the IEEE Photovoltaic Specialists Conference.) shows a horror story involving any number of solar panel anomalies only.

In studying the Physics of Failure, we find two major categories of root causes in an otherwise well-designed and well-built system. One is from latent (or built-in) defects of a part. The other is from overstress. Overstress is the exposure at any level of assembly to an excessive electrical, mechanical, thermal or other condition beyond its documented specifications or requirements. The scope of this paper is therefore on anomalies common in a typical CubeSat EPS.



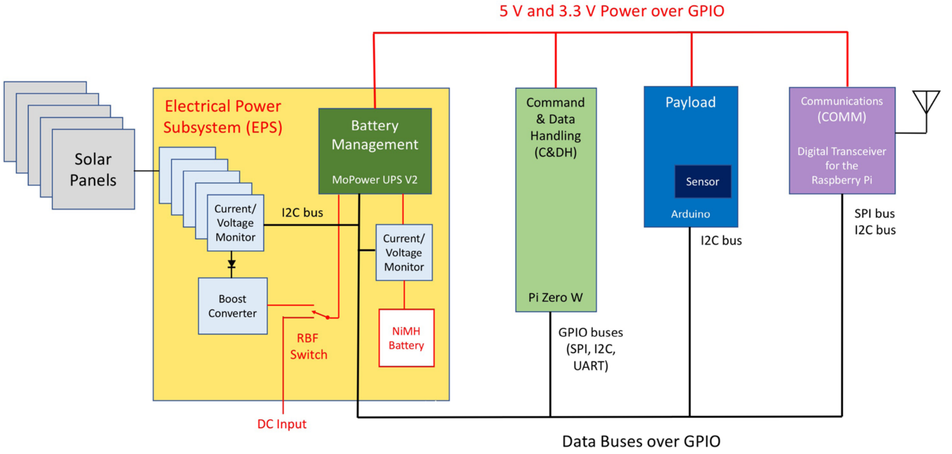


Figure 4—Block Diagram of the CubeSat Simulator showing EPS subsystem on left side.

In this section, we will simulate a degrading performance parameter or two and a few nearly-catastrophic failures, and then walk you through some steps on how to detect and diagnose the symptoms by using the available housekeeping telemetry. Our real-life training anomalies relating to the EPS are the following:

- Solar cell short circuit
- Solar cell open circuit
- Solar cell polarity reversal
- Solar cell high impedance
- I2C sensor failure
- I2C bus failure
- Boost converter failure

These failures can be easily simulated with the AMSAT CubeSat Simulator with a few test leads. In the latest design, we use JST connectors between the solar cells and the Solar Power Board. These connectors are widely used in RC vehicles and aircraft. We use a few special JST connectors as well as some mini clip test leads to simulate these failures.

The block diagram for the AMSAT CubeSat Simulator is shown in Figure 4, which shows the Electrical Power Subsystem (EPS). We will reference this diagram several times in this article. For more information about the Solar Power Board, including a full-size schematic diagram in color, see our CubeSat Simulator Wiki (at **github.com/alanbjohnston/CubeSatSim/wiki**).

To simulate a short circuit, we can simply (and safely) connect the positive side of the solar cell to ground after the current and voltage sensor module. Interestingly, this actual failure occurred in our first iteration of the concept simulator model built using the Beta vB3 PCB. Using telemetry, we were able to diagnose this failure and find the cause. Figure 5 shows the telemetry we observed after constructing the simulator where one solar panel was accidentally directly tied (or shorted) to ground.

At first, the telemetry appears to be correct, as we see four peaks of the +X, +Y, -X, and -Y panels as it rotates on the turntable in front of the halogen work lamp, as shown in Figure 3. However, upon a closer look, we see the -Y solar cell current, but there is no

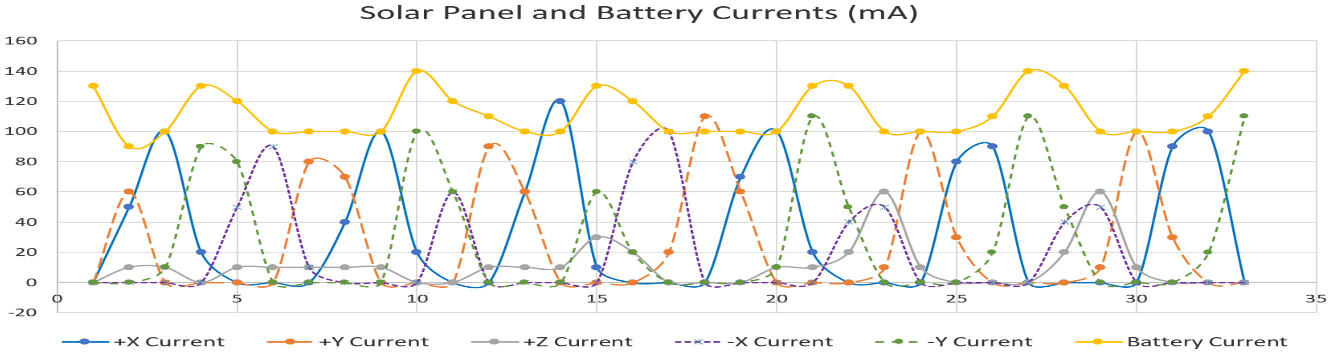


Figure 5— Solar panel shorted circuit to ground failure.

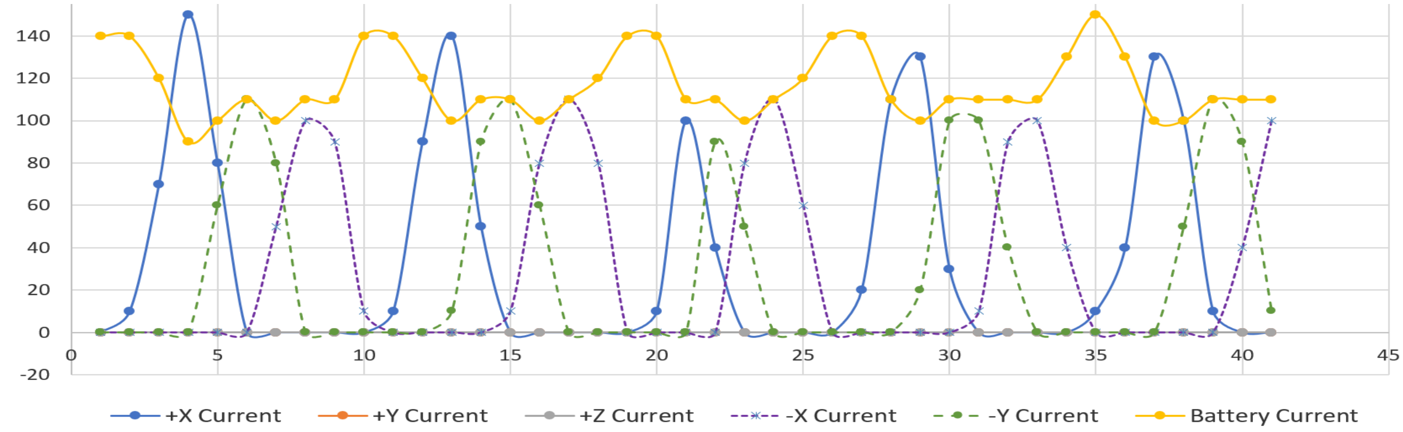


Figure 6— Solar panel open circuit failure.

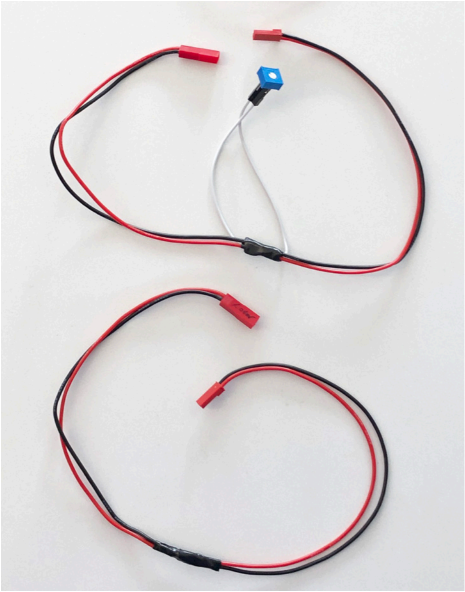


Figure 7— Back-to-back cables used to simulate solar panel failures, top: series potentiometer cable, bottom: polarity reversal cable.

corresponding drop in the battery current, indicating that none of the power has been transferred to the Simulator. (Under a short circuit condition, a solar cell will produce maximum current, but since the voltage across it is zero volts, no power is generated). This condition of maximum current but no power output indicated that the solar cell was short-circuited. Using this actual telemetry, we were able to find the location of the short circuit and repair it.

An open circuit can be simulated by unplugging the JST connector to the solar cell. This results in the telemetry shown in Figure 6, where there is no current detected for the +Y panel which has been disconnected. Note that a short circuit before the current and voltage sensor would also show up in the telemetry this way.

To simulate a polarity reversal, we made a back-to-back JST connector by swapping the red and black wires. This cable is shown at the bottom of Figure 7. Note that this would be an unlikely in-flight failure but could be a construction failure that was only detected after launch. A series diode in the EPS circuit (diodes D1 tA series diode in the EPS circuit (see the diodes shown in the EPS block between the Current and Voltage Sensors and the Boost Converter module in Figure 4) in the CubeSat Simulator prevents the solar cell from drawing current from the circuit or applying a negative voltage to the output. The resulting telemetry is shown in Figure 8 where the reversal has been applied to the +X panel. The data is identical to Figure 6 where the panel was open circuited.

To simulate a failing solar cell or a high resistance contact on a cell, we made a back-to-back JST connector with a series 100 Ohm potentiometer -- a variable resistor, which was inserted between the solar panel and the board. This cable is shown in Figure 7, the top cable. The resulting telemetry is shown in Figure 9 when the resistance was connected in series with the -X panel and set to approximately 36 Ohms. The telemetry

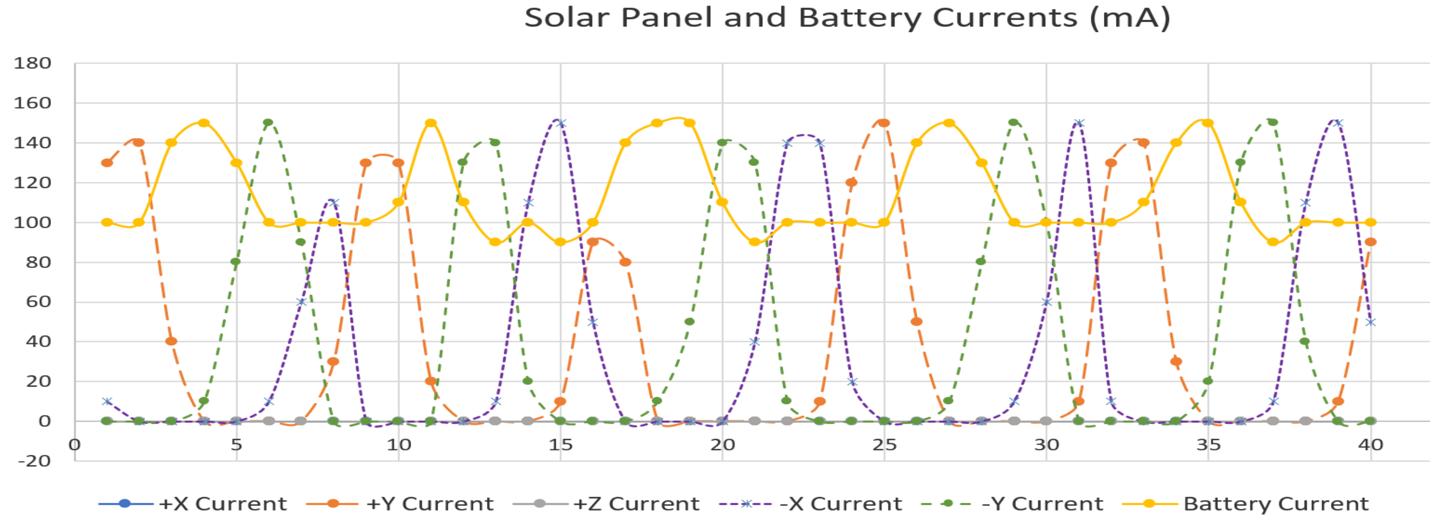


Figure 8— Solar panel reverse polarity failure.

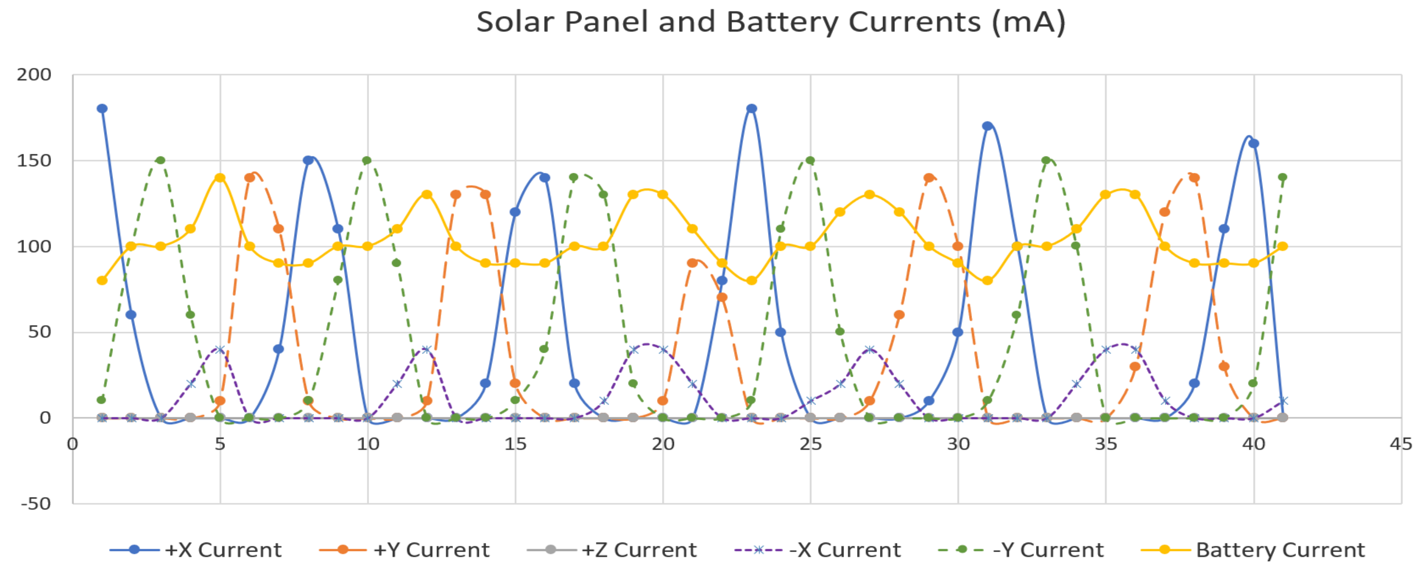


Figure 9— Solar panel high resistance failure.

shows a current peak for the -X panel, but it is much less than the other three panels (45 mA compared to 145 mA). If the simulator were tilted to simulate an off-axis rotation, we would see a corresponding change in the +X current peak, but on this graph it is unchanged.

The Inter-Integrated Circuit (I2C) bus is how the Raspberry Pi gathers current and voltage data for telemetry. On the Solar Power Board, the INA219 current and voltage sensor modules plug into connectors J7 through J13 in Figure 4. An I2C sensor failure can be simulated by merely unplugging the current and voltage monitoring module from the Solar Power Board. This results in no current being detected, which is identical to the open circuit telemetry of Figure 6.

A failure of a complete I2C bus can be simulated in software by disabling the bus. The CubeSat Simulator uses three I2C buses on the Raspberry Pi: i2c-0, i2c-1, and i2c-3.

Bus	Use
i2c-0	-X, -Y, and -Z current and voltage sensors (addresses hex 40, 41, and 44)
i2c-1	+X, +Y, +Z, and battery current and voltage sensors (addresses hex 40, 41, 44, 45) and the 5V power bus current sensor (address hex 4a)
i2c-3	Temperature sensor on Digital Transceiver board (address hex 48)

Table 1. Raspberry Pi I2C Bus Telemetry Data

For this simulation, we disable the i2c-0 bus on the Raspberry Pi (by commenting out the dtparam=i2c_vc=on setting in the /boot/config.txt file and then rebooting the Pi -- see **github.com/alanbjohnston/CubeSatSim/wiki/Software-Install** for details of the software configuration). Note that if the pull-up resistors R1 and R2 are omitted from the board (see Figure 4), the I2C bus will effectively be disabled as well.

The result is a loss of current telemetry on the -X, -Y, and -Z solar cells, as shown in Figure 10. This lack of telemetry on all of the sensors on the same bus points to a bus failure rather than individual sensor failures. If the i2c-1 bus had failed, we would have lost the +X, +Y, +Z,

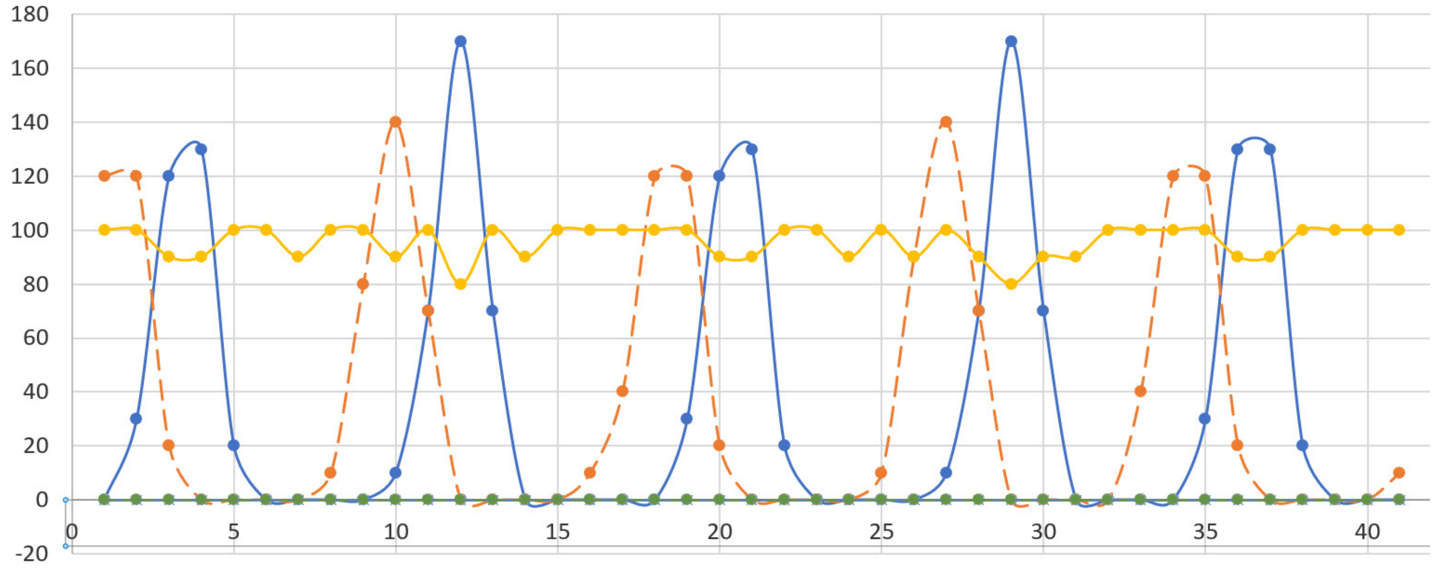


Figure 10— I2C bus failure.

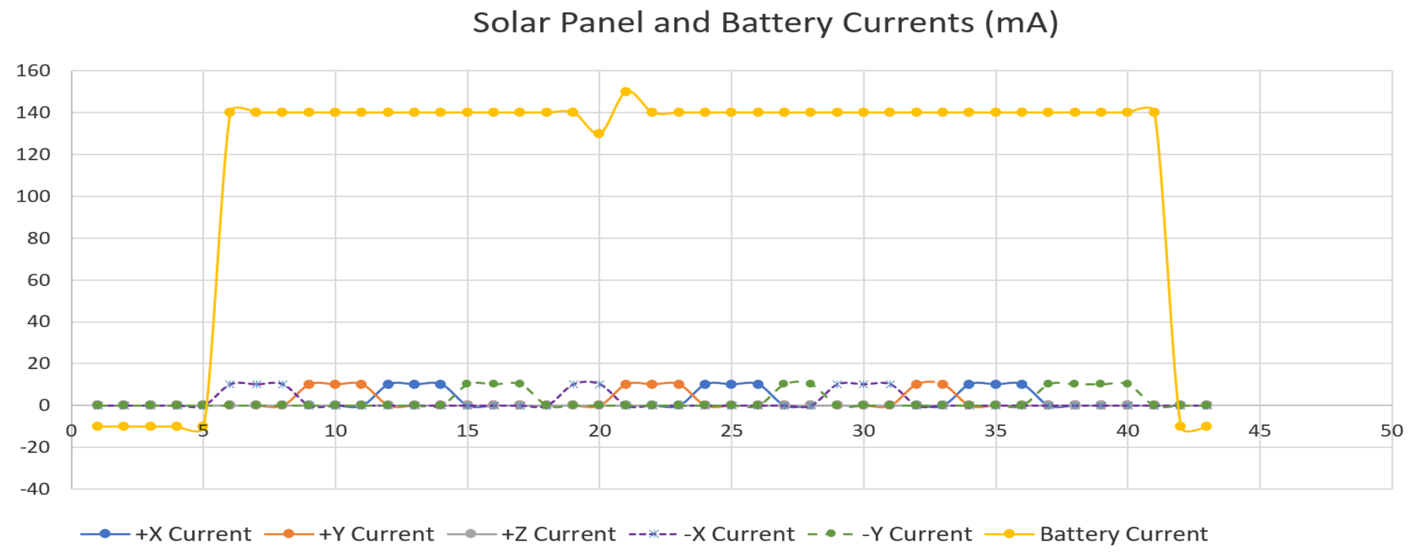


Figure 11— Boost converter failure.

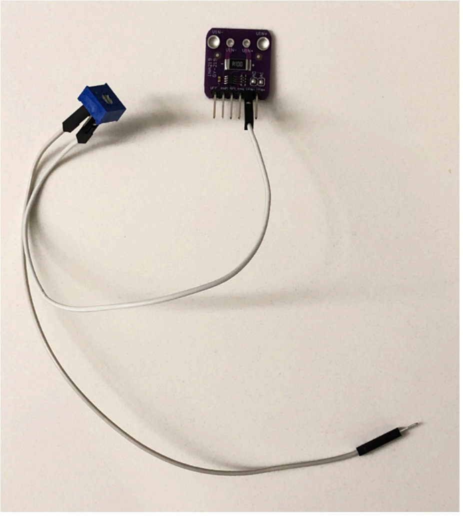


Figure 12 — Modification of voltage and current monitoring board to characterize solar cell.

and battery current telemetry information.

One curious thing about this telemetry is that the battery current dropped by approximately 40 mA from previous data. We haven't had time to investigate why this is, although it was repeatable.

During the building of a Solar Power Board, we incorrectly adjusted the potentiometer on the boost converter module (U1 in the schematic Figure 4). This resulted in telemetry that simulated a boost converter failure. The telemetry is shown in Figure 11. The +X, +Y, -X, and -Y current waveforms can be seen, but they are all much smaller than expected, and the resulting reduction in the battery current from 140 mA doesn't appear. Seeing this telemetry, we disconnected the output from the Solar Panel Board and measured it under illumination. Instead of the desired 15 V, it was reading 4.5 V. After re-adjusting the boost converter module, so the output was 15 V under full illumination, the telemetry curves returned to normal.

Efficiency and Maximum Power Point

Using the voltage, current, and power sensor information available on the CubeSat Simulator, we can determine the efficiency and maximum power point (MPP).

Two electrical efficiencies can be determined in the CubeSat Simulator from our telemetry. The first is what we will call the battery efficiency. This is the efficiency in transferring power from the NiMH battery to the 5 V bus on the GPIO (General Purpose Input Output bus) connector. This measures the

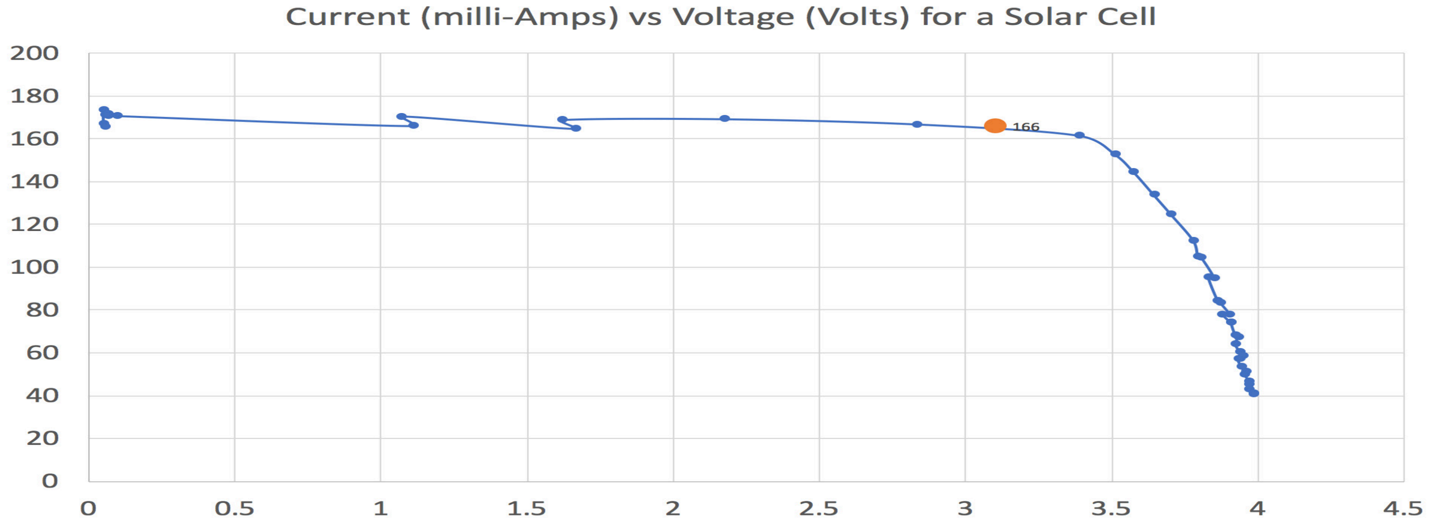


Figure 13— Current versus voltage for the solar panel.

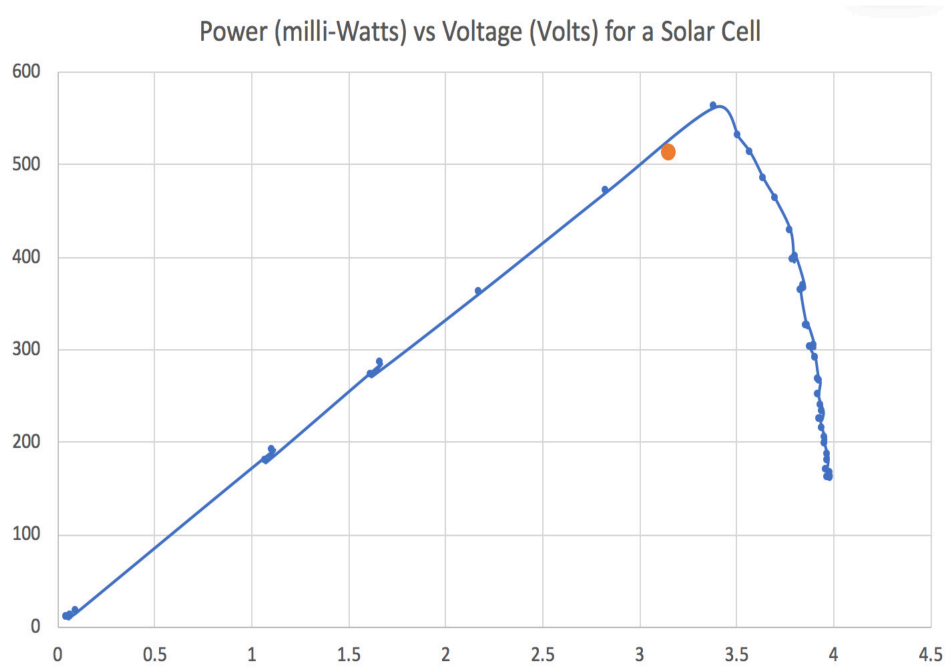


Figure 14— Power versus voltage for the solar panel showing maximum power point.

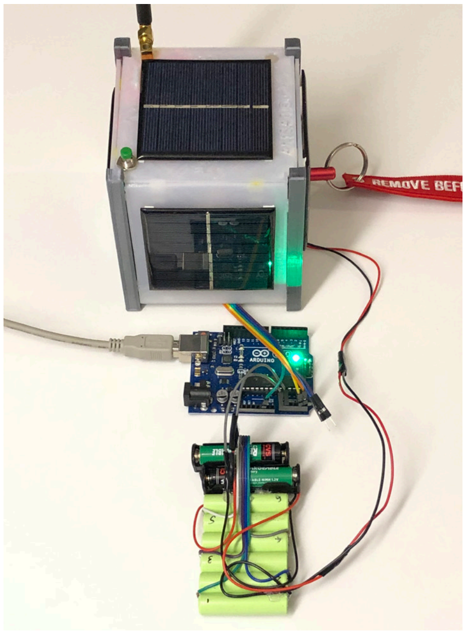


Figure 15 — Arduino Uno as a payload on the CubeSat Simulator.

efficiency of the voltage transformation on the MoPower UPS V2 board. The product of the battery voltage and the battery current is the input power, while the 5 V bus voltage multiplied by the bus current represents the output power for this efficiency calculation.

The other efficiency is solar power charging efficiency. The solar panels provide power to the simulator which reduces the power needed to be supplied by the battery to energize the 5 V bus. In this efficiency calculation, the solar cell power plus the battery power is the input power, while the output power is as measured on the 5 V bus.

Using the telemetry-only software on the Raspberry Pi, we measured both of these efficiencies. First, we measured the battery efficiency, running with the RBF (Remove Before Flight) pin removed but under no illumination. The data point was the battery voltage of 8.5 V, battery current of 148 mA, which is an input power of 1258 mW, and the bus voltage of 5.1 V, bus current of 209 mA, which is an output power of 1065 mW. This gave an efficiency of 85%.

Next, we used a 250 W halogen work lamp at a distance of 10 cm to illuminate one of the solar panels. We used this data to calculate the solar power charging efficiency. The data point was the solar panel voltage of 3.15 V, solar panel current of 167 mA, which is a power of 526 mW from the solar panel, a battery voltage of 8.6 V, battery current of 90 mA, which is a power of 774 mW from the battery, and the bus voltage of 5.1 V, bus current of 201 mA, which is an output power of 1025 mW. This gave an efficiency of 79 %. This is lower because the Solar Power Board contains a series diode (diodes D1 through D6 in the schematic of Figure 3) and a boost converter circuit, U1 in the schematic, each of which produces losses.

We also characterized the solar cell in terms of its current (I) versus voltage (V) curve and power (P) versus voltage (V). We measured this by unplugging the Vin- pin on the +X solar cell current and voltage sensor. We then connected this pin to ground through a 100 Ohm potentiometer (variable resistor). This modification is shown in Figure 12. With the telemetry-only software running, we adjusted the potentiometer from 100% to 0% at 10% intervals, pausing for 1 second so that the telemetry could record the values. We then plotted this data in Excel. This graph is shown in Figure 13.

We also graphed the Power versus Voltage characteristic for the solar cell to find the Maximum Power Point (MPP) for this illumination level. Note that a Maximum Power Point Tracker (MPPT) is an algorithm which tracks this maximum efficiency point automatically in an EPS. This curve is shown in Figure 14. The peak of this curve represents the maximum power point for this solar panel and level of illumination, which is about 3.4 V. Dividing by the power at this point, 562 mW, gives the current of 166 mA. Note that this solar cell is rated at 4 V, 160 mA, 0.5 W, which agrees well with these results.

We then compared the actual voltage and current operating point with this maximum power point and found it to be fairly close. The operating point of 3.15 V and 167 mA is plotted on Figures 13 and 14 as a dot so you can see how close it is to the maximum power point. This indicates that the design could be improved to extract another 35 mW of power from the solar cell.

Arduino Payload

Just like a real CubeSat flight model, the new AMSAT CubeSat Simulator can support payloads. To show this, we connected an Arduino Uno (**www.arduino.cc/**) as a payload. An Arduino is a low-cost open source hardware and software microcontroller board which is popular with experimenters and educators. We used the Raspberry Pi i2c-3 I2C bus to make the connection, using the expansion header J6 on the Solar Panel Board (see Figure 4). We set the Arduino to the address of 0x4C so that it would not conflict with the other devices on the bus (the -X, -Y, and -Z current sensors). The setup is shown in Figure 15.

To demonstrate the Raspberry Pi reading data from the Arduino, we read the Arduino analog inputs A0, A1, and A2 over the I2C bus. On the Raspberry Pi, we first wrote the address number (0 to 2) then read a byte from the Arduino. The Arduino Uno sketch used the Wire library to listen on the I2C bus at address 0x4C to read the address number from the Raspberry Pi, then did an analogRead of the right analog input, converted this to a single byte, then wrote it to the Raspberry Pi.

We took eight AAA NiMH battery cells and tapped each cell individually. We read the first three cell voltages using A0, A1, and A2. For example, we read the equivalent values of 230, 480, and 715 which represented the cumulative voltages of the first three cells. Converting these to voltages gave 1.12 V, 2.35 V, and 3.49 V. Taking the differences gave the first three cell voltages of 1.12 V, 1.23 V, and 1.14 V. These telemetry values could be used to detect the failure of one cell in a battery. This could be simulated by removing and discharging one cell from the battery, then replacing it back in the battery.

Conclusion

We have shown some new activities possible with the AMSAT CubeSat Simulator. An underlying theme of these activities is detecting and troubleshooting failures using housekeeping telemetry. This article documents and explores these activities. In the future, we will provide detailed instructions so that these activities might be more efficiently replicated in the classroom to illustrate satellite and STEM principles.

Brainstorming Future Topics

Would you like to explore the topic of adding new sensors to the AMSAT CubeSat Simulator to serve as either a payload or as a subsystem element? How about sending commands by laptop or smartphone? Or might you like to develop a satellite technology acronym "decoder" or glossary? We are listening.

If you are interested in using an AMSAT CubeSat Simulator in your classroom or public demonstration, then you have options: to build or to borrow. You are encouraged to follow our open source blueprints to build your own AMSAT CubeSat Simulator (**github.com/alanbjohnston/CubeSatSim**) or perhaps borrow one from AMSAT. The AMSAT directors plan to have a limited number of simulator units available for loan after Hamvention. Contact us for information.

The authors and our beta testers are always looking for feedback on these activities or new activities. Please share any feedback with us at **ku2y@amsat.org** and **n8pk@amsat.org**.

Tom Clark, K3IO and the Event Horizon Telescope (EHT)

Or how I helped take a picture of a black hole and didn't know I would live to see it.

Bob McGwier, N4HY

Introduction

I have known Tom Clark since when he was W3IWI, and I was a young man, 21 years old. Since I am now 65, that gives you how long I have known Tom. He is the person outside of high school and home that has known me the longest that hasn't disowned me (and vice versa). I write this lighthearted tale to give you an idea of one of the many areas where Tom's life, career, and amateur radio avocation have impacted so many. Long after Tom is gone, his enduring legacy will be not only the work and papers with his name on it but the impact his mentorship and encouragement have had on others.

Tom's autobiography is available in lots of places, and the ones he has written himself and those done by others are better than I dare attempt here. So I am going to limit myself to talking about some scientific work he did at a very high level, some basic approaches he and others developed, and a word on what, in my opinion, are his unique contributions.

Interferometry

Just about everyone reading this is an amateur radio operator. I want to talk about this fancy name: interferometry. It is a big word for a simple concept that almost all of you know about. The radio waves (and light if you do laser comms) are electromagnetic (EM) waves. We are mostly accustomed to thinking of the EM as coming into a single antenna and going down our coaxial cable into our receiver.

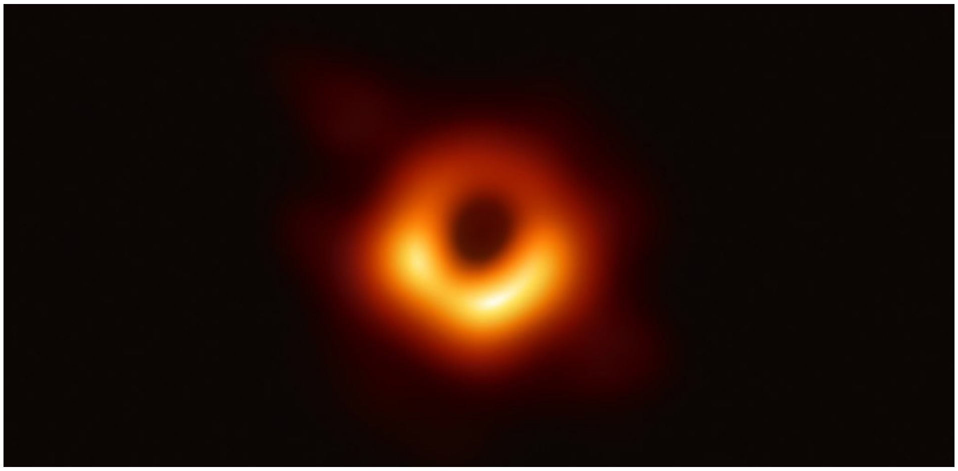
If you own a telescope or think about one, it is well known from geometric optics, that the larger the diameter of the mirror, the smaller the angle can be between objects it can easily differentiate as being different in the image that reaches your eye.

$$R = \lambda/D$$

If D is the diameter of your mirror or dish, and λ is the wavelength of the EM wave entering the instrument, then the equation gives you the angular resolution R the instrument is capable of, and it is measured in Radians (180/π multiplying this gives you degrees).

So, if we want to be able to see tiny features R apart, we need short wavelength λ or large diameter D or a combination of the two. If R is really small, we may not be able to physically construct a dish or telescope that is D in diameter and uses the wavelength λ. And if the object is outside the Earth's atmosphere, we have to contend with all sorts of disturbances in the atmosphere that result in refraction and attenuation or come from interference (radio signals or light pollution). This last issue is why telescopes and radio dishes are located high on mountains, in remote locations, etc.

For right now, let's keep this simple. I can afford to put up an antenna(s) on a piece of property I have that is 100 meters in



Black Hole - Messier Object, M87, Event Horizon Telescope [CC BY 4.0 (https://creativecommons.org/licenses/by/4.0)]

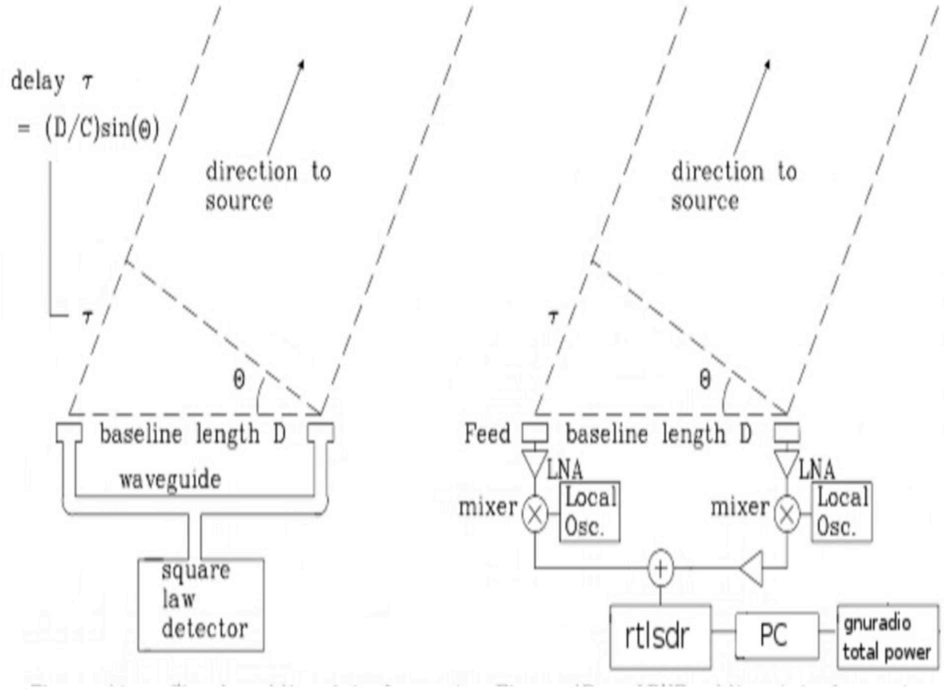


Figure 1.

diameter. I don't know about you, but I don't think I can afford an antenna or a mirror that is 100 meters in diameter. But I would really like to have 100-meter geometric optics calculations determine the angular resolution of my instrument. So, we can consider a simple example to begin with in the following figure.

In Figure 1, I have two antennas, and I want them D meters apart. I am going to combine the signals by introducing a delay τ in the signal from the antenna on the right which enables the signals originating at the angle Θ away from vertical that arrive on the left to be added constructively before we send the signals into the square law detector where intensities are measured. We can also allow sources to drift through the view of the antennas and we will get different delays between the antennas, and this will cause to them alternatively add up and then cancel out as they drift through. This adding and subtracting pattern is the interference pattern of the two antennas with the delay of τ involved. We cannot record all of these signals and process them efficiently. So, we need to sample them in some way. The study of the degradations and fixes of doing this kind of practical signal collection is the vast body of work that goes into making useful interferometers. The other thing to notice is that nothing is free. The sensitivity of the two antennas combined is not even close to the sensitivity of a telescope or antenna D meters in diameter, because sensitivity is proportional to the area of the mirror or dish.

Very Long Baseline Interferometry (VLBI)

Suppose we want to have the best possible resolution and, to image the object we want, we need the baseline to be 10000 km apart. This is so long that we cannot combine these signals using coaxial cables and square law detectors. Now we are beginning to enter the arena where Tom Clark made enormous contributions. In everyone's interferometry "bible" or "encyclopedia," Interferometry and Synthesis in Radio Astronomy, 800+ pages of details about theory and practical considerations in doing radio astronomy, Tom is referenced in many places for his work as a radio astronomer, leading the VLBI group, at the NASA Goddard facility in Maryland. Tom and others solved one problem after another. Let’s discuss some of them.

To combine these signals, I need to have all of the signals from each of the antennas in my array arrive at a single location so they can be combined to make an interferometer rather than individual antenna apertures. But the simple figure above illustrates that, even to do that with two antennas, I need to know and compensate for the exact delay τ between them. How do I do this when they are separated by thousands of kilometers? First, I insert some kind of timing signal to ride along with the signal of interest. Second, I record the signal of interest and the time signal with as much fidelity as possible. I bring the collection of recordings to one location, and I run computer programs to do the combining and the making of any images I might want.

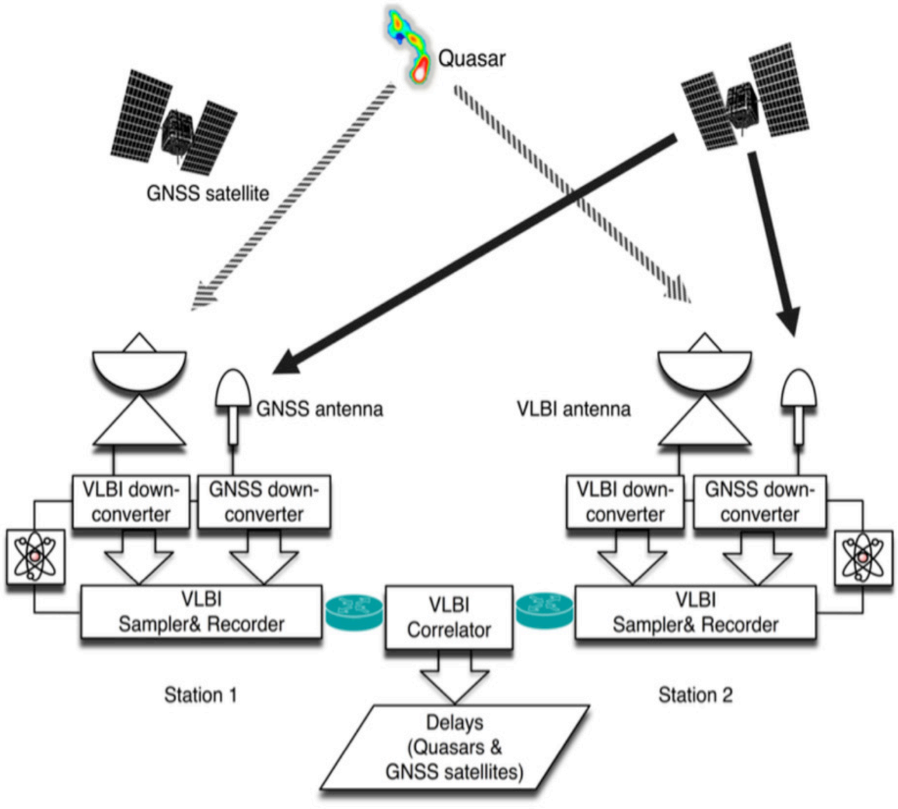


Figure 2.

In the early days, Tom and others used a hydrogen maser, which had been calibrated and understood and transported to each antenna. It was used to generate a clock signal. The clock signal from a h-maser is so good, that is good enough to have separate masers at each antenna and the unknown time and the delay needed will be easily taken care of back home at the combining computer. Masers are very expensive. Manufacture and transport of the tapes used in the early system was not an inexpensive addition to the operation. But this allowed Tom Clark, for a long time, to become the world's most accurate geodesist. He mapped plate tectonics, changes in flows and currents in the world's oceans, and could even see El Niño and measure it before others could based on the rate of change of the rotation of the Earth using the system he ran for NASA.

In the next figure, we will see most of the elements of this system. This system is the modernized one. Rather than expensive tapes, much less costly to acquire, deploy, return to home base and consume the data are hard drives. The density of data on them, the physical reliability of them, and the steadily decreasing weight, power, and number of moving parts have made them the mainstay of transporting petabytes of data around the world. Next, Tom, with help from others, developed the Totally Accurate Clock (TAC - also Tom's initials) and developed it into a GPS or GNSS disciplined oscillator and clock. This replaces the hydrogen maser in many different applications. TAPR sold the TAC kit for a long time and Rick Hambly, W2GPS, operates a successful business at CNS Systems, Inc., around the concepts in the TAC.

In Figure 2, you can see the GNSS system, the VLBI sampler, and recorder at each of the antennas. The VLBI correlator is "home base" computer where all the data is assembled and analyzed. Tom became the leader of the team that was the world's most accurate geodesists using this system, and as in the figure, his signal of interest was from the quasars, as depicted. They provided the common signal of interest used by all the antennas in the array.

Event Horizon Telescope (EHT)

The ideas demonstrated in the previous picture are the basis for the EHT. They are at the heart of the system. Astronomers like to make images to quickly get a look in a useful way at the data collected. Lots of brilliant work has gone into cleaning up the data, figuring out how to patch holes in the coverage on the sky and in the objects of interest (CLEAN, etc.), and achieving excellent resolution in the images that are now being shown. This includes a form of super resolution derived by training neural network models (deep learning) to take the really good, but still fuzzy images, and automatically answer the question: If I see this fuzzy image, which is my best estimate of the picture underneath it if I had much better resolution than I have now? Lots of data and lots of physics go into calculating the "high resolution" version of these pictures to train the neural networks to work reliably. And, in the end, you get the world's first image of the event horizon of a 6.5 billion solar mass black hole in another galaxy. It is simply amazing as is the next figure.

This donut is a miracle of modern science and engineering, and is the latest proof that Einstein is one of the greatest minds of all time.

Last Word On This

One can never know where one's work will lead. And even the smallest contributor to major efforts is a benefit to humanity. Examples include the achievement of landing humans on the moon and returning them safely, finding the last remaining predicated particle in our knowledge of the microscopic universe governed by quantum mechanics at the Large Hadron Collider, called the Higgs Boson, which is proof of the conjecture that the Higgs field is real (and badly needed since it is responsible for us having mass and not being a bundle of things flying around at random at the speed of light) and confirm the "Standard Model" of physics not including gravity. And finally, to have contributed in a major way to the science and engineering of VLBI for a career that was the underpinning of the event horizon picture of the supermassive black hole at the center of the Messier Object, M87, a galaxy in the Virgo galaxy cluster. M87 is easily visible in amateur telescopes that you can use in your back yard. The work of Tom Clark and many others enabled us to build a telescope the size of the Earth and see Einstein's second weirdest creation, a black hole. Who knows Einstein's first weirdest creation? It has nothing to do with gravity. He discovered entanglement and brought us all the weird wonders and applications that this will bring. My last remark is thank you, Tom, for mentoring and involving so many people in your endeavors.

Reference

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RF Generator Techniques for Space Applications

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A deeper insight into the performance of a Hilbert transform and PLL-based generation technique for space missions

The use of an RF generator is quite common in lab testing environments as well as in commercial applications. Many different RF generation techniques exist, both analog and digital. The frequency domain sets the complexity of the circuit. It is commonly accepted that the higher the frequency, the more complex the design becomes. Designing for space applications change things quite drastically. Elements as survivability, radiation and redundancy also come into play. Taking into account that adaptations are not any longer possible after launch, implies that the implemented design has to be one hundred percent robust. The complexity rises when designing for scientific missions like for NASA or ESA because of the more severe imposed constraints. This article tries to give an idea about how to design a pure sinewave RF generator at rather low frequencies (< 500 MHz) for a scientific mission capable of surviving under the harsh environmental conditions of space, dealing with the space agency restrictions and limited availability of approved electrical components.

1. Designing for space

Designing for space applications forces the engineers to use techniques which sometimes look a little bit odd. The reason for this is the lack of available and approved components for space. While designing for space, the first thing that needs to be checked is if the components used in the proposed design have space qualified counterpart. The design based on commercial devices needs to be transferrable into a space-grade version. This limits the search for components drastically. Not all commercial components have a space-grade version available. Different qualification levels for components exist like V-class or Q-class, depending on the orbit or mission for which these devices are going to use. Also, military grade components exist, but in most cases, the resistance against radiation and shock is not high enough for use in space.

A space grade model of a component will

be subjected to a suite of environmental tests such as thermal-vacuum, vibration, radiation, shock and Electromagnetic Compatibility (EMC). Also, the foreseen lifetime of the mission and the selected orbit around the earth (or beyond) has an impact on the design process. Besides the selection of components, also the PCB-design and manufacturing have to be done following space qualified standards. Working for ESA, for instance, implies that the designer has to follow the so-called ECSS-standards[1]. These rules describe meticulously what can and can't be done in the design work. Besides that, power and mass limitations, voltage restrictions on the available supply lines and PCB (Printed Circuit Board) area limitations are other vital parameters influencing the design.

2. RF generation techniques

Taking into account all restrictions listed in the previous paragraph, still, several different RF generation techniques are feasible. The signal can be produced digitally and converted into an analog form or generated in a pure analog way. For this article only two analog pure sine wave generation techniques are being discussed, namely the Hilbert transform technique and the PLL-technique (Phase Locked Loop). Both are composed of commercial-grade components, but having a space-grade counterpart available on the market.

2.1 The Hilbert transform technique

This technique is a rather old way of generating an RF signal[2]. The Hilbert transform principle (see Figure 1) splits the input signal m(t) into two chains from which one chain is shifted by 90° in phase. Additionally, a local oscillator is split into two chains. Again one part is shifted by 90° in phase. These two chains produce two parts of the signal namely 0.5 Ac sin(-c t) and 0.5 Ac cos(-c t). Combining each signal with the input signal m(t) into a mixing circuit creates two shifting output chains. One in which a phase shifting occurred and another in which no phase shift is done. Both outputs chains are combined into a summing device creating a USB (Upper Side Band) and LSB (Lower Side Band) signal s(t), depending on the mathematical operation.

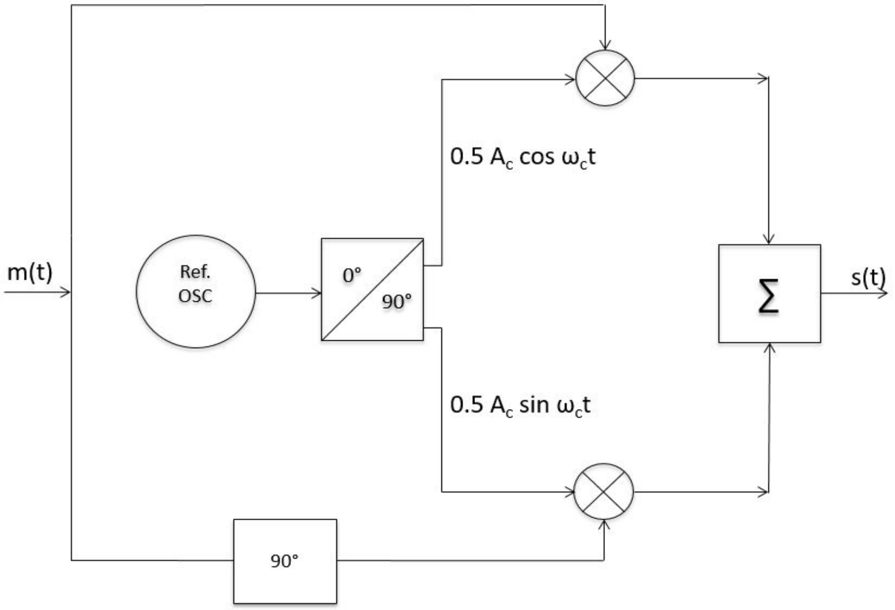


Figure 1 — Hilbert transform setup.

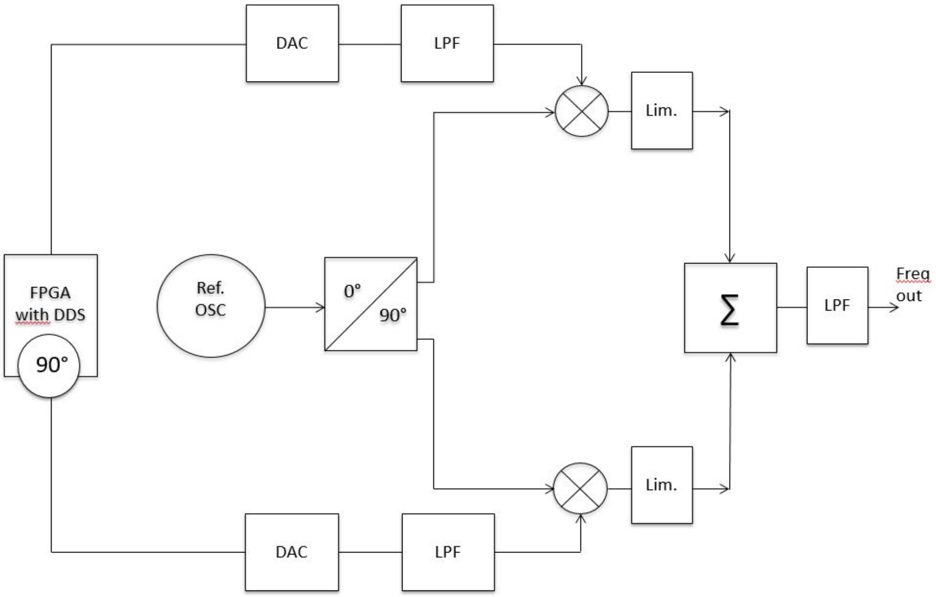


Figure 2 — Practical implemented Hilbert transform setup for an RF generator.

The practically implemented concept of the Hilbert transform to build an RF generator is shown in Figure 2. The core of this technique is a space qualified reference oscillator linked to a space qualified Actel-Microsemi RTAX-FPGA (Field Programmable Gate Array) [RTAX2000S-CQ352V (V-flow)[3]]. The selected FPGA, one of the few available on the market for space applications, is a one-time programmable device, capable of withstanding a high level of radiation. This device consumes around 1 W and runs at a frequency of 127 MHz. Inside this FPGA a DDS (Direct Digital Synthesis) is programmed in VHDL to generate a pure digital sinewave in the desired frequency range. The output signal is fed to a space qualified DAC (Digital to Analog Converter) of Texas Instruments[4] on one side and 90° shifted and fed to another DAC on the other side of the setup. Both outputs of the DACs need to be filtered in an adequate way to remove all spurs and harmonics to achieve a pure sinewave. The phase of the output signal of the reference oscillator is shifted in one track by 90°. Both signals are applied to two mixers, combing the oscillator outputs of the DACs and reference oscillators. A summing device, together with an additional low pass filter, combine the two chains to produce the final output signal. All components used in this Hilbert setup are available in a space-grade and commercial version.

To proof the concept a commercial fixed oscillator of 90 MHz was used, together

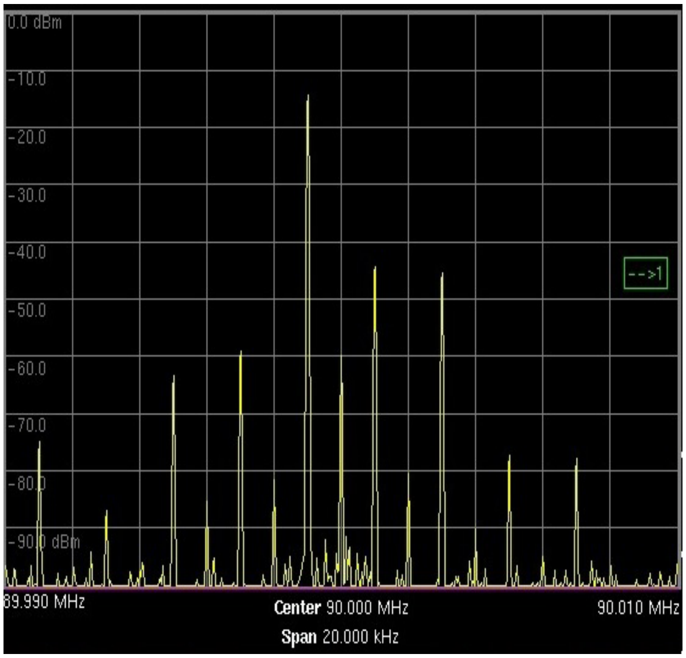


Figure 3 — Spectrum of the combination of 90 MHz and 1 kHz LSB.

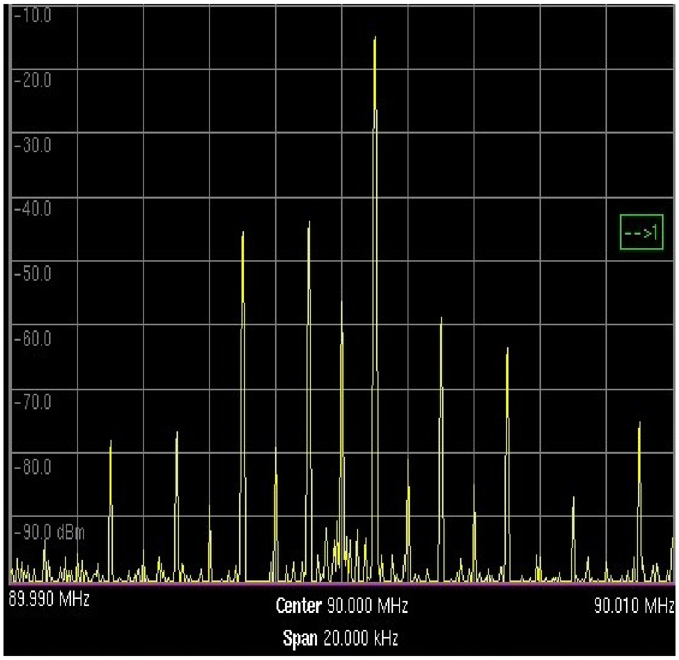


Figure 4 — Spectrum of the combination of 90 MHz and 1 kHz USB.

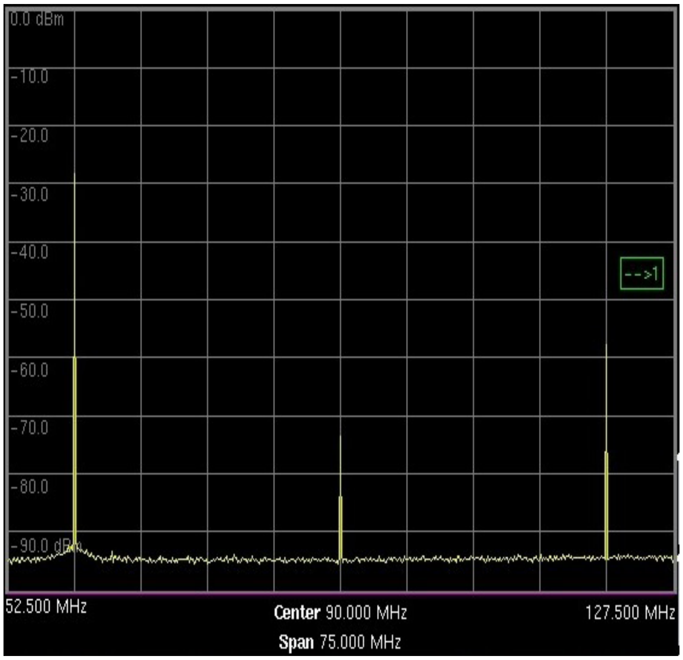


Figure 5 — Spectrum of the combination of 90 MHz and 30 MHz LSB.

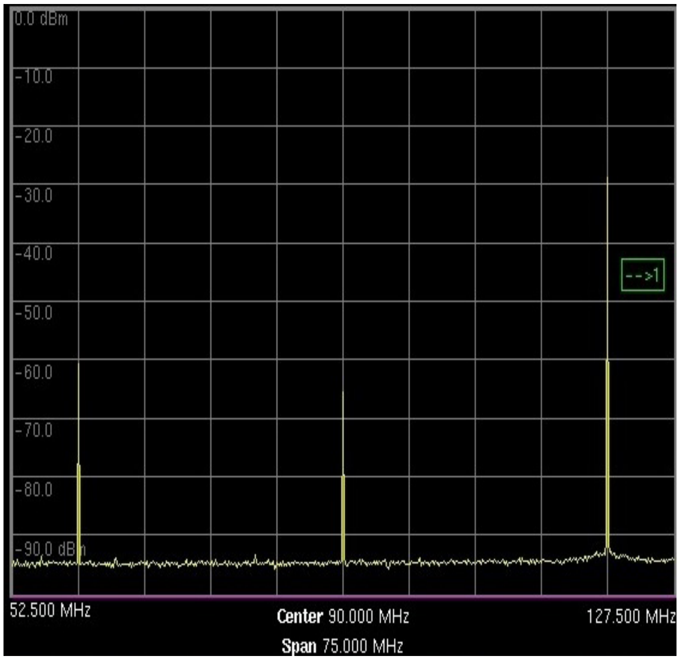


Figure 6 — Spectrum of the combination of 90 MHz and 30 MHz USB.

with a programmed frequency in a DDS-DAC combination between 0 and 30 MHz, leading to a sinewave with an output frequency between 60 MHz (= 90 MHz – 30 MHz) and 120 MHz (= 90 MHz + 30 MHz). All in-between frequencies can be generated by selecting another driving frequency in the DDS. The produced spectrum in Figure 3 highlights an output frequency of 90 MHz with an LSB at 1 kHz. In Figure 4, the same 90 MHz signal is created with a USB of 1 kHz. Additionally, in Figures 5 and 6, the lower range of 60 MHz and the upper range of 120 MHz is shown. It is clear that the output signal around 90 MHz has an amplitude of -12 dBm, whereas at the borders of the frequency range this falls back to less than -28 dBm. This means significant amplification of the output signal is needed. It is clear that many spurs and harmonics are generated, depending on the used frequency setting. The origin lays in the combination of several mixing circuits and the summing at the end of the chain. The difference between the desired signal and the first undesired spur is around – 30 dBc which is a common requirement in space generation techniques. A solution can be the limiting of the signal at the end of the chain, directly after the summing device.

By selecting different reference oscillator values and DDS ranges, other output frequencies can be covered. For instance, using a reference oscillator of 45 MHz and a DDS covering between 0 and 15 MHz a frequency range can be generated between 30 MHz (= 45 MHz – 15 MHz) and 60 MHz (= 45 MHz + 15 MHz). The only limitation here is to create a DDS inside a space qualified (and approved) FPGA that can generate a broad frequency range. Additionally, a space qualified reference oscillator with a frequency that can cover the needs has to be found. For the approved RTAX device the maximum DDS-DAC output frequency is about 60 MHz taking the Nyquist theorem into account. Combining this with for instance a 90 MHz reference oscillator would create an output frequency between 30 MHz and 150 MHz. Of course, the filtering of the output signal after the DAC will be a major issue in this case.

As shown in Figure 2, the number of building blocks is high. Also, the consumed power of 1 W for the FPGA and two times 600 mW for the DACs is not negligible. Another impact of using more building blocks is the rise in mass, complexity and used volume on the PCB. The positioning of the blocks has to be done intelligently not to destroy the PCB during launch due to shocks and G-forces imposed by the launch vehicle. The kind of launcher will impact these parameters as well because each vehicle has his key properties.

2.2 The Phase Locked Loop technique

This fully analog technique is widely used in commercial applications for telecommunication. Also, many telecommunication satellites use this setup to generate a stable pure sinewave RF signal in a rather high-frequency range (above 1 GHz). The general idea of a PLL is to use a feedback loop to constantly correct the frequency of the output signal by comparing the phase of a stable reference oscillator signal with the generated output signal of a VCO (Voltage Controlled Oscillator). The general concept is shown in Figure 7. Based on the phase difference between f_{REF} and f_{DIV} an error signal is generated by the PFD (Phase and Frequency Detector) as a pulse width modulated signal. The width of the pulses is determined by the magnitude of the measured phase difference. This signal is fed into a charge pump mechanism to generate constant current pulses. Additionally, a loop filter (active or passive) is used to convert the current pulse train into a continuous voltage capable of driving the VCO into the requested output frequency (f_{OUT}). The combination of a charge pump and PFD significantly reduces the settling time of the PLL loop due to the independence of the requested frequency and generated frequency. The difference between these parameters is measured directly via the phase difference.

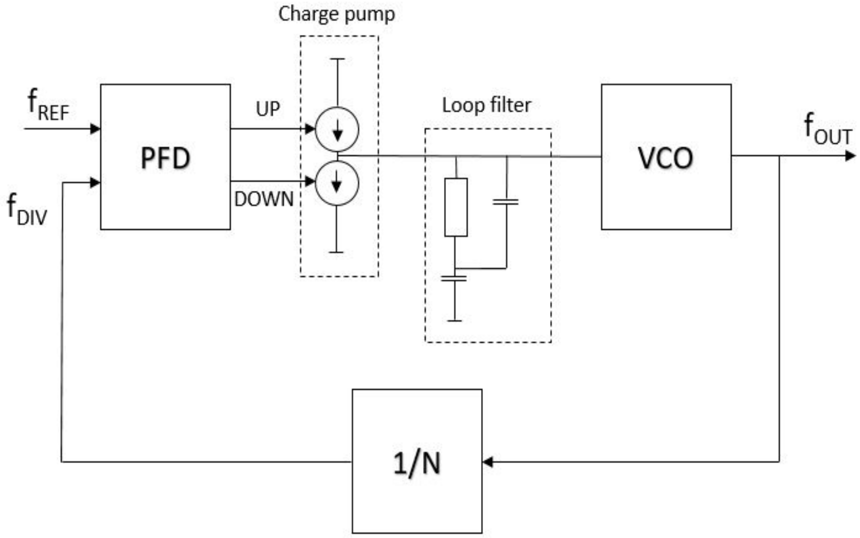


Figure 7 — The general PLL concept.

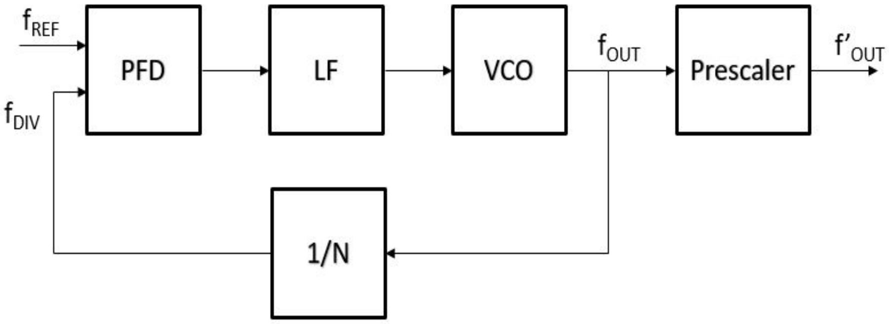


Figure 8 — An adapted space qualifiable PLL concept to run at lower frequencies (< 500 MHz).

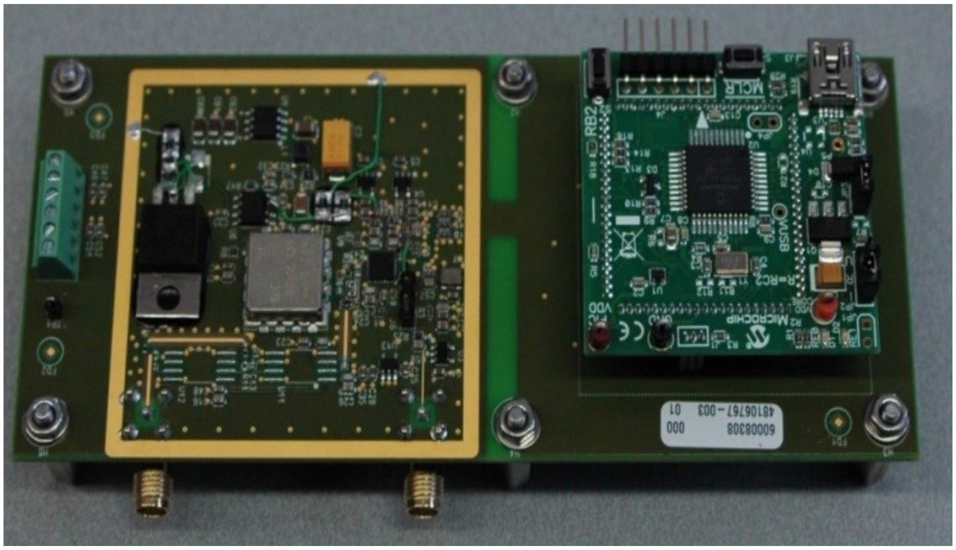


Figure 9 — Picture of the assembled PCB containing the PLL chain, power handling and PIC.

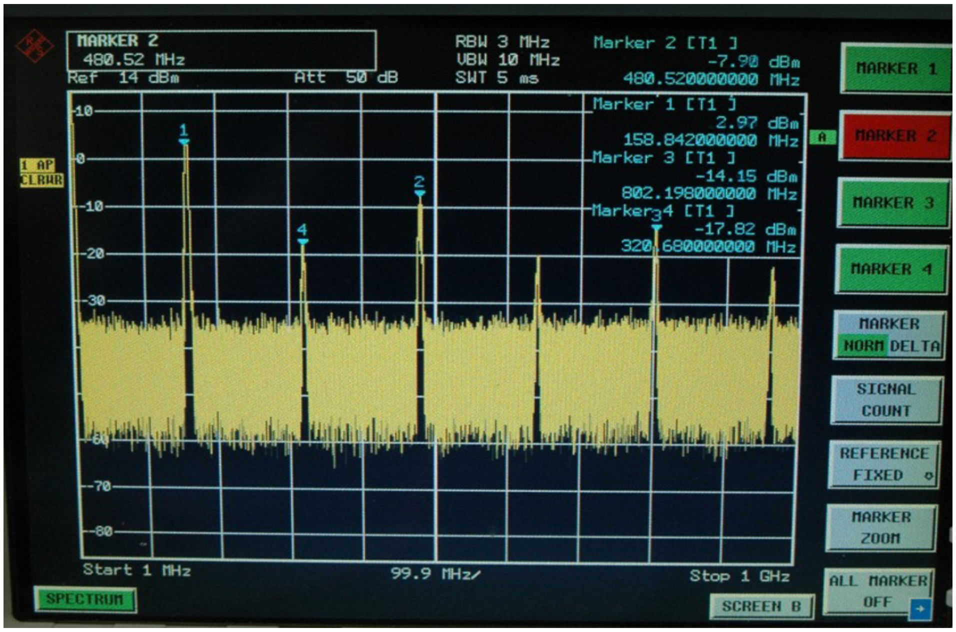


Figure 10 — Spectral output @ 1 GHz VCO frequency.

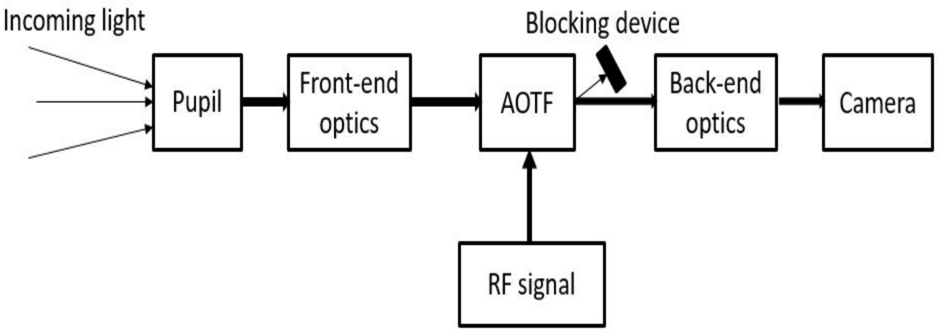


Figure 11 — ALTIUS space mission concept.

Figure 12 — Limb of the atmosphere.

On the contrary, the use of a charge pump introduces glitches caused by imperfections in the two UP and DOWN signals in the charge pump itself. Besides the integration function of the loop filter, it is also capable of eliminating these glitches. The choice of loop filter significantly influences PLL chain key parameters such as bandwidth, spurious emissions and noise.

The loop filter can be active or passive. The concept of a passive filter is easier to implement and requires less board area compared to an active setup. An active loop filter is used in case the tuning voltage range of the VCO exceeds the capabilities of the frequency synthesizer. An active loop filter setup is capable of driving the VCO into a higher tuning range so that a VCO with a broader output frequency range can be used. Both filter concepts work as an integrator on the incoming signal.

The use of a PLL makes it possible to generate a broad range of frequencies. In telecom mostly a high range of frequencies is required in ground-based as well as space-based applications. In scientific missions, interests go rather to lower frequencies, preferably below 500 MHz. For this, it is not so convenient to find suitable space qualified components, especially a dedicated VCO. So the idea was to generate a rather high frequency in the PLL and additionally downscale this frequency to a lower range by the use of prescalers. A possible general setup of this idea is shown in Figure 8.

In the described example a VCO is used in the frequency range between 1 and 2 GHz. Teledyne has several space grade products on the market[5]. For the tests, a commercial model of this device was not available at that time (due to lead time in the production), so a commercial alternative of Minicircuits was used, namely the ZX95-2500W+[6]. Of this device, no space grade counterpart exists, but the space grade models available by Teledyne have comparable properties. A frequency synthesizer of Analog Devices[7] is used to compare the two signals. The output frequency is additionally downscaled by the use of two cascaded prescalers (divide-by-8 and divide-by-2) to a range between 62.5 MHz and 125 MHz. No direct divide-by-16 prescaler suitable for space exists. By adapting the prescaler value, other frequency ranges can be generated. Different prescalers are available as space qualified components by Teledyne/E2V/Peregrine[8].

To perform the programming of the frequency synthesizer, a PIC microcontroller (PIC18F46J50) of Microchip[9] is used

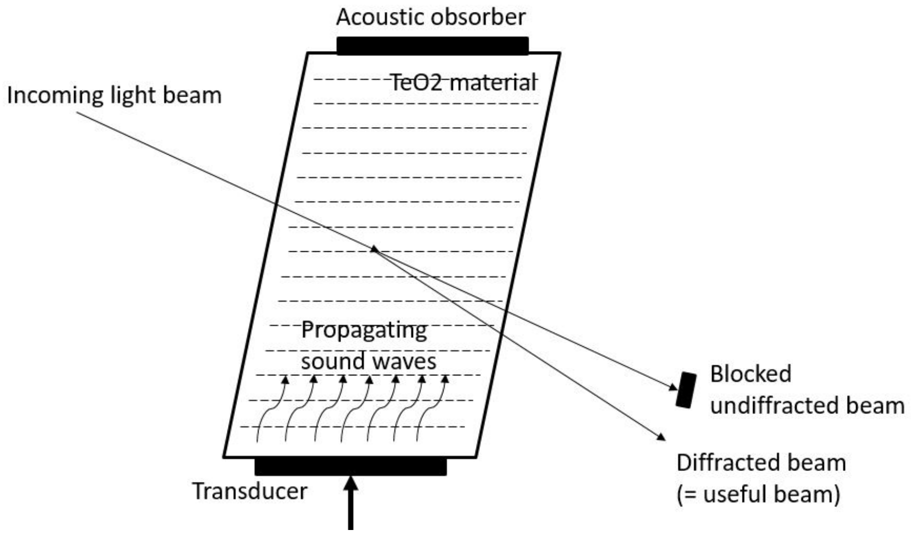


Figure 13 — Acousto-Optical Tunable Filter concept.

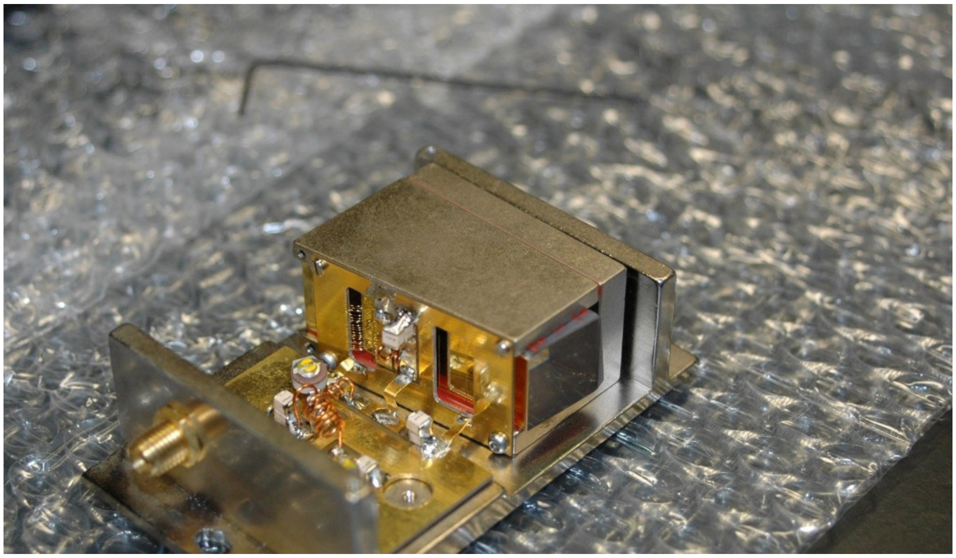


Figure 14 — Acousto-Optical Tunable Filter used by the author.

together with an own build GUI (Graphical User Interface). This device is not suitable for space, but many space grade microprocessors exist capable of performing the same task.

The complete assembly of the PLL can be seen in Figure 9. On the left, the assembled PLL chain is shown, including the prescalers and power handling part is included. The latter is mostly separated in space grade RF generators but is currently integrated onto the PCB using non-space grade components for test purposes. On the right, the microcontroller can be seen. The generated output spectrum can be seen in Figure 10. It is clear that the generated signal has a higher amplitude (+2.97 dBm) compared to the Hilbert transform based generation technique. Also, the amount of generated spurs and harmonics are less, and the amplitude is lower. For example, the second harmonic is -20 dBc without any filtering.

The power consumption of this RF generation technique is around 2 W in total. Also, less building blocks are used which means the design can be compact which is very important for space applications due to the limited space available in payloads.

3. Space mission applicability

This paper gave an overview of two possible RF generation techniques suitable for space applications. Currently, the PLL technique is proposed as an RF generation technique for an ESA (European Space Agency) space mission called ALTIUS[10] (Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere). The concept of the instrument consists of three separate independent channels, each observing the atmosphere in a different wavelength domain, namely in the ultraviolet (250 nm to 450 nm), visible (440 nm to 800 nm) and near-infrared (900 nm to 1800 nm). The visible and near-infrared channel is built according to the concept shown in Figure 11. Light enters the front end optics, and additionally, a filter mechanism selects the desired wavelength. Further, the back end optics focuses the image onto a camera at the end of the channel. The camera is capable of making images of the limb of the atmosphere (see Figure 12). By mathematically analyzing the captured images, the concentration profile of different gases like ozone, greenhouse gases and others can be monitored related to a height profile.

The RF generator is used to select the different wavelengths by driving an AOTF (Acousto-Optical Tunable Filter). This device is a sort of SAW-filter (Sound Acoustic Wave) capable of using RF to select different optical wavelengths[11]. In Figure 13 the concept of the device is explained, while in Figure 14 a practical device, used by the author, can be seen. A more detailed explanation of this device would lead too far, but the principle is based on birefringent interaction inside the device itself. An RF signal is applied to a transducer which is mounted on the side of the device. The transducer converts the RF into sound which propagates through the crystal. For each different RF frequency, a different soundwave propagates through the crystal, which makes another optical wavelength coming out of the AOTF. A specific mechanism blocks the undiffracted beam. By this, different wavelengths can be displayed onto the detector at the end of the instrument. By analyzing the captured image, different concentration profiles can be composed, related to the altitude above ground level.

4. Conclusion

This paper tried to give a non-exhaustive overview of possible RF generator techniques applicable for (scientific) space missions (imposed by agencies such as ESA and NASA) with a primary focus on generating a pure sinewave at rather low frequencies usable in scientific space-related missions. Based on the two investigated techniques, it became clear that the PLL technique has more advantages compared to the Hilbert transform technique. Less power, fewer harmonics and spurs, and less building blocks imply that the PLL technique is the preferred solution out of the two. Both techniques are transferable into space grade designs. Designing for space is clearly limited by the availability of space grade components and constraints which can lead to the use of sometimes rather strange techniques.

Notes

[1] ESA ECSS standards for space missions, **ecss.nl/standards/**.

[2] P. Das, D. Shklarsky and L.B. Milstein, “SAW implemented real-time Hilbert transform and its application in SSB, *IEEE Ultrasonics Symposium, 1979*, pp 752-756.

[3] The Actel RTAX FPGA, RTAX2000S-CQ352V (V-flow), **www.microsemi.com/products/fpga-soc/radtolerant-fpgas/rtax-s-sl9.**

[4] Texas Instruments Digital to Analog Converter, DAC5675A-SP.

[5] Minicircuits ZX95-2500W+ VCO, **194.75.38.69/pdfs/ZX95-2500W+.pdf.**

[6] Space grade products of Teledyne; **www.teledynemicrowave.com/index.php/teledyne-microwave-space/microwave-solutions-space.**

[7] Frequency synthesizer of Analog Devices (1 – 7 GHz) ADF4180(S); **www.analog.com/media/en/technical-documentation/data-sheets/adf4108.pdf** (commercial version) and **www.analog.com/en/products/clock-and-timing/phase-locked-loop/integer-n-pll/adf4108s.html** (space grade model).

[8] Teledyne/E2V/Peregrine prescalers; **www.e2v.com/products/semiconductors/peregrine/.**

[9] The PIC microcontroller (PIC18F46J50) of Microchip; **ww1.microchip.com/downloads/en/DeviceDoc/39931b.pdf.**

[10] E. Dekemper et al., "ALTIUS: a Spaceborne AOTF-based UV-VIS-NIR Hyperspectral Imager for Atmospheric Remote Sensing," *Proceedings Of SPIE*, 9241-92410L(1-10), 2014.

[11] I.C. Change, "Noncollinear Acousto-Optic Filter with Large Angular Aperture," *Applied Physics Letters* 25, 1974, pp. 370-372, doi: d**x.doi.org/10.1063/1.1655512**.

Bibliography

Jurgen Vanhamel – ON5ADL – received his call in 2002 (formerly ON1ADL). He has a bachelor degree in mathematics, a master degree in industrial sciences (electronics), a postgraduate in avionics and spacionics and holds several courses in aeronautical subjects. He is currently working on his Ph.D. He works as a project engineer at the Belgian Institute for Space Aeronomy in Brussels – Belgium. He is responsible for a space mission as well as several other ground-based projects. Besides that, he is also active as a radio amateur and interested in amateur satellites, propagation predictions and SDR.

DM31 Activation, Organ Pipe Cactus National Monument

Patrick Stoddard, WD9EWK/VA7EWK

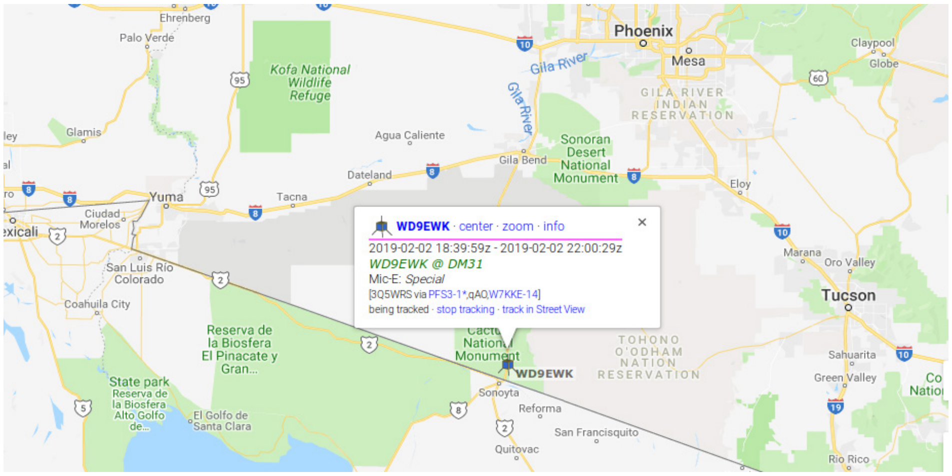
Among satellite operators who are interested in confirming contacts with the 488 grids making up the continental USA, grid DM31 is one of the rarest grids. Most of DM31 lies in Mexico, where there aren't any operators working satellites or any VHF/UHF bands. The northeast corner of DM31 extends into southern Arizona around the Organ Pipe Cactus National Monument and the town of Lukeville. For most who wish to operate from DM31, the Arizona portion of the grid is the destination for any grid expeditions. I have done this several times since 2009, doing my part to put this grid on the satellites. On 2 February 2019, a Saturday, I made another excursion out to DM31 for a day of satellite operating. This was my first trip to DM31 in almost a year after my last trip in mid-February 2018, and it was the busiest of any of my DM31 trips.

Before going on the road, I prepared a list of passes I could work from DM31 on satellites in FM, SSB, and packet. AO-85 had been back in operation for a few days, meaning all 4 FM satellites should be available for passes. With the CAS-4 and XW-2 satellites, there was no shortage of passes I could work in SSB. FalconSat-3 passes were happening during the daytime, and a pleasant surprise happened while I was in DM31 - the ISS digipeater was active once again, after several weeks of being unavailable. I made sure I had the right mix of radios to work all of these passes... an Icom IC-2730 dual-band mobile radio for the FM satellites, a pair of Yaesu FT-817NDs for SSB, and two different radios for the packet digipeaters (Kenwood TH-D72 for FalconSat-3, Kenwood TH-D74 for the ISS), and an Elk log periodic antenna. I packed a lunch, since the options for getting a meal out there are few - a convenience store and restaurant at the border, or other convenience stores and a small casino about 25 to 30 miles to the north. The nearest fast-food restaurant was over an hour away to the north, at Gila Bend along Interstate 8.

The Organ Pipe Cactus National Monument is in southern Arizona, a 2.5- to 3-hour drive from the Phoenix area. I had initially planned to get out to DM31 around 9am (1600 UTC), in time for an AO-92 pass. The list of passes I prepared showed a SO-50 pass just after 1430 UTC, a pass favoring the eastern half of the continental USA. With this in mind, I changed my departure time to around 1200 UTC.

With no traffic around Phoenix at that hour on a Saturday morning, and no rain to slow traffic on the way to DM31, I made the drive to DM31 in about 2.5 hours. I parked near the national monument's visitor center a few miles north of the U.S./Mexico border and had a few minutes to prepare for that SO-50 pass. I took some pictures of the radio and antenna on my car, along with a GPS receiver to document my location. When SO-50 came up over the hills to the north,

The author's portable station: 2 Yaesu FT-817NDs, Kenwood TH-D74 and TH-D72, ICOM- 2730, Elk log periodic antenna.



QTH at DM 31.

Border crossing at Lukeville, AZ.

I was able to make a quick contact with Jeff, WB8RJY, in Michigan for my first DM31 contact of the day. I logged six other QSOs during this pass, for a good start to the day.

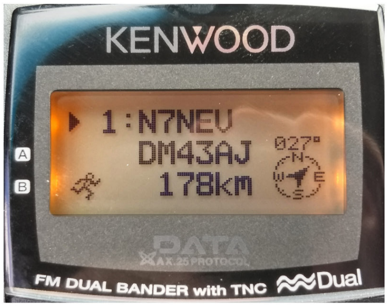
After SO-50 went away, I had over an hour until the next pass, XW-2A at 1600 UTC. I took a quick drive to the USA/Mexico border for some pictures of the border crossing - the town of Lukeville on the Arizona side, and the city of Sonoyta in the Mexican state of Sonora across the fence - before returning to the visitor center for a stamp to have additional proof I was at the national monument. I parked in the same spot I used for the earlier SO-50 pass and stayed there for the rest of the time I operated from DM31.

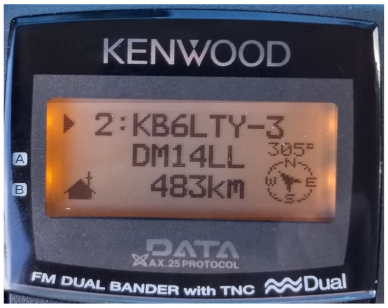
When XW-2A came up at 1600 UTC, this turned out to be my busiest SSB pass of the day. I logged QSOs with 5 different stations - two in Texas, two in Arizona, and one in California. AO-85 came up just after XW-2A, but was in safe mode. Then I had two FM passes that overlapped - a low AO-92 pass to the east lasting 6 minutes, and a SO-50 pass that went almost directly over me lasting 13 minutes. I decided to work the AO-92 pass, and then switch over to SO-50 once AO-92 went away.

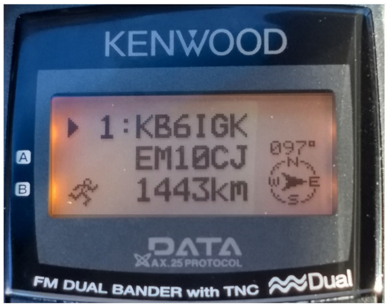
AO-92 was, as expected, busy for a Saturday morning. Once I could hear the downlink, I called the first station I clearly heard: Tanner, W9TWJ, in Texas. Once I made that QSO, the contacts started to flow from Texas and Oklahoma to the east coast. Near the end of the pass, I heard Jose, YS1MS, in El Salvador, and I made a QSO with not much time remaining on that pass. Ten QSOs went in the log on this AO-92 pass, and now I quickly dialed up the frequencies for SO-50, so I could jump on the last half of the SO-50 pass. In about 5 minutes on SO-50, 8 more QSOs went in the log. I had already worked 5 passes, making QSOs on 4 of those 5 passes, and logging 30 QSOs in 2 hours — a great start for the day.

I had two passes in the 1700 UTC hour: CAS-4A at 1710 UTC, followed by AO-92 just before 1800 UTC. Three QSOs were logged on CAS-4A, with a light sprinkling of rain during the pass, the only rain I saw in DM31. On the AO-92 pass, 12 QSOs were logged. Despite the crowd on AO-92, this western pass was orderly. Two of the 12 stations I worked were new operators from the Phoenix area I hadn't heard before: K3TP in grid DM33, and AF7IN in grid DM43.

Stations worked by WD9EWK from DM31 via FalconSat-3 on 2 February 2019







The 1800 UTC hour saw 4 passes: SO-50 at the top of the hour, AO-91 around the bottom of the hour, followed by FalconSat-3 and another CAS-4A pass. The SO-50 pass was a low pass to my west, with maximum elevation of only 9 degrees. I didn't hear anyone else on there. AO-91 passes around this time of day are busy, any day of the week. This Saturday in DM31 was no exception. With some work, three of the first 4 stations I worked on the AO-91 pass were in Central America - HP2VX, YS1MS, and TI2VLM. I was happy to get DM31 in the logs of these stations. After those stations, I was able to work XE2IMA in northeastern Mexico and seven other stations from coast to coast across the continental USA, for a total of 12 QSOs on AO-91. A couple of minutes later, FalconSat-3 came up from the west, and I was ready to go with my TH-D72. I saw three other stations on the 79-degree pass - KB6LTY in California, N7NEV in Arizona, and KB6IGK in Texas - and completed QSOs with each of them using APRS messages. When FalconSat-3 went away, CAS-4A was coming by again. I worked 4 stations from California to Texas on CAS-4A, wrapping up just before 1900 UTC for lunch.

At midday (1900 UTC), I had already worked 11 passes in 4.5 hours. I logged 64 QSOs on 9 of those 11 passes. I had previously worked passes in all 3 modes (FM, SSB, packet), and took a break before getting on the radio for the afternoon. I had some lunch and was visited by a pair of U.S. Park Rangers patrolling the national monument while eating lunch. One of these two rangers said his father is an amateur radio operator, and had some idea what I was doing out there. I was asked if I could track animals with the radios and antenna I had. I answered that I could track animals, but - from an encounter with a ranger on a previous trip to DM31 - I knew the answer to that question: no, I wasn't going to track animals. Doing that in a national park or monument, when not participating in a recognized research project with the National Park Service, is a federal felony.

While eating lunch, I had heard that the ISS packet digipeater came on earlier in the day. I had included ISS passes in the list of passes I had with me, and quickly put the DM31 information into the TH-D74 in time for a pass just before 2000 UTC - an 11-degree pass, going across the southeastern sky. For some reason, I was unable to get my position packets through the ISS digipeater and received a couple of RS0ISS status packets. I have worked the ISS digipeater on a past trip to DM31, and it appeared that the packet system was deaf. I hoped I could do better on the next ISS pass, a 45-degree pass, and got ready to work more passes.

Just after 2000 UTC, AO-91 made another appearance. A 47-degree pass slightly to the west, I worked 12 stations up and down the west coast and into central and western Canada. FalconSat-3 came by again, and I worked the only other station I saw (N7NEV), followed by two more QSOs on another CAS-4A pass.

From this point until sunset around 0100 UTC, things were slowing down. I was still working passes, but only logging contacts with one to four stations on each pass. The ISS came by again just after 2130 UTC, and I was able to get through the digipeater for one QSO with KB6LTY in California. AO-85 was in safe mode earlier in the day but was operational for two afternoon passes over DM31 - three QSOs on a 6-degree pass to the northeast, and 4 more QSOs with stations in the western USA on the later 52-degree pass. I had other passes on AO-7, CAS-4A, CAS-4B, and FO-29, wrapping up with an FO-29 pass just before 0100 UTC as the sun was setting behind the hills west of the visitor center.

Before the last two passes I worked (CAS-4B at 0037 UTC, followed by FO-29), I was visited by yet another U.S. Park Ranger. This ranger was preparing to patrol a remote part of the national monument and was getting his gear in order as he checked on me. We were talking about radios initially, the radios I had on the roof of my car, and the radios in the ranger's truck. The conversation turned to the equipment on his belt and vest (mostly a utility vest, but with heavy bulletproof plates in front and back). I missed part of one pass, and completely missed another pass when we were chatting. Not a bad thing, as the rangers made sure I was okay during the afternoon. Other people who saw me in the same spot for many hours also asked if I was okay. I assured them I was fine and was taking advantage of the great weather to play radio as they were hiking around the national monument.

After the last FO-29 pass wrapped up after 0100 UTC, I packed up my equipment under the remaining daylight. I made a quick drive south to the border for some additional pictures of the border crossing, and to make a couple of phone calls (coverage was better at the border crossing than near the visitor center). After that, I made the drive home in about 3 hours. I drove 358 miles out to DM31 and back, with good weather.

I worked 27 passes on 11 different satellites: eight passes on all four FM satellites (AO-85, AO-91, AO-92, and SO-50); eleven passes on 5 different SSB satellites (AO-7, CAS-4A, CAS-4B, FO-29, XW-2A), and five passes on two orbiting packet digipeaters (FalconSat-3, ISS). I logged at least one QSO on 23 of those 27 passes, leading to a total of 103 QSOs from this DM31 day-trip. AO-91 had the busiest passes, where I logged 12 QSOs on each of the two passes I worked. AO-92 wasn't far behind with 22 QSOs. I worked more passes on CAS-4A (four) than any other satellite from DM31. I worked stations all over the continental USA, and a few other countries (Canada, Costa Rica, El Salvador, Mexico, and Panama).

Until my next trip to DM31... 73!

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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.

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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 President, Joe Spier, K6WAO, at "OSCAR Park" display with OSCAR-1 (on loan from ARRL).

Joe Spier, K6WAO, with Virginia Smith, NV5F, at satellite demo station.

Joe Spier, K6WAO, and the Lea sisters (in matching outfits, L-R), Hope, ND2L, Faith Hannah, KD3Z, and Grace, KE3G, with friend (far left).

L-R, President, Radio Amateurs of Canada, Glenn MacDonell, VE3XRA; Secretary, IARU, Dave Sumner, K1ZZ; Joe Spier, K6WAO, and ARISS-International Chair, Frank Bauer, KA3HDO.

L-R, Pat Kilroy, N8PK, with Villanova University CubeSat Club members and newly licensed hams Kai Ji, AC3EN, Curtis Aaron, KC3NNE, and Dawson Duckworth, KC3NNB, with AMSAT Vice President, Educational Relations, Alan Johnston, KU2Y.

AMSAT Manager, Martha Saragovitz.

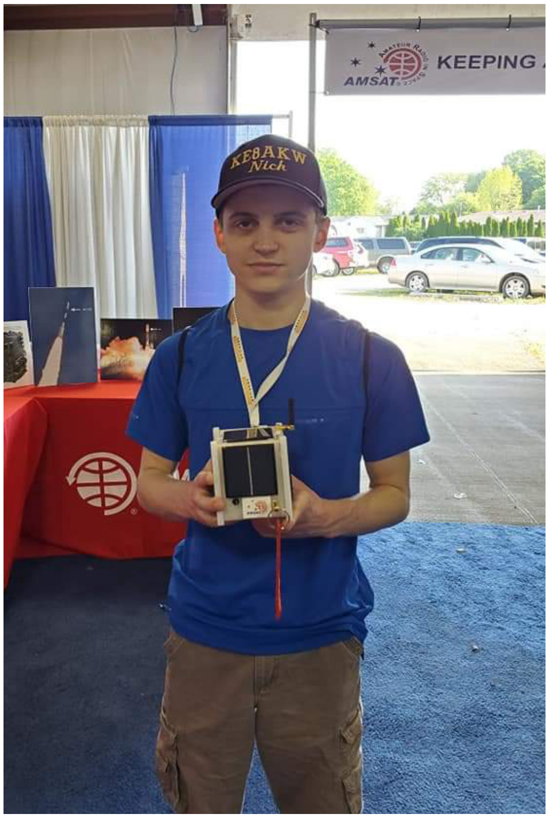
AMSAT satellite demo station

AMSAT Executive Vice President, Paul Stoetzer, N8HM, operating.

Joe Spier, K6WAO, and John Shew, N4QQ.

The AMSAT Academy about to start.

The AMSAT Education booth with OSCAR Park in background.



Nick Mahr, KE8AKW holding the AMSAT CubeSat Simulator.

Ruth Willet, KM4LAO.

L-R, Rachel Frissell, W2RUF, Nathaniel Frissell, W2NAF - winner of the Dayton Hamvention Amateur of Year Award, and Nobel Prize in Physics laureate, Dr. Joe Taylor, K1JT.

Joe Spier, K6WAO, and Carole Perry, WB2MGP.

DARA Awards Banquet — L-R, Michael Kalter, W8CI, Dr. Chip Cohen, W1YW, Rachel Frissell, W2RUF, Dr. Nathaniel Frissell, W2NAF, Dr. Joe Taylor, K1JT, Joe Spier, K6WAO, Dr. Alan Johnston, KU2Y, and Linda Kalter, W8AAV.

Joe Spier interview by local news media.

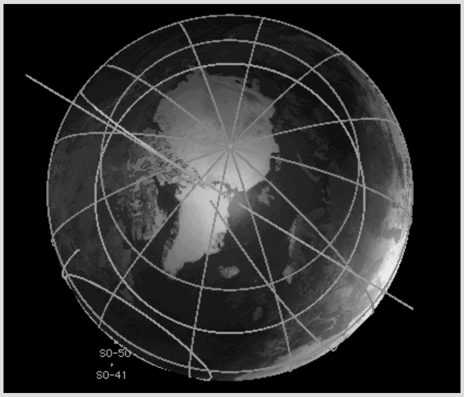
Burns Fisher, WB1FJ, and AMSAT Vice President, Engineering, Jerry Buxton, N0JY.

This year, AMSAT's Treasurer, Keith Baker, KB1SF (above center) played Hamvention host to four amateur Japanese radio operators who run a community FM Radio station in a large suburb of Tokyo. The station features several amateur radio-related programs, one of which is a weekly program called "CQ Ham For Girls," hosted by Ms. Kaori Mita, JI1BTL. [Courtesy: Keith Baker, KB1SF/VA3KSF.]

Besides being a "JARL Ambassador" (JARL is the Japanese equivalent of our ARRL and RAC) Kaori is also a very famous professional singer in Japan. Keith brought her and her group by the AMSAT booth (left) where she gave us a copy of the album cover for her latest CD. [Courtesy: Keith Baker, KB1SF / VA3KSF.]

Virginia Smith's (NV5F) character, Quasi Modo.

Virginia Smith's (NV5F) character, Boovi.



Support AMSAT

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

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

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

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

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

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

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

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

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

AMSAT GOLF $125,000 Development and Launch Initiative Goal

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

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

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

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

Your help is needed to get the AMSAT GOLF-TEE and GOLF-1 Cubesats launched.

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

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

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- Offering personal mentoring and coaching to new enthusiasts either in-person or via online means
- Connecting members and potential enthusiasts with proper resources at AMSAT.

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

AMSAT Internet Presence

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

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

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

AMSAT Engineering Team

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

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

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

AMSAT User Services

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

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

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

AMSAT Educational Relations Team

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

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

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

ARISS Development and Support

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

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

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

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