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SECTION C: Satellites and Education

The Radio Amateur Satellite Corporation

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September 17, 2007

Dear AMSAT Member:

Welcome to the 2007 AMSAT-North America Space Symposium and Annual Meeting. It seems like just yesterday that we were at last year's great Symposium in the San Francisco area and now we are meeting near Pittsburgh as guests of the Wireless Association of South Hills Amateur Radio Club. I hope many of you will take advantage of this opportunity to visit some of the sites in this city that has improved itself in many ways since the end of the steel mill era. The symposium pages on the AMSAT Web site have information on sites to visit.

This past year has been filled with much behind the scenes development work in anticipation of new AMSAT space missions. The AMSAT Lab was moved to Pocomoke City Maryland and is still under construction. The P3E satellite continues to take shape in Germany with assistance from the AMSAT-NA and AMSAT-UK communities. The Eagle satellite development has moved forward with the design of some transponder modules and construction of a half-scale space frame model. Development continues on the hardware for a second SuitSat mission. The AO-51 satellite continues to perform very well offering a variety of operating experiences and reliable service thanks to a dedicated operations team. AMSAT's AO-7 satellite has continued to provide enjoyable operating experiences since its surprise return to service in 2002.

The coming year will again be one dedicated to design, construction and new initiatives. The AMSAT Lab will be made ready for use. The P3E satellite will be finished and readied for testing and launch. Eagle will begin to look like the final products. The new SuitSat payload will be finished. AO-51 will continue to receive attention, hopefully leading to improved capabilities. We have initiated discussions that could lead to a new educational program centered on our new lab and our relationship with the University of Maryland Eastern Shore.

AMSAT is engaged in initiatives that we hope will revolutionize the future of the amateur radio satellite service. To accomplish this we need the hands-on involvement of you, the dedicated members of the amateur radio community. When you leave this Symposium I hope you will ask yourself how you can contribute to AMSAT and give something of yourself back to this wonderful hobby.

'73

Richard M. Hambly

Richard M. Hambly, W2GPS
President

AMSAT's Phase IV (lite)?

Is this ground hog day or amateur radio?

Bob McGwier, N4HY, AMSAT Vice President of Engineering (or am I Bill Murray?)

In AMSAT, it is déjà vous all over again. We have been working ***SLOWLY*** on Eagle for years, trying to find a way to get it into space. We have done a complete redesign of Eagle. We have put it into a space frame that makes mechanical sense and will allow us to address the many issues of delivering the SERVICES we want to deliver to our users as well as all of the new users we wanted to attract. We have a paper design of a fantastic digital communications system. It is designed to carry digital voice or digital video (depending on the size of your ground antenna). We call it the advanced communications payload rather than digital payload to help everyone distinguish it from our previous digital communications endeavors. We have assured ourselves of having power in all seasons and times of the year. This is provided by the fold out solar panels you see depicted in Figure 1. We have a solid complement of linear transponders provided by software defined radio transponders (hey, I am the boss after all!)

Figure 1 Eagle Model, 1/2 Scale

We were planning on providing 60% efficient 50 to 100 kHz wide linear transponders based on the use of this software radio transponder in addition to brand new devices and the good work of N2UO, KK7P, KD6OZH, WA6HTP, G6LVB, AB2KT, and N4HY.   We have a new receiver design, new transmitter design, new transponder design. In other words, we have an RF team doing work on our satellite projects unlike we have had on previous Phase 3 birds.   We are even considering providing an SMS text messaging service!

Matt Ettus, N2MJI, of USRP and GnuRadio fame, is the principle investigator on the advanced communications experiment. The communications engineers helping AMSAT met in San Diego, hosted by Franklin, N6NKF.

Figure 2 Matt Ettus, N2MJI and Phil Karn, KA9Q ACP at San Diego design meeting

We were fully prepared to spend $1,000,000 U.S. on solar panels to make this happen as well as $250,000 to $500,000 on the propulsion system we would need. We were going "all in" on this for AMSAT.

This summer, AMSAT's Executive VP, went to the "Ride Share" conference. This is a conference specifically addressing the small community of people who want to share rides with others. An earthquake happened in AMSAT's world view. First, a little history. It has been a goal since AO-13 went into orbit to consider building a geostationary satellite for AMSAT-NA, engineering lead, Jan King, W3GEY. We called this program Phase IV. The artist's conception for Phase IV is seen in figure 3.   The goal was to put a fully stabilized satellite into geostationary orbit. We had all sorts of wild ideas about how to do things. In possible the single most difficult piece of mathematics I have ever done in applied mathematics to engineering, I derived the equations governing the viscuous fluid suspension and control of magnetic particles in a fluidic momentum controller. This was done with Lou McFadin, W5DID who had the original idea. I was his "math geek" to figure out the control equations and to decide if it was possible.

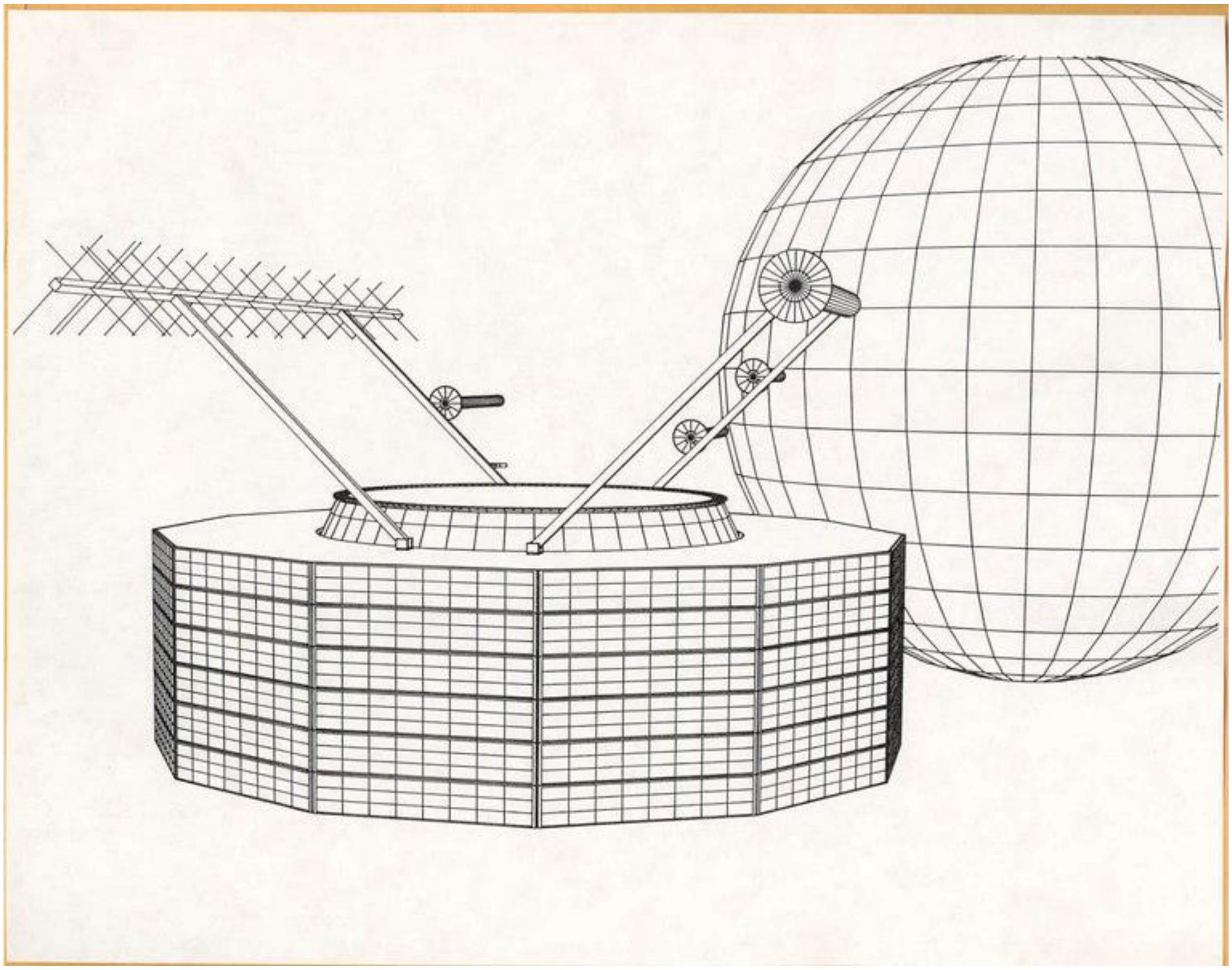

Figure 3 Phase IV (WD4FAB drawing)

One of the things that is readily apparent when you put a spacecraft into geostationary orbit and the rotate it very slowly (as in once per day, DOH!), you have one side in the sun and one side point at dark cold space for long periods of time. The thermal gradient across the spacecraft is huge. As such, we had to buy and use heat pipe technology to balance the temperature across the spacecraft. In another piece of clever engineering, we made ourselves the support mechanism for the primary payload so it would be easier for us to get a "free ride". In figure 4, these two major features, heat pipes and support structure are readily apparent in the Phase IV model.

In the end, Karl Meinzer, DJ4ZC and AMSAT-DL said to us “come on guys, get real” and join us on Phase 3D. We did and AO-40 was born. Our Phase 3 program has been remarkable. That several top notch scientists and technologists could build such systems and have them work is remarkable.

Figure 4 Phase IV model, heat pipes and support visible

Figure 5 shows the first design meeting for Phase 3D (AO-40) after we gave up on Phase IV. Yet with AO-40, the Phase 3 expansion era clearly came to an end. We did use experience garnered in building phase IV as will be readily apparent in the following.

Figure 5 Phase 3D Design, Marburg, DL, 5/90

And this led eventually to AO-40, a true monster.

Figure 6 AO-40, over 500 Kg at launch.

The AO-40 spacecraft used the heat pipe technology and was intended to have fold out solar panels. We also used the structure technology experience from Phase IV. Our structure carried the primary payload, PANAMSAT-1 into orbit above us! We have had some serious engineering successes in AMSAT. But no one will claim that AO-40 is an unqualified success. The motor, readily apparent in figure 6 blew up after its first burn, forever changing our view of ourselves, these large missions, and our ability to do this kind of engineering. Eagle was to be a simpler Phase 3 spacecraft and then Karl, DJ4ZC, decided to do Phase 3E, which is essentially a copy of AO-13 but testing new technology for his Phase V goal of sending a spacecraft to Mars.

As I said earlier, Lee, KU4OS, AMSAT-NA's EVP, went to a conference. At this conference Intelsat told the audience it was selling rides to worthy payloads. Rick Hambly, W2GPS, our president knows a just retiring executive from Intelsat. He just happens to be a neighbor of Rick's and a ham! He has been helping us prepare our request. We have had meetings with Intelsat to prepare for the formal request.

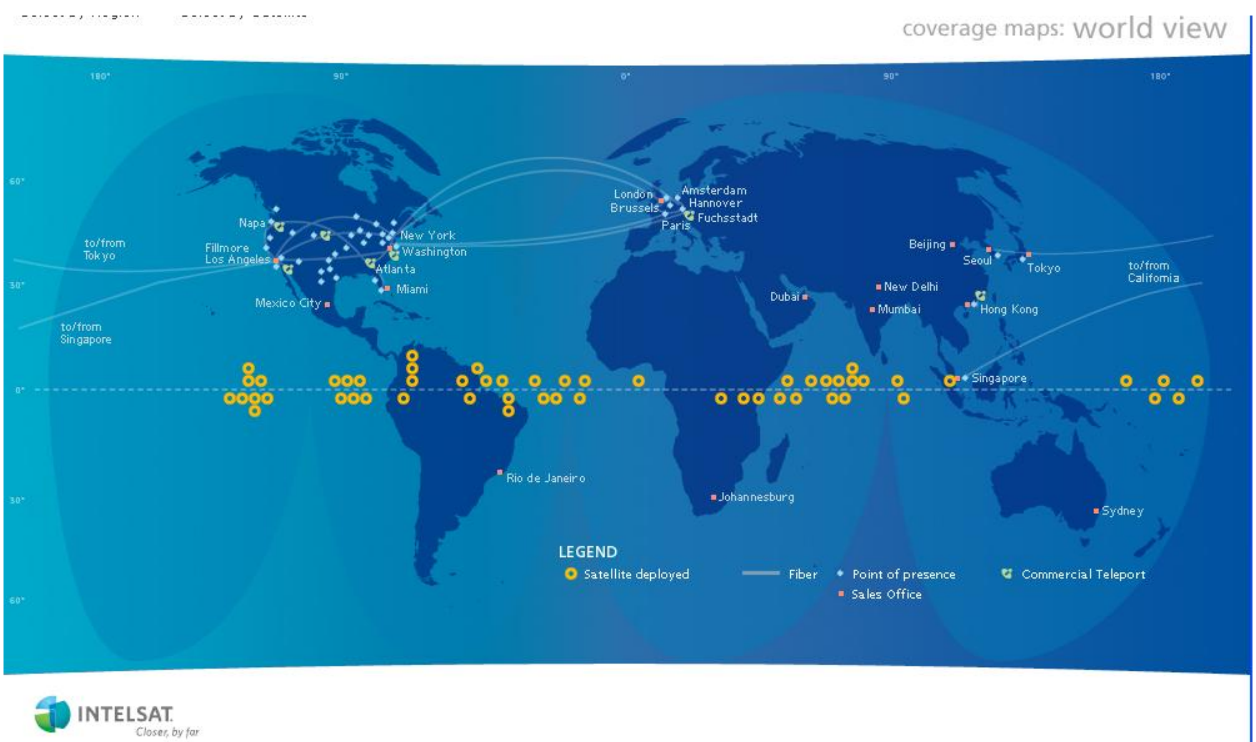

Figure 7 Intelsat view of the world

What can we do with a picture like this in our minds? I could have told you this story without all of those incredible photo's of our engineering prowess, some successes, some failures. Probably our greatest successes came in areas the typical user could not possibly care about. They just want it to work so they can use it. Take all of the incredible engineering you see in figures 1-6 and a lot of the people and thank them for their efforts, look back at the "glory days" because, they are not needed. Intelsat has one THOUSAND watts of excess generation power generation capacity at the beginning of life. This is aimed at 300 watts of excess capacity at the end of life after fifteen YEARS of solar degradation. They have a huge amount of extra room and lift capability on the rockets they ride, so it would be good for them for all sorts of engineering reasons to have us ride and use that capacity. So what do we need to do. Let's see, they will provide us a place on the bottom, nadir pointing (earth pointing) side of their spacecraft and we ride and stay there forever. So what does this mean? We have no need for solar panels. We have no need for a motor. We have no need to care about mechanical balance to fire the rocket motor. We simply fly our RF and control electronics. They provide us with enough territory for our package that we can put very good antennas on the outside of our package. What does this buy us? Geostationary means never having to say you are sorry. We never apologize for being out of view. Once it is up, the user points their antenna at it and forget the antenna rotators forever. Once it is up, the user can use it the first day they give us power. Because there is no major commissioning and no motor to burn. Intelsat will burn their motor to go to geo. They provide us with attitude control. So we need no magnetorquers or gas jets or momentum wheels or attitude sensors. The complexity of our spacecraft just falls away as if by magic. The magic of a good ride on someone else's platform and we provide RF and services.

Which rides do we want? You see those orange dots in figure 7. Those are the ones we want. We want to build a long term mutually beneficial relationship with Intelsat. Because if we do, and we get these rides, we will not only change AMSAT, stop for a moment and ponder. We will change all of amateur radio forever. It will quite literally never be the same.

AMSAT will want to provide local emergency ARES teams with ground terminals, the red cross, etc. We will NEVER be off the air because a hurricane, earthquake, terrorist attack, etc. brought us down. Point the lower power consumption terminal at the satellite and talk. MARS will be completely revitalized. Imagine every foreign deployment having a MARS station where we have to get new authorizations to conduct MARS communications through these satellites. ARRL could provide LIVE digital television broadcasts around the world. So could RSGB, etc. Our SMS text messaging service will operate on something like a PDA attached to a little RF gizmo with low power and small antennas and operate over most of the planet. Now you know WHY we need ALL of those dots on the Intelsat map. After a short time, we will be full on our first system. We need to have a plan to go forward with an increase in our system capacity on every possible Intelsat launch for the foreseeable future.

If you think you have ever seen me excited before, forget it. Nothing compares to this. I want to be the AMSAT engineering leader that helped give amateur radio a rebirth by making this happen.

70 cm Eagle Receiver Prototype
Progress Report and Lessons Learned

Presented by

Juan Rivera, WA6HTP

Abstract

The 70 cm Receiver is the first Eagle payload hardware to be fabricated. Testing, troubleshooting, and debugging are now well underway. The processes and procedures developed, the bumps in the road, and the lessons learned can all provide insight to other teams as they begin their development efforts.

This presentation will chronicle the journey so far.

RF and PCB Design

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1. Introduction

The 70 cm Receiver prototype is the first Eagle payload to be fabricated, integrated with a CAN-Do module, installed in a module chassis, and extensively tested. The Receiver fabrication and testing is being undertaken by Project OSCAR, the group responsible for building OSCAR 1, the first amateur radio satellite that was launched in 1961.

For the first time an AMSAT satellite payload using surface mount components will be constructed by unpaid amateur radio operators. Using processes and procedures borrowed from industry, as well as a few original we developed ourselves, the OSCAR team intends to avoid the use of paid outside help during all phases of the project.

As expected, during testing a number of issues were identified with the prototype Receiver, the CAN-Do module, and the Enclosure. Some of these probably could have been minimized by conducting a broader and more thorough top-level analysis and peer review, and some could not. During this presentation I'll attempt to pass along the lessons we've learned.

2. Payload Overview

The 70 cm Eagle Receiver Payload consists of three functional blocks – the CAN-Do interface, the Receiver itself, and a single-compartment enclosure where the CAN-Do module and the Receiver will be housed. They should be considered as one subsystem.[1]

CAN Bus: The Internal Housekeeping Unit (IHU) communicates with all of the payloads using a bus called CAN (Controller Area Network). The CAN bus utilizes a balanced interface running over a Shielded Twisted Pair. The CAN-Do Module (Figure 1) interfaces the CAN bus to the Receiver via a 40-pin header and provides network services, DC power and 12 digital control lines as well as accepting up to 8 digital and 5 analog outputs from the Receiver. Five unassigned lines are also provided. The module also measures current and temperature and returns them to the IHU.

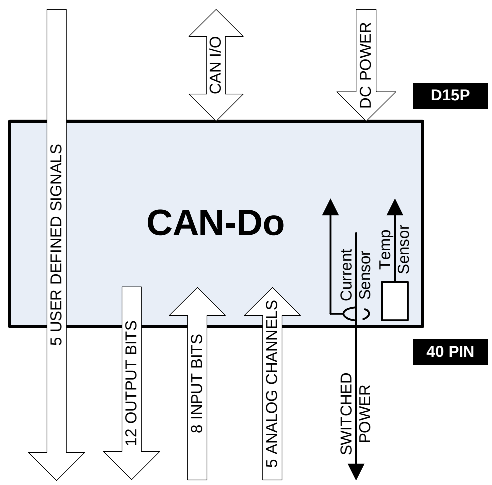

Figure 1. CAN-Do Module

This module is at the heart of every payload on the satellite and is currently designed to mount directly to the payload PCB (printed circuit board). Extensive functional, radiation, and vacuum testing was conducted during its development and over 100 units have now been produced and distributed to users in the U.S. and Germany.

Because of its essential function in multiple locations throughout the satellite, it is one of the most critical assemblies on Eagle. [2]

[1] These three elements were each developed independently rather than as elements of one subsystem.
[2] A serious CAN-Do module EMI problem was discovered during Receiver testing. A partial CAN-Do module redesign will be required to correct it.

70 cm Receiver: The Receiver is a dual-conversion superhetrodyne block downconverter with an IF output of 10.7 MHz and a bandwidth of 200 kHz (Figure 2). Both local oscillators are tunable frequency synthesizers allowing the Receiver to be initialized and set in 200 kHz steps to any frequency in the 435 to 438 MHz satellite sub band. Initializing the Receiver, as currently constituted, requires a lengthy sequence of commands from the IHU via the CAN-Do module.

The Receiver also contains a power supply with an over-temperature protective feature that will shut it down if it overheats. Should this happen in flight, the Receiver would eventually cool down and power would be restored. The IHU would have no way of knowing the Receiver had lost power and needed to be reinitialized. As a result the Receiver would remain inoperative until manual intervention from a ground station could reset it. The original receiver design assumed that the CAN-Do modules could be customized to execute device-specific initialization code on power-up. This was incorrect. Customization creates a potential for software errors and bus failures so this feature cannot be implemented.[3] The next upgrade revision will be autonomous and will not require external commands to function.

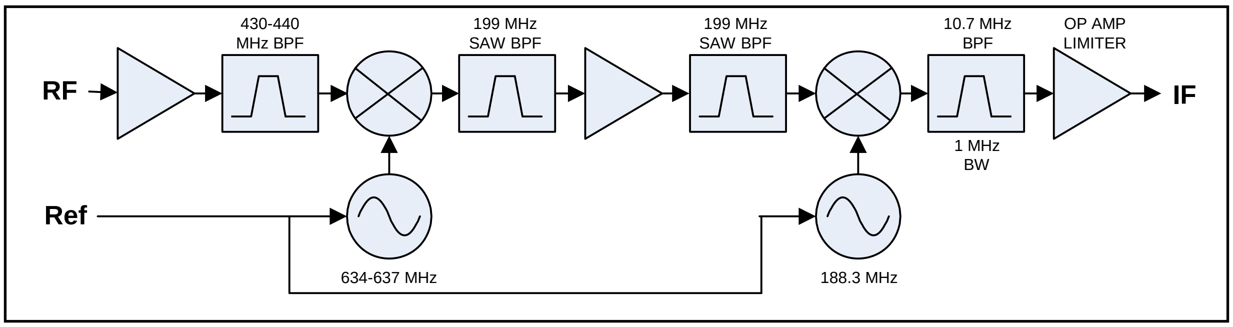

Figure 2. 70 cm Receiver Block Diagram

Module Enclosure: The enclosure is fabricated from aluminum sheet. A base plate serves as the foundation for the enclosure. A front panel attaches to the base plate and serves as the mounting support for the CAN-Do module. The Receiver PCB is secured to the base plate using self-clinching standoffs, and the chassis is enclosed with a thin sheet metal lid that covers the top and the remaining three sides (Photo 1).

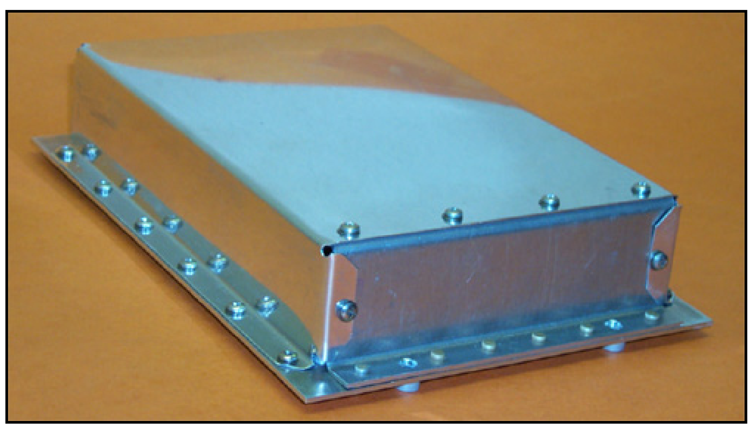

Photo 1. Module Enclosure Assembly

[3] Although this subject was discussed during the peer review, the Receiver requirement was never corrected.

3. Characteristics of SMT Components

When we started this project most of us were unfamiliar working in a high-reliability environment with surface mount technology (SMT) components. It's been a fantastic learning experience. The learning curve was steep, the work was demanding, and the results have been gratifying.

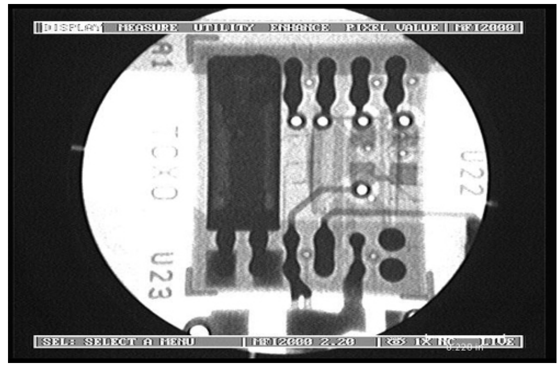

Photo 2. BGA X-ray

The Receiver uses a variety of leadless surface mount components including a BGA (Ball Grid Array.) Since BGA balls cannot be visually inspected, this type of device presents unique challenges during soldering and subsequent inspection.[4] Some of the specialized tools used during inspection included an x-ray machine (Photo 2) and a fiber optic camera that can peer under the body of the BGA and view the outer balls (Photo 3).

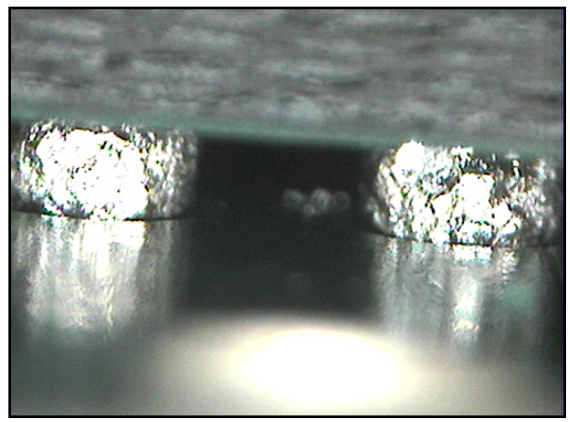

Photo 3. BGA balls

4. Considerations when working with SMT components

Electrical Overstress (EOS) and Electrostatic Discharge (ESD): Throughout this presentation you'll see me caution against a number of seemingly harmless practices that most of us are guilty of using. There's a very serious reason for this. Components can be damaged but not necessarily destroyed by a small static charge, a careless poke with the tip of a soldering iron, a dropped screw driver, or even the oils from our fingers. Latent defects can be caused that may not show up for months or even years – probably after Eagle is in orbit.

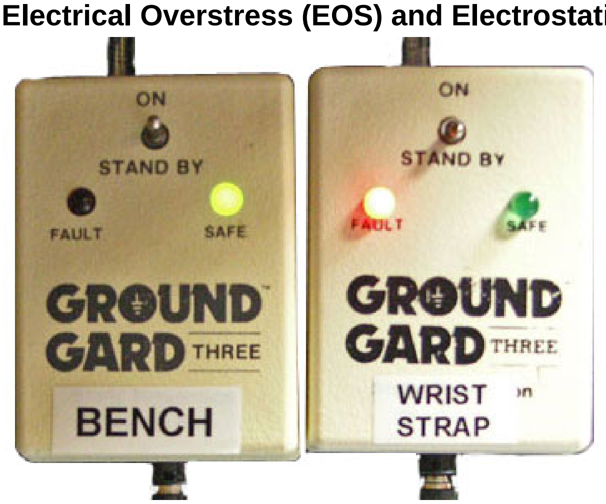

Photo 4. Full-time ESD Monitors

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[4] The next revision of the Receiver probably will not utilize BGAs. This will simplify the inspection process considerably.

Always use an ESD workbench when handling all components and observe industry standard ESD precautions at all times [1]. Photo 4 shows the two full-time ESD monitors I use in my shop.

Always determine the ESD sensitivity rating for all of your components and take the necessary precautions. ESD protection should be one element of an effective project plan. Let's not put Eagle into orbit and then have to say, "Gee, I wonder what happened. It was working fine when we tested it before launch."

Components are Small: Most SMT components are very small and may have contacts that are hidden beneath the component (Photo 5). Since finger oils can cause contamination always wear ESD gloves or ESD finger cots when handling them.

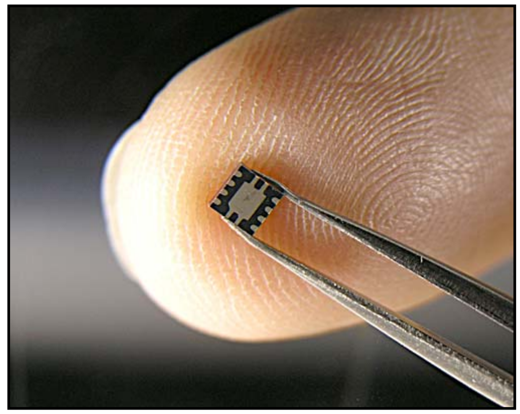


Photo 5. Leadless SMT Component

Stress Relief – there isn't any: Because many SMT components are leadless they have no way to absorb stresses of any sort. This fact impacts every facet of SMT circuit board design and fabrication. This particular trait may not have been sufficiently considered during the top-level analysis phase and may force a redesign of the chassis. This is an example of the interrelationship between subsystem elements and the sort of very small detail that, if not considered early in the project, can come back to bite you later.

CTE Mismatch: Every component has a property called CTE (Coefficient of Thermal Expansion.) CTE mismatches inside individual Plastic Encapsulated Microcircuits (PEMs) and between components and the underlying circuit board cause stresses to develop as the temperature changes and the various elements that make up your payload expand and contract at different rates. These stresses cannot be absorbed by the leads on leadless devices, and if not accounted for can lead to the possibility of solder joint failure and cracked components. Often these cracks are microscopic and invisible to the eye. Only later, after multiple temperature cycles, will the component fail, often causing unexplained premature failure of the entire circuit.

Minimum PEM Operating Temperature: One area of great concern to me is the minimum operating temperature of PEMs. They are usually rated at -40°C. The rating is based on the CTE mismatch between the thermoplastic body of the PEM and the die. Powering up a cold soaked PEM at or below its minimum rated temperature[5] causes tremendous internal stress as the die heats up and begins to expand since it is in intimate contact with the very cold body. These CTE mismatch stresses can lead to premature component failures. In our case, these failures would probably manifest themselves only after Eagle has been exposed to repeated shutdowns, cold soaks, and start-ups during eclipse. This poses a very serious reliability issue that must be considered. Looking for automotive under the hood devices will not help you with the low temperature end of the operating range.

[5] The Receiver is expected to reach -60°C during eclipse.

MSL (Moisture Sensitivity Level): Most PEMs absorb moisture and some PEMs are especially sensitive [2]. During the soldering operation the absorbed moisture can flash to steam, causing microscopic cracks. These cracks can open paths for moisture and contamination from finger oils or other surface contaminants to migrate into the die area inside the device. This contamination can cause galvanic corrosion and lead to latent defects and unexpected and premature failures. Special precautions must be taken when working with moisture sensitive devices.

Government contractors and satellite manufacturers try to avoid PEMs if at all possible[6] and take extraordinary precautions if they do decide to use them [3]. Since we lack the resources to space-quality parts we must proceed with great caution [4].

Soldering: Warning! The old ways will not work. Soldering irons are out. Just the act of touching the soldering iron tip to a ceramic capacitor can cause thermal shock and cracking leading to latent defects and failures at a later date.

The PCB must be preheated along with the components prior to soldering to avoid building in huge CTE mismatch stresses. One of the most effective soldering methods for small production runs is to use an infrared reflow oven. These ovens are very sophisticated devices, with precise control over the temperature at every phase of the soldering operation. They are normally very expensive. I'll get to that later in the presentation.

Post Soldering Handling Stress: Under this heading are such operations as soldering large connectors to the PCB, mounting the PCB to the enclosure, and anything else that happens to the PCB after reflow soldering is completed.

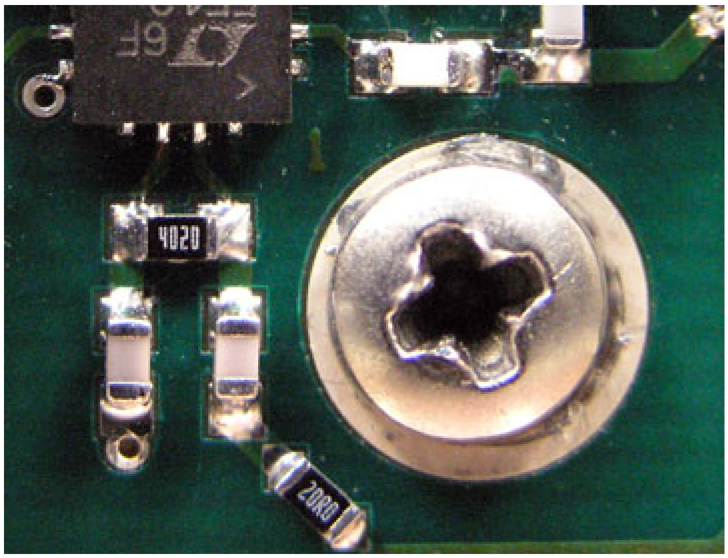


Photo 6. An Area of High Stress

As mentioned, SMT components, especially ceramic chip capacitors, are brittle and don't like to be stressed. To avoid cracking components AVX recommends a PCB bending specification based on bend radius. Their experience suggests a minimum bend radius of 60 inches is necessary to avoid damage to a broad range of SMT components [6]. A 60-inch bend radius results in a maximum board deflection of 0.0084" over any one-inch board segment – that's less than the thickness of three sheets of paper.

They caution against placing components near the edges of the board or around mounting screws since those are especially high-stress areas. Photo 6 shows a typical heat sink mounting screw on the 70 cm Receiver PCB. It's a perfect example of the need to consider all aspects of a design as a whole. Heat sinks (Photo 16) are an essential part of any thermal management plan for a PCB that will operate in space. Heat must be removed from critical areas on the PCB primarily through conduction

[6] Many modern integrated circuits are only available as PEM, leaving the designer with a difficult choice – look for an older and less capable ceramic part or use the PEM and hope for the best.

rather than convection as would normally be the case on the ground. This requires heat sink mounting screws to be placed closer to critical components than we might otherwise choose.

Placing components this close to the mounting screws forces added demands on the enclosure designer to provide an absolutely flat mounting surface for the PCB and one that will not flex. I should note that both of those little white components closest to that 4-40 screw are critical ceramic chip capacitors. If either one fails the radio is toast.

5. The Infrared Reflow Soldering Process

In reflow soldering the solder is applied as a paste using a stencil and squeegee and then the components are all placed on the PCB at once. Photo 7 shows a section of the PCB after the solder paste has been applied.

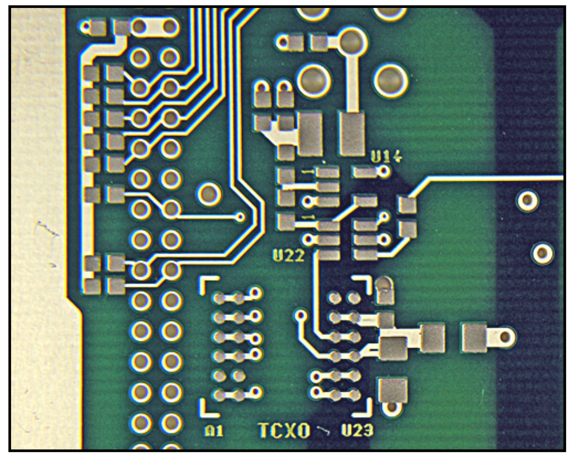


Photo 7. Solder Paste Applied to PCB

Solder Paste: The solder paste consists of microscopic spheres of solder mixed with flux.[7] The solder alloy, the sphere size, the flux composition, and the stencil characteristics were all carefully matched to the width and spacing of the traces on the PCB. Type-6 powder distribution was selected, with a solder sphere size of less than 20 microns, and a water washable, no-clean flux. Although this flux is non-corrosive and non-conducting, it is removed after soldering in a high-reliability situation to facilitate inspection and possible conformal coating at a later stage.

RoHS Compliant No-lead Solder: Many components are now being manufactured to new RoHS (Reduction of Hazardous Substances) requirements. Often the leads of these devices are plated with pure tin. Pure tin is outlawed on military and commercial spacecraft due to the random formation of microscopic growths called 'tin whiskers' that can cause shorts [7]. Tin whiskers have been blamed for the in-flight failure of several commercial communication satellites, at a cost of hundreds of millions of dollars. It's important that pure tin and tin plating both be avoided on Eagle.

No-lead solder balls on BGA devices can be particularly problematic since their melting temperature is considerably higher than normal 63Sn/37Pb solder. During reflow the lead-free balls may not all reflow properly and mix with the tin/lead solder paste. The higher melting point of no-lead solder also requires a reflow profile where peak temperatures approach the maximum allowable temperature of many PEM devices. We need to avoid RoHS compliant components whenever possible. If they are used then they will require special attention.

6. The Thermal Profile

The reflow oven's temperature controller follows a preprogrammed thermal profile that must be developed for each PCB based on the unique thermal characteristics of the

[7] Most solder paste must be kept refrigerated. Since lead is a major health hazard keeping solder paste in your kitchen refrigerator is not advised.

components on the board and the PCB itself (Figure 3). Once the profile is properly adjusted it provides a high level of repeatability. The profile consists of four sections, each serving a specific purpose.

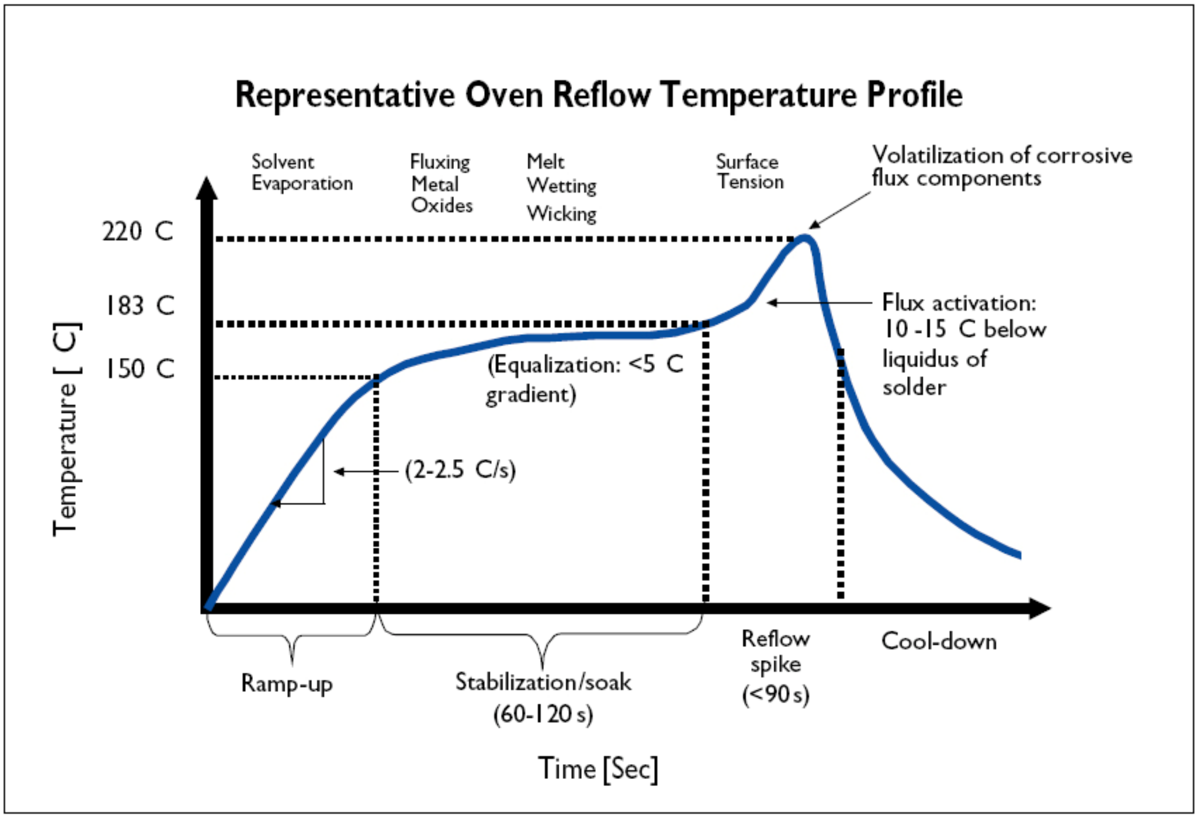


Figure 3. A typical solder reflow profile, courtesy of Bergquist Company

Ramp-up: The first phase of the reflow profile raises the temperature of the PCB and components up to the flux activation temperature of approximately 145°C. The rate of temperature rise (ΔT) is carefully controlled to minimize component stress.

Stabilization/Soak: This phase continues the temperature rise up to the liquidus temperature of the solder at 183°C. We hold ΔT to less than 1.0°C/Second to minimize stress on the components and to allow the PCB and the components to all reach thermal equilibrium. During this phase the flux is activated, removing oxides from the component leads and PCB pads and preparing the joints to accept solder.

Reflow: During reflow the PCB surface temperature is brought up past the liquidus temperature of the solder to the maximum temperature specified by the component manufacturers[8] (225°C for the Receiver) and then lowered back below the liquidus temperature.

Manufacturers specify the maximum time their components may be above liquidus, typically 30 to 60 seconds, and the maximum solder temperature. This phase is very critical and directly affects the structure of the solder joints. During this phase the melted solder wets the metallic surfaces, the components are wicked into position on

[8] At peak reflow temperatures the plastic devices and the PCB will probably pass through their Glass Transition Temperature, Tg, where their mechanical characteristics change from a glass-like material to a rubbery consistency. Once past Tg the CTE of these materials can increase dramatically.

the pads, and a molecular bond is formed with the base metals. Finally the corrosive and volatile flux components are evaporated.

Cool-down: During the cooling phase the PCB is brought down to ambient temperature at a controlled rate to avoid thermal stress. The rate of cool-down affects the final grain structure of the solder joints.

7. Requirements Definition, Design, and Review Process

There is a great deal of engineering and logistics work that must take place before the first component is placed on the PCB (Figure 4). Lack of thoroughness during this stage will almost always cause delays, wasted effort, or much worse.

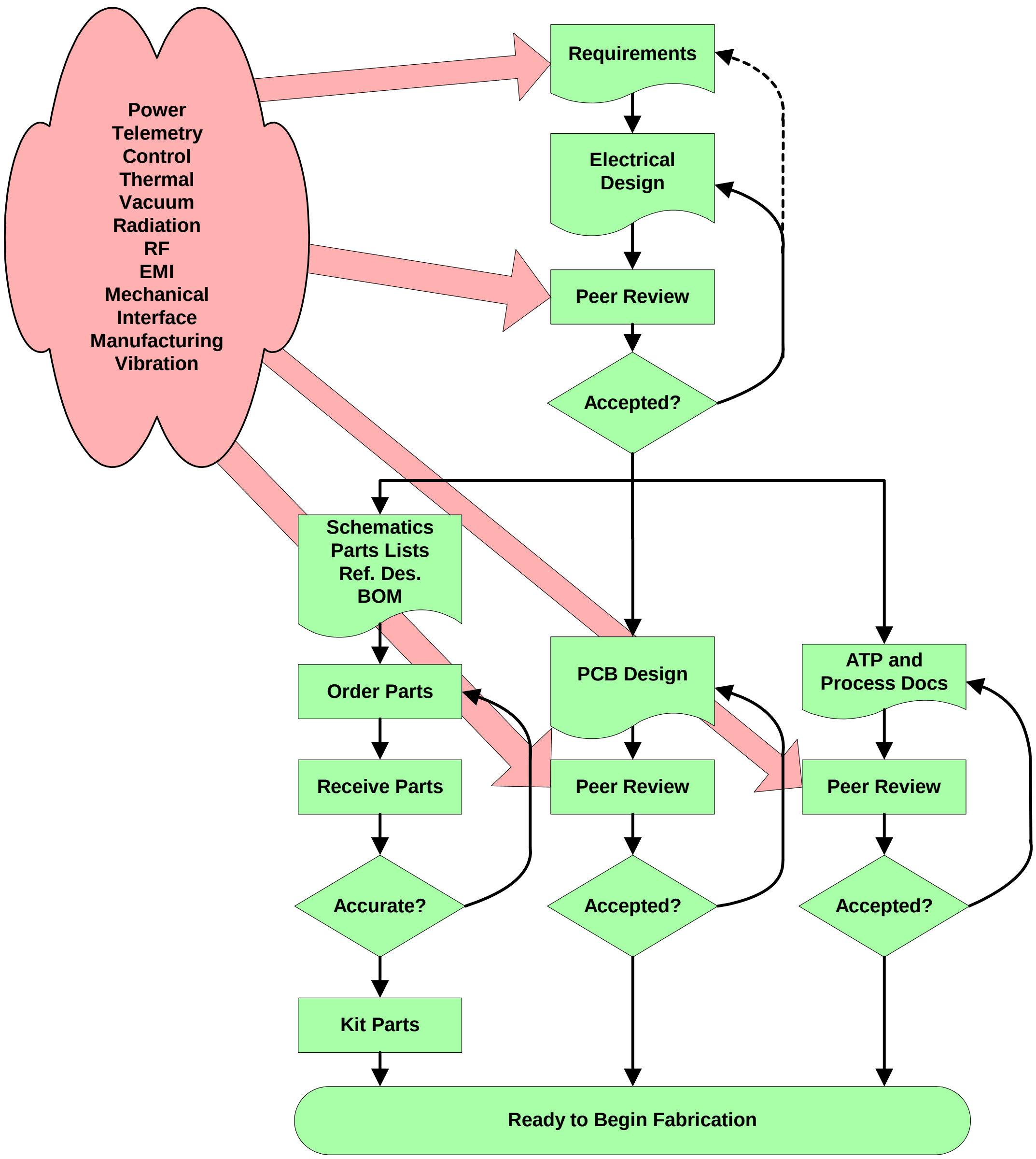


Figure 4. The Vital Steps Leading Up to Prototype Fabrication

The Requirements: Every project starts with a plan. The 70 cm Receiver started with a set of receiver requirements. It's important to ensure that the requirements are as thorough and complete as they can possibly be. This is where a top-level system engineering perspective is very critical. What are all of the inputs and outputs? What sort of environment does this subsystem require to be able to function effectively? What impact will it have on other subsystems? What are their requirements? For example, there is always some local oscillator leakage out of the RF input of superhetrodyne receivers which will be fed directly to an antenna on the exterior of the satellite. How much coupling will there be between antennas? Can this local oscillator leakage have an adverse impact on other receivers? Are there EMI (Electro-Magnetic Interference) levels that cannot be exceeded? Are there particular frequencies that should be avoided for this receiver's local oscillators? What about radiated and conducted EMI emissions and susceptibility in general? How does the Receiver interface to the housekeeping computer? What telemetry inputs must it provide? How will the Receiver recover from an upset? All of these global issues, and not just RF, need to be considered and dealt with in the Receiver requirements document.

The Electrical Design: The requirements and the design were both created by John Stephensen, KD6OZH, with input from AMSAT managers.

The Electrical Design peer review process: This peer review process was very thorough and detailed, but narrow in scope and perhaps too informal. It appears that it focused almost exclusively on RF. You'll hear more about this later.

The Paperwork: The output from this initial process detailed in Figure 4 is the schematic and the parts list. In our case there were several loops through the design/review process and the schematic was revised a number of times, along with the component reference designators. Creating the reference designators early and then revising the schematic causes the top-to-bottom / left-to-right assignment of reference designators to get out of sequence making components harder to find.

The PCB Design and Peer Review Process: Designing a multi-layer PCB for a double-sided SMT board requires completely different techniques than would a thru-hole board. Everything is completely different and attention to the smallest detail is critical to ensure high reliability. This process needs to be taken very seriously and carefully peer reviewed by knowledgeable folks with SMT experience.

I don't believe anyone that attempted to peer review John's design had any real SMT experience, including the Project OSCAR team. Fortunately John knew what he was doing and the board is of very high quality.

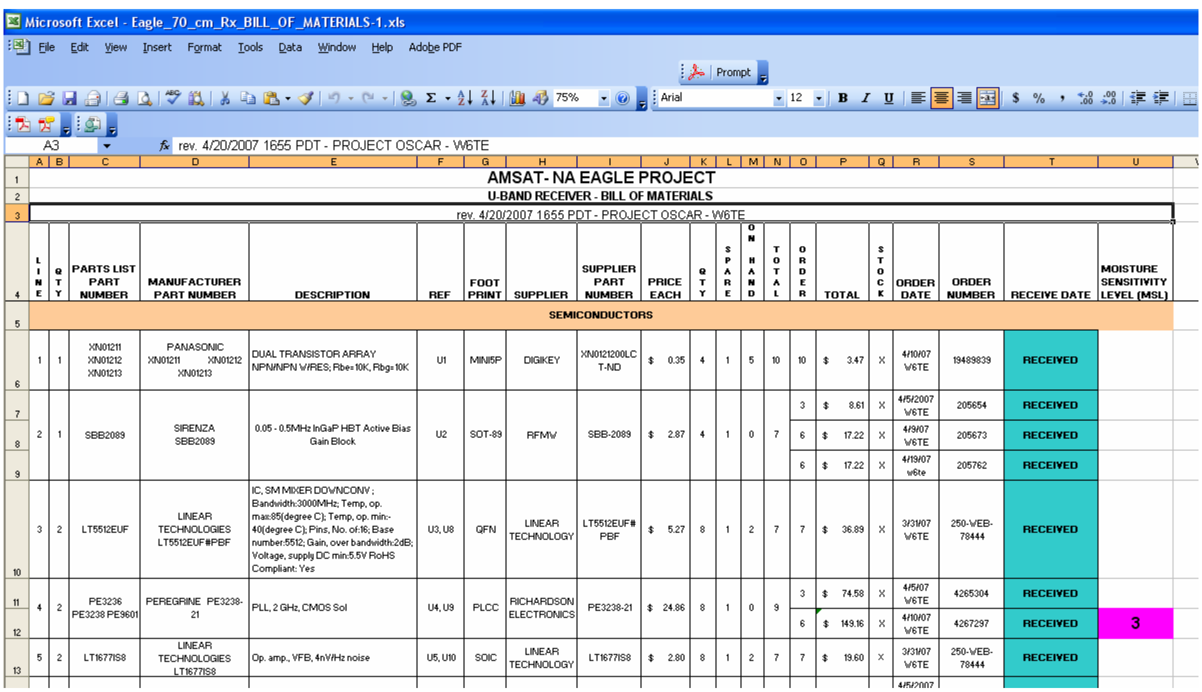
The ATP (Acceptance Test Procedure): The purpose of the ATP [8] is to ensure that the Receiver meets the requirements, satisfies the real-world conditions and the expectations of the customer, in this case AMSAT management, and to provide a vehicle for disseminating performance characteristics and any problems that may exist. This is called verification and validation.[9]

[9] As you will see, the Receiver met most of the requirements but the requirements didn't reflect real-world conditions as well as they should have. A disconnect between the requirements and the customer expectations or real-world conditions often results in a design that meets the requirements but falls short of expectations. It happens all the time. In this case I think we've caught just about everything early enough in the project to minimize the impact. Still, proper prior planning is absolutely essential.

I wrote the ATP based on the requirements document that John had created. I modeled my ATP on other Receiver ATPs that I was familiar with. Quite a few receiver parameters that I am accustomed to seeing were not included in the requirements.[10] When I encountered one I would create a test based on my experience and note the fact in the test introduction. The ATP is 57 pages long and has never been harmonized with the Receiver requirements. I believe the receiver requirements and the ATP should both be reviewed side by side. We'll bring these two documents into alignment before moving on to the next upgrade revision.

The BOM (Bill of Materials): The BOM amplifies on the basic data in the parts list and is the document that is used to order all the parts for the project. Dave Smith, W6TE, took on the tedious and demanding job of creating the BOM from a still evolving parts list. He also ordered all of the parts, tools, and supplies. It may sound simple, but the pile of invoices is at least an inch thick. The BOM is twelve 11x17" pages of small print (Figure 5). Notice that the MSL (moisture sensitivity level) of the PEMs is captured here in red. Anything over an MSL of 2 requires special handling from the moment the component is manufactured.

Because we did not follow our own advice to wait until the design was completely stable, poor Dave had to revise the BOM and reorder parts many times. This was a very stressful exercise for Dave and also for me as the incoming parts receiver. Trust me on this. Wait until the schematic is completely stable before proceeding.



AMSAT- NA EAGLE PROJECT

U-BAND RECEIVER - BILL OF MATERIALS

rev. 4/20/2007 1655 PDT - PROJECT OSCAR - W6TE

LINE	QTY	PARTS LIST PART NUMBER	MANUFACTURER PART NUMBER	DESCRIPTION	REF	FOOT PRINT	SUPPLIER	SUPPLIER PART NUMBER	PRICE EACH	QTY	SPARE	ON HAND	TOTAL	ORDER	TOTAL	STOCK	ORDER DATE	ORDER NUMBER	RECEIVE DATE	MOISTURE SENSITIVITY LEVEL (MSL)
SEMICONDUCTORS																				
1	1	XN01211 XN01212 XN01213	PANASONIC XN01211 XN01212 XN01213	DUAL TRANSISTOR ARRAY NPN/NPN W/RES; Rbe=10K, Rbg=10K	U1	MINI5P	DIGIKEY	XN0121200LCT-ND	$ 0.35	4	1	5	10	10	$ 3.47	X	4/10/07 W6TE	19489839	RECEIVED	
2	1	SBB2089	SIRENZA SBB2089	0.05 - 0.5MHz InGaP HBT Active Bias Gain Block	U2	SOT-89	RFMW	SBB-2089	$ 2.87	4	1	0	7	3	$ 8.61	X	4/5/2007 W6TE	205654	RECEIVED	
														6	$ 17.22	X	4/9/07 W6TE	205673	RECEIVED	
														6	$ 17.22	X	4/19/07 w6te	205762	RECEIVED	
3	2	LT5512EUF	LINEAR TECHNOLOGIES LT5512EUF#PBF	IC, SM MIXER DOWNCONV ; Bandwidth:3000MHz; Temp, op. max:85(degree C); Temp, op. min:-40(degree C); Pins, No. of:16; Base number:5512; Gain, over bandwidth:2dB; Voltage, supply DC min:5.5V RoHS Compliant: Yes	U3, U8	QFN	LINEAR TECHNOLOGY	LT5512EUF#PBF	$ 5.27	8	1	2	7	7	$ 36.89	X	3/31/07 W6TE	250-WEB-78444	RECEIVED	
4	2	PE3236 PE3238 PE9601	PEREGRINE PE3238-21	PLL, 2 GHz, CMOS SoI	U4, U9	PLCC	RICHARDSON ELECTRONICS	PE3238-21	$ 24.86	8	1	0	9	3	$ 74.58	X	4/5/07 W6TE	4265304	RECEIVED	
														6	$ 149.16	X	4/10/07 W6TE	4267297	RECEIVED	3
5	2	LT1677IS8	LINEAR TECHNOLOGIES LT1677IS8	Op. amp., VFB, 4nV/Hz noise	U5, U10	SOIC	LINEAR TECHNOLOGY	LT1677IS8	$ 2.80	8	1	2	7	7	$ 19.60	X	3/31/07 W6TE	250-WEB-78444	RECEIVED	
																	4/5/2007			

Figure 5. A small section of the BOM (Bill of Materials)

[10] This should have been a red flag to me that something wasn't quite right with the requirements or the ATP but I was new to the team and the requirements peer review had already been completed so I didn't sound an alarm. I know better now. Always speak up!

8. Fabrication Preparations

Photo 8. Three-Inch binder and ESD parts bins sorted by reference designation

Binder Contents

- 70 cm Receiver Requirements
- Schematic Diagrams
- Parts List
- Bill of Materials
- Acceptance Test Procedure
- PCB Layout Details
- Construction Procedure
- Tuning Matrix
- Gain Trimming Procedure
- Moisture Sensitivity Level of Each PEM
- ESD Data for each Component
- Maximum Solder Temp and Duration for Each Component

ESD Bin Contents

- Semiconductor ESD Bin
- Other Components ESD Bin

Circuit Boards

- 4-Layer PCBs

The Team Gets Busy: Once we'd completed all the steps outlined in Figure 4, produced everything you see in Photo 8, and adjusted the reflow profile by making several dry runs, the team was ready for a busy weekend. Our construction documentation divided each side of the PCB into 6 physical zones. Each zone had its own large drawing showing the location of each component along with any construction notes. For example, some parts required an application of thermal gap-filler between their base and the PCB, and some components were to be installed later on as a separate operation. All this was documented in the zone drawings.

With a double-sided PCB, you'll want to reflow the side with the lightest components first since these components will make a second run through the oven hanging upside down. Capillary action will keep the lighter parts from falling off when the solder melts a second time, but the heavier parts will need to be attached with a special SMT adhesive designed for this purpose.[11]

Preparing the PCB: Following my partially written construction procedure,[12] I washed the PCB using deionized water and a phosphate-free detergent and then baked it for four hours at 155°C to remove moisture. It was then placed in an air-tight bag.

Baking the PCB is important if it has been exposed to the environment since the board material is hygroscopic and absorbs moisture. The trapped moisture can flash to steam during the reflow process and cause delaminations or other impairments between layers. Obviously the PCB needs to be baked if it was washed.

Component Kitting: Once the decision has been made as to which side to do first, it's time to kit up the parts for all of the zones on that side. For this we used small ESD kitting trays with lids. They were perfect. Each component went into a bin in the tray and its reference designator and location were noted using masking tape on the lid.

In Photo 9 Don Ferguson, KD6IRE, (foreground) is pulling parts using the BOM and the zone drawings as guides, and Dave Hartzell, N0TGD, is placing them in the kitting trays. The solder paste dries in a few hours. You won't have time to look for components or to decide where they go, so do this step ahead of time before applying the paste.

Photo 9. Component Kitting

[11] See our BOM on EaglePedia for part numbers and manufacturer information for the thermal gap filler and SMT adhesive we used.

[12] Since we had no experience to draw on I was unable to create a complete and final version of a construction procedure at this point. There were just too many things that still needed to be worked out. You'll want to have this done and follow it closely before you fabricate the non-flight boards. Then you can follow it exactly when you make the flight hardware.

9. Fabricating the First Prototype Receiver

Photo 10. I Apply the Solder Paste

Applying Solder Paste: Once the PCB is cleaned and baked and the parts are kitted, it's time to apply the solder paste. A bead of paste is run across the entire width of the stencil. Then the paste is squeegeed on using a laser-cut stainless steel stencil as shown in Photo 10. It takes some practice to determine the correct amount of squeegee pressure and speed to use, so you may end up cleaning the PCB and trying several times.

Part Placement:

Greg Samsonoff, KI6IKG, is placing components on the PCB using tweezers, a vacuum pickup, and a magnifying light (Photo 11). Sometimes the tweezers were the best choice and sometimes the vacuum pickup was best.

Photo 11. Greg Places Components on the PCB

We also had a stereo microscope but found the field of view so small that we easily became disoriented. With the magnifying light we could see a large area so we always knew where our hands were. This is important as you do not want to brush away components by mistake.

Photo 12 shows the PCB partially populated with components. Notice that a few are slightly skewed. If the pads have been designed properly the components will wick into perfect alignment once the solder melts, due to the capillary action of the molten solder.

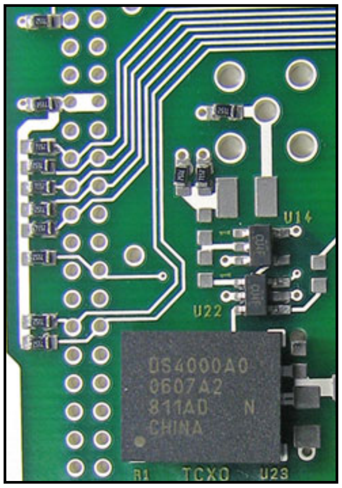


Photo 12. Parts On Paste

You'll want to give thought to the order in which the components are placed on the paste. I'm right handed so I prefer to work from top to bottom and left to right. That way I don't have to reach over parts I've already placed in position. You'll also find that placing the smallest and shortest components first makes life easier. Trying to reach behind a tall part like the TCXO in Photo 12 will be difficult.

I failed to consider the fact that solder is going to end up anywhere where paste has been applied, whether or not a part is actually placed there. Notice that the 40-pin connector vias are full. Use Polyimide tape to block off any areas where you don't want solder.[13] I had to resort to surface mount rework techniques to remove solder that had wicking through vias and collected on the heat sink mating area on the bottom.

The Reflow Oven: Everything we're done up to this point would be pointless if the reflow oven wasn't up to the job. We couldn't afford to take any chances so we went with the finest kitchen appliance available – a General Electric toaster oven! Hey, they make nuclear power plants, don't they?

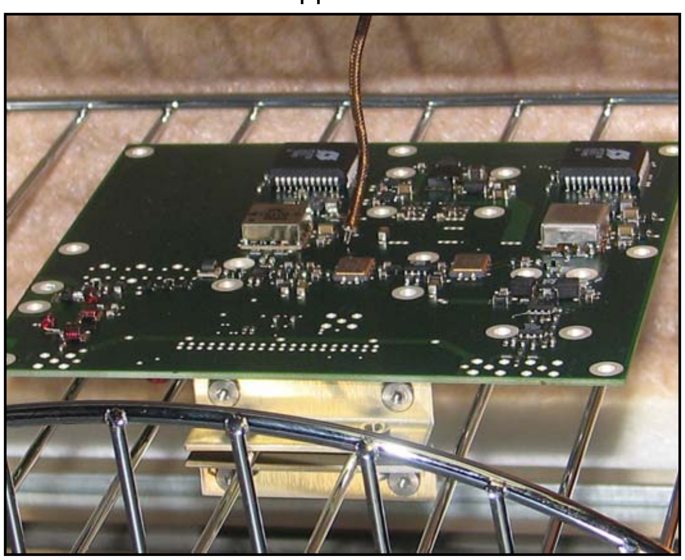


Photo 13. PCB Ready to Reflow

We purchased a modified toaster oven and a temperature controller from Stencils Unlimited for approximately five hundred dollars. The oven is modified to increase the insulation and to provide a constant flow of air. A hole is drilled into the back of the oven to provide access for a thermocouple. In Photo 13 you see the populated top side of the PCB about to be reflowed. The thermocouple is placed so as to make contact with the surface of the PCB (the dark wire coming down from the top of the picture). Since the bottom side had already been reflowed I rigged two small stands to keep the bottom-side parts from being dislodged by the oven's grill. By the way, be very careful when you place the thermocouple on the PCB. You don't want it to disturb any of the parts! You'll want to place it close to the biggest part on that side since it will be the last to heat up.

[13] Better yet, work with the stencil manufacturer to remove all the unwanted holes from the stencil. The 40-pin header, the SMA connectors, and any other thru-hole components are obvious choices.

The Temperature Controller: The thermocouple connects to the external temperature controller (Photo 14) and the controller interfaces with the PC via an RS-232 cable. The unit comes bundled with an application that is used to program the controller's microprocessor and to capture temperature data during a run.

I wanted to monitor the temperature profile in real time during a run so I wrote a LabVIEW application to do that. After a few trial runs to dial in the profile we were ready to reflow the prototype!

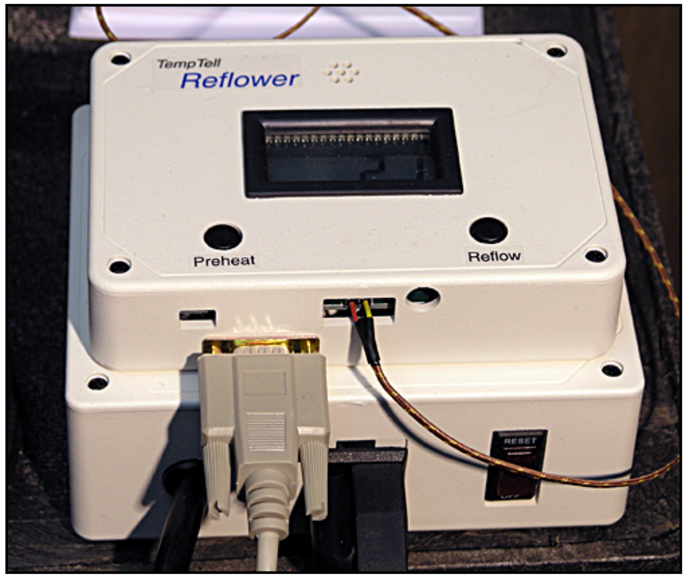


Photo 14. The Temperature Controller

Figure 6. LabVIEW Reflow Oven Thermal Profile Monitor

The Reflow Profile: During the actual run, we were able to monitor progress in real time (Figure 6). The blue line shows the target temperature the processor is attempting to follow. The red line shows the actual PCB surface temperature at the thermocouple contact point in the middle of the PCB.

Since there is a good deal of thermal inertia, the actual temperature will lag the commanded temperature as you see in the plot. You'll need to test the oven and the profile with a similar sized PCB with a similar assortment of components. Once you are satisfied, the profile can be named and stored as a file on the PC.

For comparison, look back at the sample profile in Figure 3. You'll see the four sections, each programmed with the parameters you see above the graph on the GUI of Figure 6. Notice the cool down slope. This is the weak link of this type of closed oven. It is very difficult to get the temperature to come down fast enough to stay within the 60 second limit above liquidus. After trial and error we settled on a rather crude but effective technique. As soon as the oven hit the peak temperature of +225°C we shut it down and opened the oven door completely. Then, holding a muffin fan exactly 3-feet from the door, we blew a gentle cool breeze into the oven. It's crude but it got the job done. The important thing to remember about this last manual intervention is that you are opening the door while the solder is a liquid. Any movement while the solder is changing phase from a liquid to a solid will cause very unsatisfactory solder joints. It's imperative that all vibration be eliminated during this process.

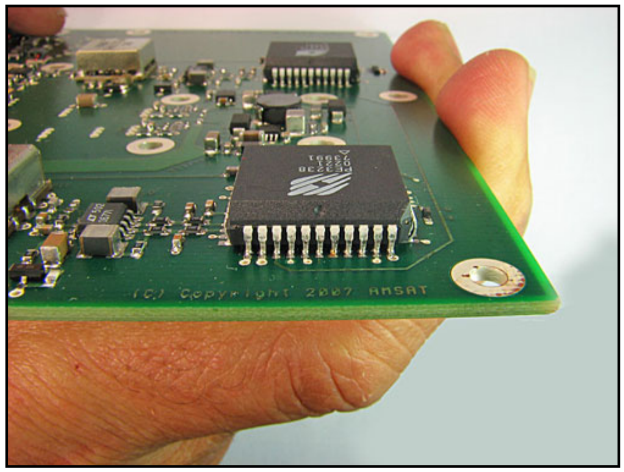


Photo 15: The Finished Prototype PCB

The Results: Here's the prototype PCB after reflow (Photo 15). The joints had a slightly grainy appearance, giving me a small heart attack. A call to the solder paste manufacturer convinced me that this was due to the tin/lead solder mixing with the silver plating on the PCB, creating a unique tin/lead/silver alloy. Unfortunately this makes it more difficult to do a good visual inspection - another example of the tradeoffs that need to be considered in a project like this one. We needed a perfectly smooth surface to mate to the heat sinks and silver seemed like a good choice at the time. In the next revision we will consider alternate plating choices that will not impact the grain structure of the solder but still provide a good interface to the heat sinks.

The whole process from component kitting to the PCB you see in my hand took four of us one weekend. As mentioned, the kitting itself can be done at your leisure beforehand. Once that solder paste is squeegeed onto the PCB it's all hands on deck because the paste will start to dry. By the time we got about half way through with our placement the paste was completely dry.[14] Once the paste dried the components had nothing to stick to and just sat where we put them. Any slight breeze or a good sneeze would have blown half of them off onto the floor! Quality Assurance folks would call that a "process indicator" meaning we need to fix it for next time.

[14] It's important to get the parts placed into the paste before it dries. Working in a cool area will help stretch that time out. We started at noon on a very hot day – big mistake! Take the paste out of the refrigerator 24 hours before use to allow it to return to room temperature. Remember, lead is toxic. Wash your hands before eating and keep the paste away from food, pets, and kids.

10. The Inspection Process

Inspecting a double-sided, multi-layer SMT PCB can require some specialized equipment, especially if the board contains BGA devices and is destined for space. The BGA solder balls were inspected using an x-ray machine (Photo 2) and then inspected visually using a fiber optic camera specifically designed for this purpose (Photo 3). Those little balls are very small!

11. Receiver Final Assembly

When the PCB was completed it was mounted it to its three heat sinks (Photo 16). We then developed a process that would allow the CAN-Do module to be mounted to the Receiver PCB so that it was completely flush with the front panel. This was necessary to prevent stressing the solder joints when the CAN-Do module was mounted to the panel. Once the CAN-Do module was mounted the finished board was installed in the module enclosure.[15]

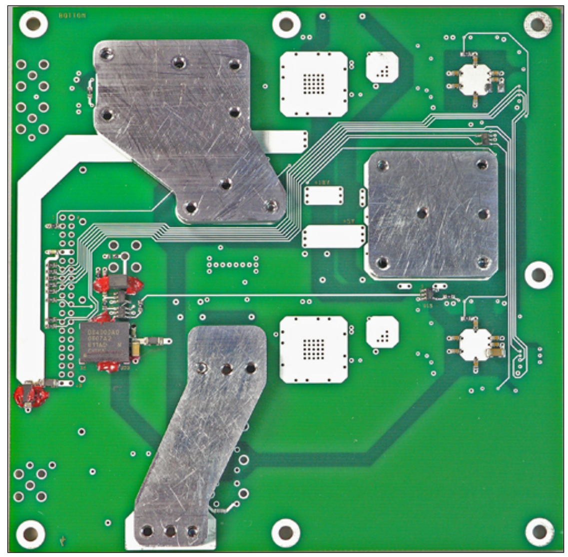


Photo 16. Bottom Side with Heat Sinks

12. Testing

Preliminary Test Results: The standard test setup is shown in Figure 7. All the equipment that is capable of accepting an external frequency reference is phase locked to a GPS disciplined clock and all the GPIB (General Purpose Instrument Bus) capable equipment is connected to the PC.

The first tests in the ATP involved checking the power supplies for proper output. There was one error on the PCB that prevented one of the supplies from functioning. That was corrected by cutting a trace. Next we were unable to get either of the local oscillators to come up on the correct frequency. This problem turned out to be cockpit error with the CAN-DO initialization string. Once that was corrected the Receiver started to come alive.

[15] The prototype heat sinks differ slightly in thickness from each other and from the mounting standoffs. This will cause stress to concentrate around the heat sink mounting hardware. We will need to sort this out and it may require a change in the enclosure design and/or fabrication process.

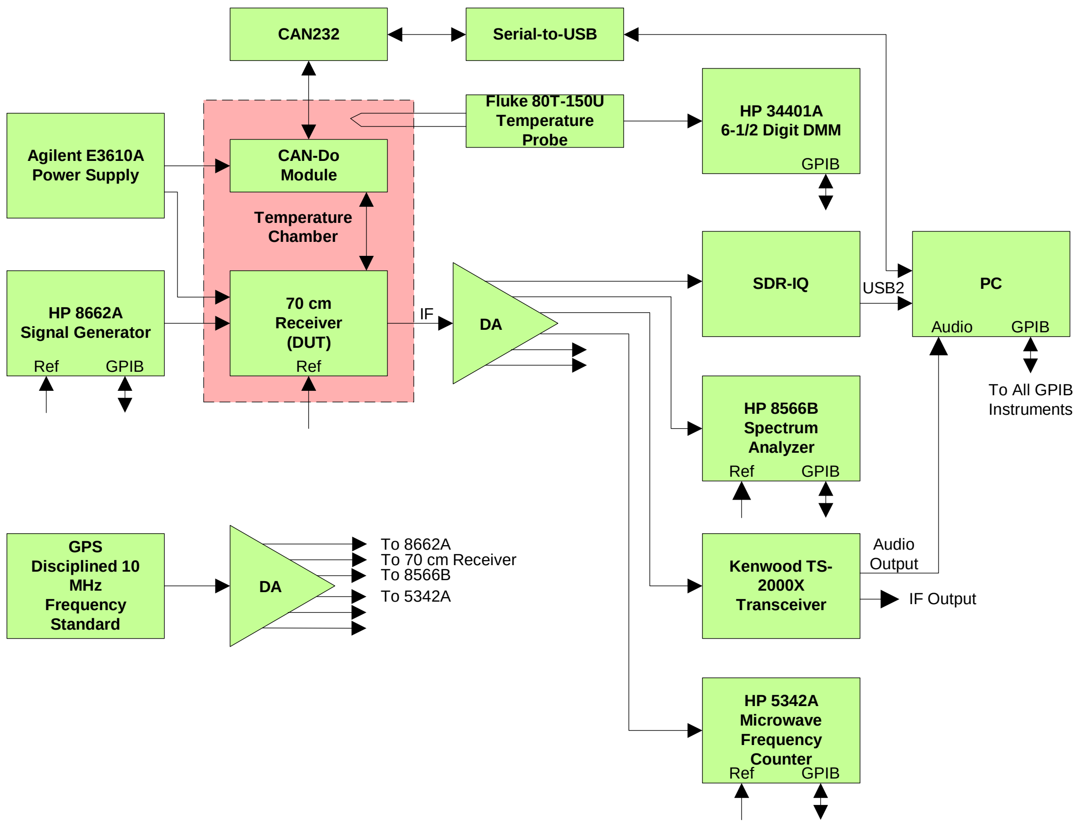


Figure 7. The Eagle 70 cm Receiver Test Setup

Excessive Passband Ripple: Once testing began we discovered a number of problems. The first was severe ripple in the passband (Figure 8). This problem is being worked as this is being written. Once we understand the cause John can modify the circuit for the next revision.

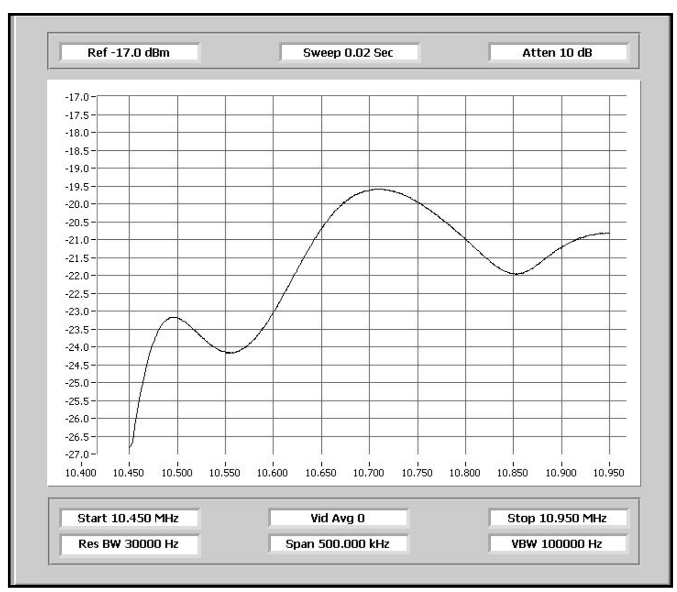


Figure 8: Excess Passband Ripple

The SDR-IQ: Things were looking pretty good when I saw an ad with a very attractive introductory price for a small software defined radio called the SDR-IQ. It promised to be a great addition to my ham shack so I ordered one immediately. I had planned to use it as a panadapter for my TS-2000 transceiver but I thought it might also prove useful as another way to look at the Receiver's IF output. Little did I know…

As soon as I connected the SDR-IQ to the Receiver's IF output I began to see spurs that were otherwise hidden under the noise floor of my Agilent 8566B spectrum analyzer. It didn't take long to realize that the SDR-IQ, with its extremely low noise floor, was allowing me to see a world of problems that had previously been undetectable to me.

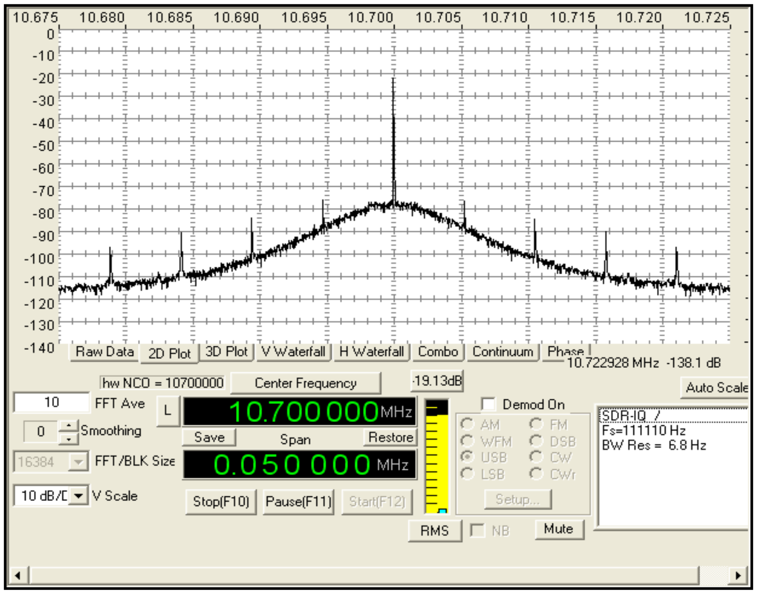


Figure 9. CAN-Do 5 kHz EMI

5 kHz Spurs: The first thing that jumped out at me was a nasty series of spurs at 5 kHz intervals all the way across the passband of the Receiver (Figure 9).

The source of the spurs was identified as radiated EMI from the CAN-Do switching power supply's inductor and conducted EMI from the Can-Do switched DC power.

Identifying the radiated EMI entry path into the Receiver took some time. The CAN-Do module was removed from the Receiver PCB and mounted at the end of a 2-foot ribbon cable. This allowed me to move the CAN-Do module over the top of the Receiver to identify the susceptible areas. It appears that both of the Receiver VCOs provide the main entry path for radiated EMI from the CAN-Do module.

13. CAN-Do Module EMI Troubleshooting and Temporary Corrective Action

Photo 18. CAN-Do EMI Field

Radiated CAN-Do EMI: By mounting the CAN-Do module at a constant height (and using it as a noise generator) it was possible to scan the Receiver PCB components to determine which circuit elements were susceptible to the CAN-Do radiated EMI and at what distance. The red arc shows the range of the CAN-DO EMI radiation zone (Photo 18).

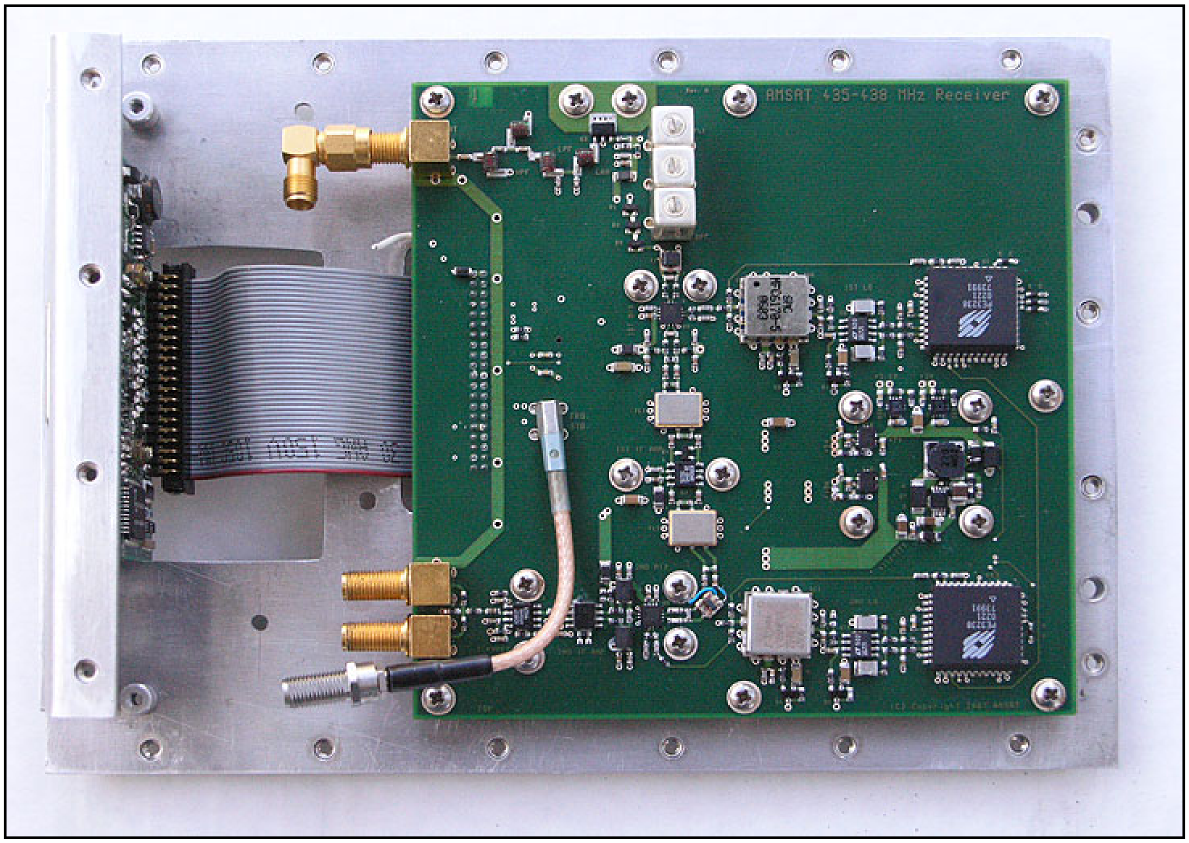


Photo 19. Temporary 70 cm Prototype Receiver Position

Temporary Radiated EMI Solution: Two voltage controlled oscillators (the square metal cans) were found to be the most susceptible to EMI. They must be kept at least 4-1/2 inches from the CAN-Do inductor. Since the Receiver does not utilize all of the space inside the enclosure it was possible to move the PCB to the rear of the enclosure to temporarily escape the radiated EMI (Photo 19).

Temporary Conducted EMI Solution: The Receiver was still susceptible to conducted EMI arriving from the switched CAN-Do DC power. To temporarily cure this problem it was necessary to bypass the CAN-Do switched DC power and take a clean feed from the laboratory bench power supply.[16] This approach bypasses the CAN-Do current monitor.

Both of these ‘fixes’ are temporary. The ultimate solution is to clean up the CAN-Do EMI at the source or shield and filter everything in its vicinity. Most payloads won’t have the luxury of vacating the front third of the enclosure and moving to the back. A two-compartment enclosure may be required in some cases. Time will tell…

[16] Without Receiver DC input filtering this problem will almost certainly reappear once the Receiver is powered from the solar panel power distribution subsystem, even if the CAN-Do module is completely noise-free.

CAN-Do EMI Analysis: The step-down converter is only providing 11 milliamps of current to the CAN-Do module. The converter IC was optimized to supply considerably more current. At this low output current it switches at a very low frequency and is not very efficient. These switching supplies are also very sensitive to PCB layout since there are fairly high switching currents involved.

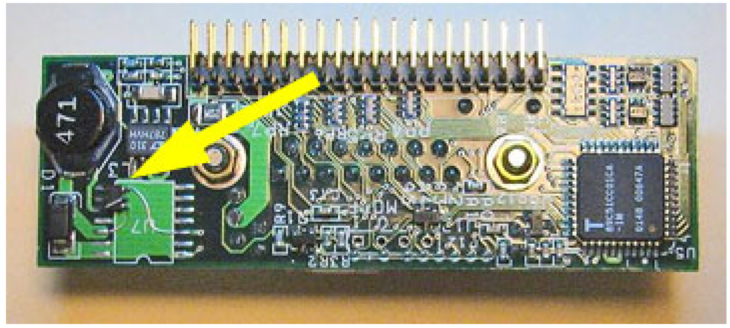


Photo 20: Step-Down Controller

The PCB was apparently designed for another much larger component and the existing Maxim IC is installed as a dead bug just barely visible, with small bare wire leads in the corner of the U7 location (yellow arrow Photo 20).

The choice of the step-down converter IC, the lack of shielding on the inductor, and the lack of a proper PCB layout all contribute to the high level of conducted and radiated EMI. Figure 13 shows frequency vs. load current for the 3.3 volt higher current version of this device (625 mA vs. 312 mA), but you can get the idea. 11 milliamps is way down at the very low end of the operating range.

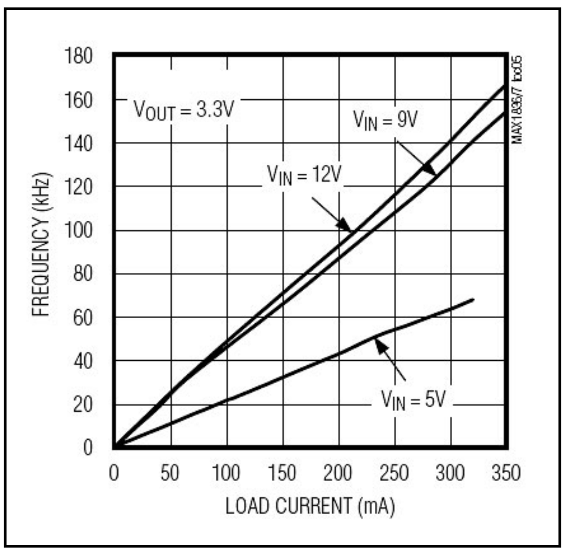


Figure 13: Switching Frequency vs. Load

Lastly, the circuit is motorboating. Maxim describes this as follows, "Commonly, instability is caused by excessive noise on the feedback signal or ground due to poor layout or improper component selection. When seen, instability typically manifests itself as "motorboating," which is characterized by grouped switching pulses with large gaps and excessive low-frequency output ripple during no-load or light-load conditions." The waterfall plot detail of Photo 21 shows the grouped switching pulses referred to by Maxim. These problems may be difficult to fix with this very light load.[17]

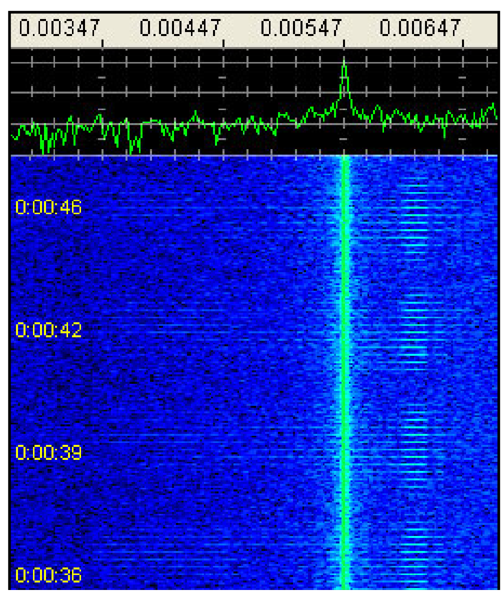


Photo 21: Converter Motorboating

[17] Most of the available step-down converters may suffer from the same problems as the Maxim IC. They may also tend to motorboat at very light loads.

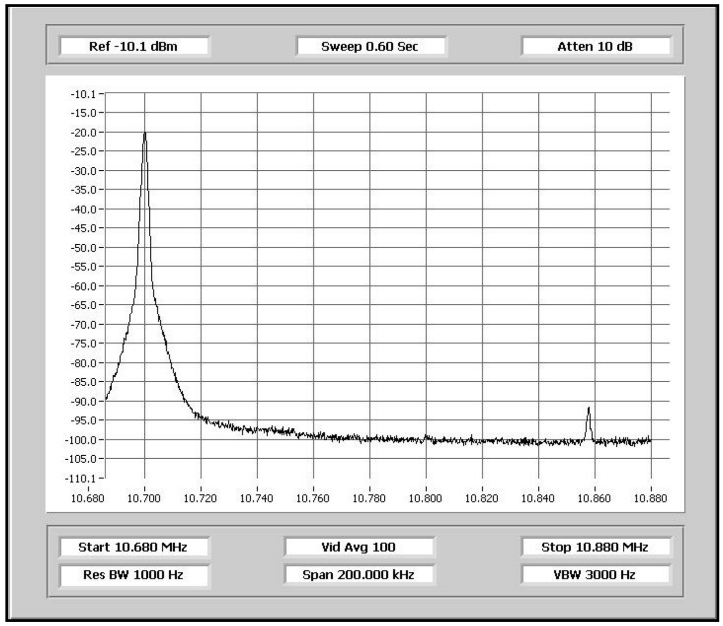


Figure 10. Self-Generated Spur at 157 kHz,

Self-Generated Spur: The SDR-IQ also allowed me to identify a self-generated 157 kHz spur in the Receiver that is caused by the Receiver's switching power supply.

In Figure 10 the -72 dBc spur is at the right. This spur will need to be dealt with in the next revision.

Microphonics: The Receiver is microphonic. Five ceramic chip capacitors in the loop filters are responsible. Barium titanate, the base ceramic material for most ceramic SMT capacitors, is inherently microphonic [9]. Figure 11 shows peak levels in red after the PCB was tapped.

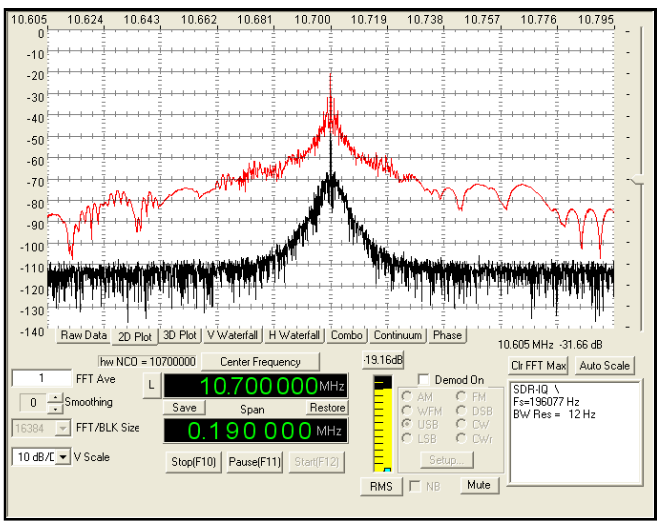


Figure 11. Microphonics

The black trace is the base line level when not being tapped. Film capacitors should be used in loop filters to avoid this problem. This one slipped past us in our haste to order parts.

Frequency instability: I connected the SDR-IQ and my TS-2000 to the IF output as you see in Figure 7. I discovered some very strange behavior while listening to a CW input through the TS-2000. Every now and then the frequency would jump about 20 Hertz. I decided to make a temperature run in my home made temperature chamber to check frequency stability versus temperature.

Thermal Testing: My temperature chamber is built from a discarded microwave oven. I pulled out the magnetron and installed a 700 watt quartz bathroom heater element in its place. Then I rigged the oven with a tank of liquid CO_2, a cryogenic solenoid valve, a nozzle, and an industrial temperature controller. It's capable of holding any temperature between about -65°C and +70°C within ±1°C. That's not bad for a discarded kitchen appliance!

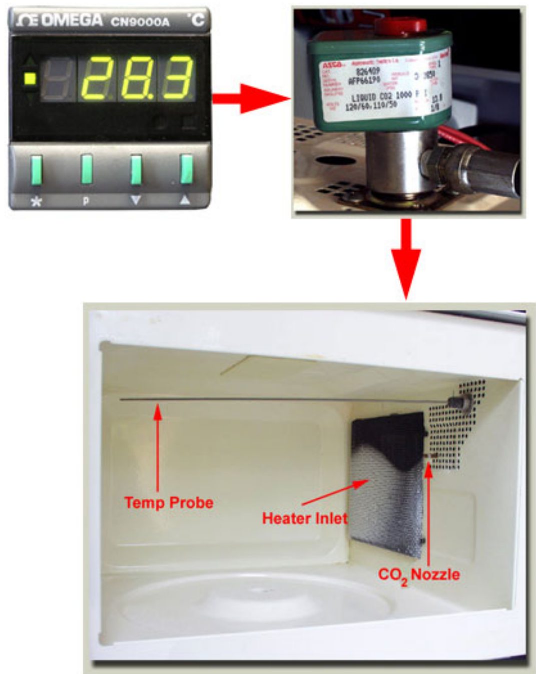


Photo 17. WA6HTP Temp. Chamber

WA6HTP Temperature Chamber: The brain of the chamber is an Omega PID temperature controller. It uses a sophisticated autotune algorithm to 'learn' the thermal characteristics of the chamber. The controller uses a zero-crossing solid state relay to control the heater and a cryogenic solenoid valve to meter liquid CO_2 into the chamber from a cylinder.

Liquid CO_2 exits the nozzle at 1400 PSI and instantly freezes to a solid in the form of CO_2 snow flakes. The snow flakes sublimate directly to a gas without passing back through the liquid state at a temperature of -78.5°C. That phase change from a solid to a gas cools the chamber (Photo 17).

Temperature Run: For this test the equipment was configured as shown in Figure 7. The Fluke temperature probe was located inside the Receiver's enclosure. The top plot (Figure 12) displays frequency and the bottom plot displays the temperature. For the first 5 minutes the temperature chamber was turned off. You can see a small drift in frequency as the temperature slowly warmed inside the enclosure.

Just after the four minute point the oscillator made several jumps of about 20 Hz and then settled at the higher frequency.

At the five minute point I started the chamber heading down slowly in temperature. You can see the large frequency jumps associated with a rapid ΔT.[18]

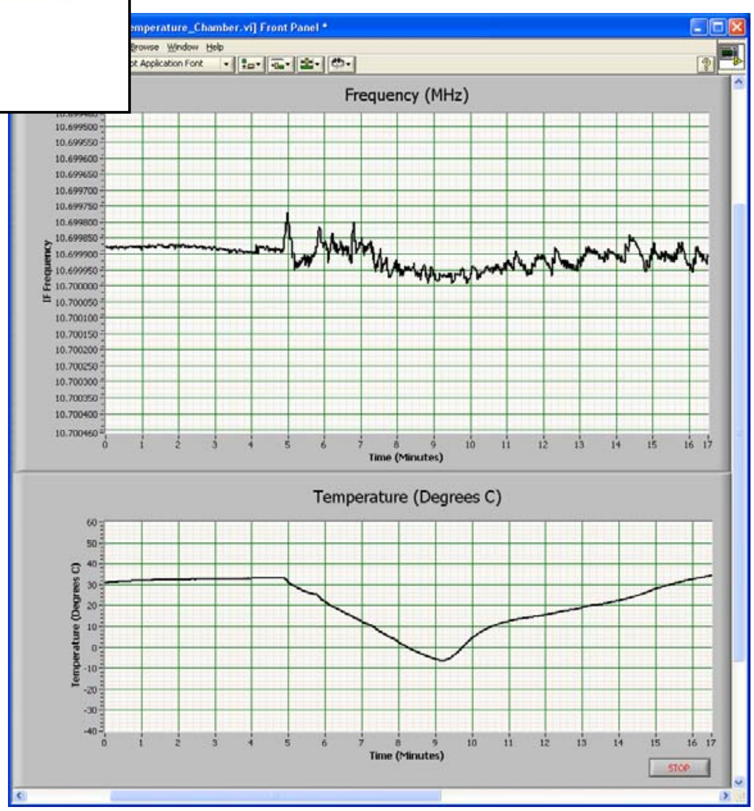


Figure 12. Small Temperature Run

[18] The initial large jump at the 5-minute point is about 200 Hz in a span of about ten seconds.

14. Things That Worry Me

Minimum Operating Temperature and Cold Soak:

- This one keeps me up at night. If we don't get this right it could cripple Eagle, especially if we get it wrong in the CAN-Do module. PEMs are normally rated at a minimum operating temperature of -40°C. There are physical reasons for this – Unlike ceramic ICs, the thermoplastic case material and the die are in direct contact in most PEMs. They have different coefficients of thermal expansion. Operation at or below the minimum temperature can and will cause stress on the die and can lead to latent defects and premature failure. Attempting to operate the Receiver at or below the minimum operating temperature or cold soak it to -60°C is very dangerous in my opinion. If no way can be found to keep the receiver at or above -40°C then some way must be found to insure that it is allowed to reach thermal equilibrium of at least -40°C before applying power after a cold soak.

EMI:

- **General EMI Observations:** We must expect the Receiver to operate from a very noisy DC power source. Since the Eagle power distribution subsystem has not been designed yet there is no way to know what to expect. This is very unfortunate. EMI is a global issue that will affect everything on the satellite. It needs to be dealt with as soon as possible. We need to develop an EMI requirement that spells out acceptable levels of emissions and susceptibility. There must be a practical way to test to the spec. We should start by fabricating and characterizing enough of the Eagle power system to capture some useful data. Guesses are worse than useless.
- **Receiver EMI Susceptibility:** DC input power filtering must be added to the Receiver to allow it to operate from the noisy satellite power and still meet the EMI susceptibility specification. As mentioned above, the Receiver EMI susceptibility requirement must flow from the Eagle satellite EMI requirement and that needs to be created based on empirical data and not guesses.
- **CAN-Do EMI emissions:** I think a move to either a linear regulator or another step-down converter operating at a much higher switching frequency, coupled with a new layout of the PCB, will bring the EMI problem down to a manageable level. Again, there needs to be a global EMI requirement to work to.

Enclosure:

The existing sheet metal enclosure has a number of issues that need attention.

- **Mechanical Stability:** My proposed maximum PCB deflection over a 1-inch span is 0.0083". Based on the prototype enclosure I have, the existing sheet metal enclosure does not meet this proposed requirement. Given the need to mount components very close to the heat sink mounting screws, this 0.0083" proposed requirement might actually not be stringent enough.
- **Shielding:** The enclosure may need to be divided into two RF-tight compartments. This will depend on a number of the factors mentioned above.

15. Lessons Learned

Preparations and Circuit Design:

- Time spent in the requirements definition phase is extremely important. The requirements must be broad and complete. You've seen several examples of what can happen when they are less than perfect.
- Look at your payload from a top-level systems perspective. Is there anything that isn't covered by the requirements that should be? Get it added during the peer review.
- Ensure that the peer review is as broad and as thorough as possible. The importance of the peer review cannot be overstated. Don't start until all the top-level details are documented and understood.
- Finalize the design and error check the schematic before assigning reference designators to components.
- Assign reference designators on the schematic moving from top to bottom and left to right. That will make it much easier to find a component on the schematic.
- Determine the Moisture Sensitivity Level (MSL), the ESD Class, and the suggested reflow profile for each component in your circuit. Plan your manufacturing process accordingly.
- Avoid the use of ceramic chip capacitors in sensitive areas since they are inherently microphonic.
- If the board has as many parts as this Receiver, break it down into zones like we did. It makes the job much easier to manage when placing the parts on the paste.

Mechanical Design:

- Consider using cap-head PCB mounting screws instead of Phillips. My screwdriver has popped off a screw head several times and landed on the PCB while I was mounting the board. It happened so fast I didn't know exactly where the screwdriver point landed. If this prototype was flight hardware I would have replaced every chip capacitor anywhere near that area just to eliminate the chance of flying a receiver with a damaged part. Cap head screws would reduce that problem considerably.
- Keep all components, especially ceramic capacitors, away from PCB edges and away from mounting screws if at all possible.
- Match the thickness of the stencil and the composition of the solder paste to the pitch of the components on the PCB. A stainless steel electro-polished stencil with trapezoidal walls[19] is recommended.

PCB Layout:

- I urge you to read *Surface Mount Zero Defect Design Check List* and *Assembly Induced Defects* by the AVX Corporation [6]. I believe these documents should be required reading for anyone contemplating SMT design.

[19] Trapezoidal walls slope outwards on the bottom side of the stencil easing paste release

- Use a PCB design package that will do all the modern automated steps like schematic capture, rules checking, auto routing, and net list generation. Some board houses can do 100% electrical testing using the net list.
- Pay special attention to pads for chip devices. Avoid asymmetrical traces that can cause the chip to rotate during reflow or wick solder away from the part.
- Make sure you leave enough clearance around the internal mounting screws to account for the slop in the flat washers. Also remember that the area around mounting screws is an especially high stress area. Keep brittle components as far away as possible.
- Attempt to design a single-sided board so that you can mount it flush on a backing plate to dissipate heat. Having components on both sides complicates everything.
- Design in test pads so you do not have to probe component pads or solder joints and risk causing latent defects.

Parts Procurement and Organization:

- Don't order any parts until the peer review has been completed. In our case the review was protracted and ran concurrently with parts ordering, resulting in much extra work for all.
- Some suppliers print your reference designators on each package of parts. This is a very useful feature and will make parts organization much easier.
- Organize your parts in whatever way works for you. We used the BOM item number since many parts are used in several places, each having its own reference designator.

Construction:

- Work from top to bottom when placing parts. Don't box yourself into a corner. Place tall parts last. Consider the placement order in advance and make notes on the assembly document package. We've found that stainless steel tweezers and a very good magnifier light are the best way to place components. A microscope has a very small field of view and you can easily get lost or forget where your hands are and stick them into the paste or brush components off the board. The magnifying light allows you to see the entire board.
- On two-sided boards use SMT adhesive to glue the larger parts to the PCB so they won't fall off while you reflow the other side of the board. You'll need a variety of applicator nozzles depending on what you're doing. Be very careful not to let the adhesive flow onto a pad and interfere with the joint.
- Kit up the parts you'll need for one side using ESD kitting trays before you apply the paste. You'll need to work quickly so the paste doesn't dry out.
- Reflow the side with the least number of heavy parts first to minimize problems when doing the other side.
- You'll need to make a board holder that allows clearance for the parts on the side you reflowed first when applying paste to the second side.
- You'll also need to find a way to support the board while it's in the oven so that you don't scrape the parts off the bottom while you reflow the second side.

- Always use an ESD work bench and wear an ESD wrist strap. Both should be connected to full-time monitors.
- Don't forget that the PCB and the components installed on the first side that have a high MSL number need to be kept from absorbing moisture until after the second side is reflowed. That means that the PCB needs to be kept in a sealed low humidity environment after reflowing the first side. If necessary the PCB with one side reflowed may need to be baked prior to reflowing the second side.

Documentation:

- Create a construction process document and then use it to guide you through the prototype, non-flight, and flight production runs. Modify it as you gain experience. The goal is to produce non-flight hardware that can be tested to the extremes of survivability and beyond and then know that if those boards do well you can reproduce them exactly for the flight hardware. The flight boards should only be tested enough to ensure that they are fully functional and reliable, but without causing any stress that might shorten their life. The only way to ensure that the flight hardware is exactly the same as the non-flight hardware is to follow the exact same process to the smallest detail.

16. Last Words

It's very hard to stop writing since this project is very much in motion. I learn something new almost every day and I want to include it here. I think the thread that seems to run through this entire presentation is CTE mismatch. It affects every aspect of the Receiver design and impacts the enclosure too. The other big worry is the use of commercial PEMs. Unfortunately they are becoming a fact of life that everyone must learn to deal with. I urge you to follow the links in the reference section and use them as a spring board to the world of zero-defect SMT manufacture.

73,

Juan – WA6HTP

References:

[1] IPC-A-610D, February 2005, *Acceptability of Electronic Assemblies*, IPC

[2] *Plastic Encapsulated Microcircuits (PEM)*, WA6HTP
http://www.juanr.com/pages/hobbies/ham_radio/pem_bok.pdf

[3] *Instructions for Plastic Encapsulated Microcircuits (PEM) Selection, Screening, and Qualification*, NASA EEE-INST-001
http://www.sonoscan.com/images/PEM-INST-001_June_03_Final.pdf

[4] *The Case for Plastic-Encapsulated Microcircuits in Spaceflight Applications*, Johns Hopkins APL Technical Digest, Volume 20, Number 1 (1999)
http://www.jhuapl.edu/techdigest/td2001/Moor.pdf

[5] *AVX Surface Mount Ceramic Capacitor Products, Surface Mount Guide*, pp. 89-92.
http://www.avxcorp.com/docs/masterpubs/smccp.pdf

[6] *Surface Mount Zero Defect Design Check List*, AVX Corporation
http://www.avxcorp.com/docs/techinfo/smzero.pdf

See also *Assembly Induced Defects*, AVX Corporation
http://www.avxcorp.com/docs/techinfo/assembly.pdf

[7] *Tin Whiskers- The Hidden Time Bomb*, WA6HTP
http://www.juanr.com/pages/hobbies/ham_radio/tw-bok.pdf

[8] *AMSAT Eagle 70 cm Receiver Acceptance Test Procedure*, rev c, 4-28-07, WA6HTP
http://www.amsat.org/amsat-new/eagle/EaglePedia/uploads/c/ca/70cm_RX_ATP.pdf

[9] *Design Loop Filters For PLL Frequency Synthesizers*, Microwaves & RF, Sept. 1999
http://www.mwrf.com/Globals/PlanetEE/dsp_article.cfm?ArticleID=9850&Extension=html

Electronic Scanning Antennas for Amateur Spacecraft

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ABSTRACT: Upcoming amateur spacecraft in high earth orbit (HEO) will require antennas with significant gain in order to provide useful signals to users on the ground. In the past, satellites like AO-40 used gain antennas fixed rigidly to the spacecraft. As a result, antenna gain was lost when the spacecraft body was not pointed in the optimum direction. This loss might be minimized if it were possible to either employ a 3-axis stabilized spacecraft, or if the antenna were to be mounted on a movable, mechanical gimbal.

We regard both of these mechanical pointing options as being too complicated for amateur spacecraft. Instead, in this paper we will consider the possibilities for using an electronically pointed antenna – a phased array.

1. HOW MUCH ANTENNA GAIN IS NEEDED? HOW BIG ARE THE ANTENNAS?

For simplicity, let us assume that our satellite is at geostationary altitude ~35,800 km. The radius of the earth is ~6,400 km. Therefore we have this geometry in figure 1:

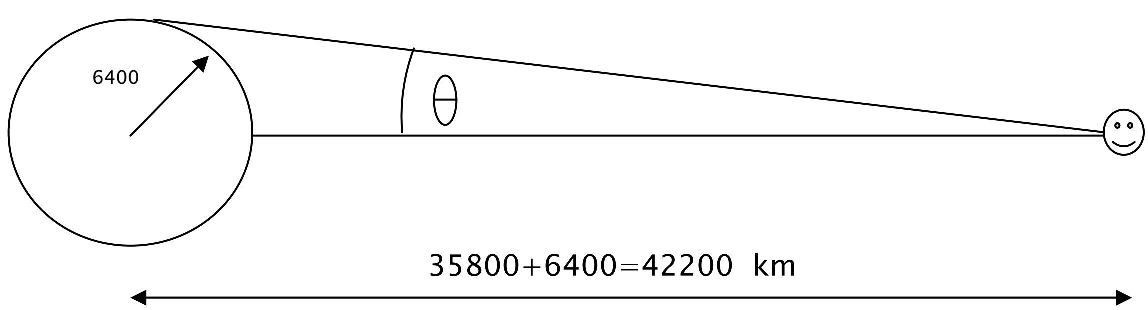


Figure 1: Earth – Satellite Geometry

The angle Θ will then be $\left[\frac{6400}{35800+6400}\right]$ = 0.152 radians = 8.7°.

The solid angle $\boldsymbol{\Omega}$ that is subtended by the earth (as seen from the satellite) is a disk with an area of

$$\boldsymbol{\Omega} = \pi\boldsymbol{\Theta}^2 = 0.0726 \text{ steradians.}$$

From this solid angle $\boldsymbol{\Omega}$ we determine that, from this altitude, in order to have the earth just fill the antenna beam, we require an antenna directivity D of

$$\mathrm{D} = \left[\frac{4\pi}{\boldsymbol{\Omega}}\right] = \text{ a factor of } 173.1 = 22.4 \text{ dBi}$$

For the purpose of these calculations, we have assumed that the antenna pattern is uniform disk the disk of the earth. With this simplifying assumption, if the antenna were to have less directivity than 22.4 dBi, then part of the spacecraft's valuable transmitter power will be wasted as it is lost around the edge of the earth. If the gain was any larger, then some users on the earth would not have satellite access. No practical antenna has the ideal uniform disk pattern, and we will see the $\mathcal{R}$eal-world directivity reduced by a factor $\mathcal{R}$. Also in the real-world, we will see an antenna efficiency η less than 100% due to ohmic losses, phasing errors, etcetera. The real-world antenna gain is given by $G = \eta \cdot \mathcal{R}D$. For the antennas we will use on our spacecraft, I hope we will achieve $\eta \cdot \mathcal{R} \sim 50\%$ (i.e. less ~3 dB of losses).

Now we compute just how big the antennas must be. The directivity D of an antenna is related to an antenna's collecting area A by the equation $\boldsymbol{D} = \left[\frac{4\,\pi A}{\lambda^2}\right]$.

Considering the five "practical" microwave satellite bands:

Frequency	Wavelength λ	Collecting Area for D=22.4 dBi	Characteristic Size = $\sqrt{A}$	Equivalent Dish Diameter
L = 1.27 GHz	23.6 cm	7672 cm²	87.6 cm	112 cm
S1= 2.4 GHz	12.5 cm	2152 cm²	46.4 cm	59.1 cm
S2 = 3.4 GHz	**8.82 cm**	**1072 cm²**	**32.7 cm**	**41.6 cm**
C = 5.7 GHz	**5.26 cm**	**381 cm²**	**19.5 cm**	**24.8 cm**
X = 10.5 GHz	2.86 cm	113 cm²	10.6 cm	13.5 cm

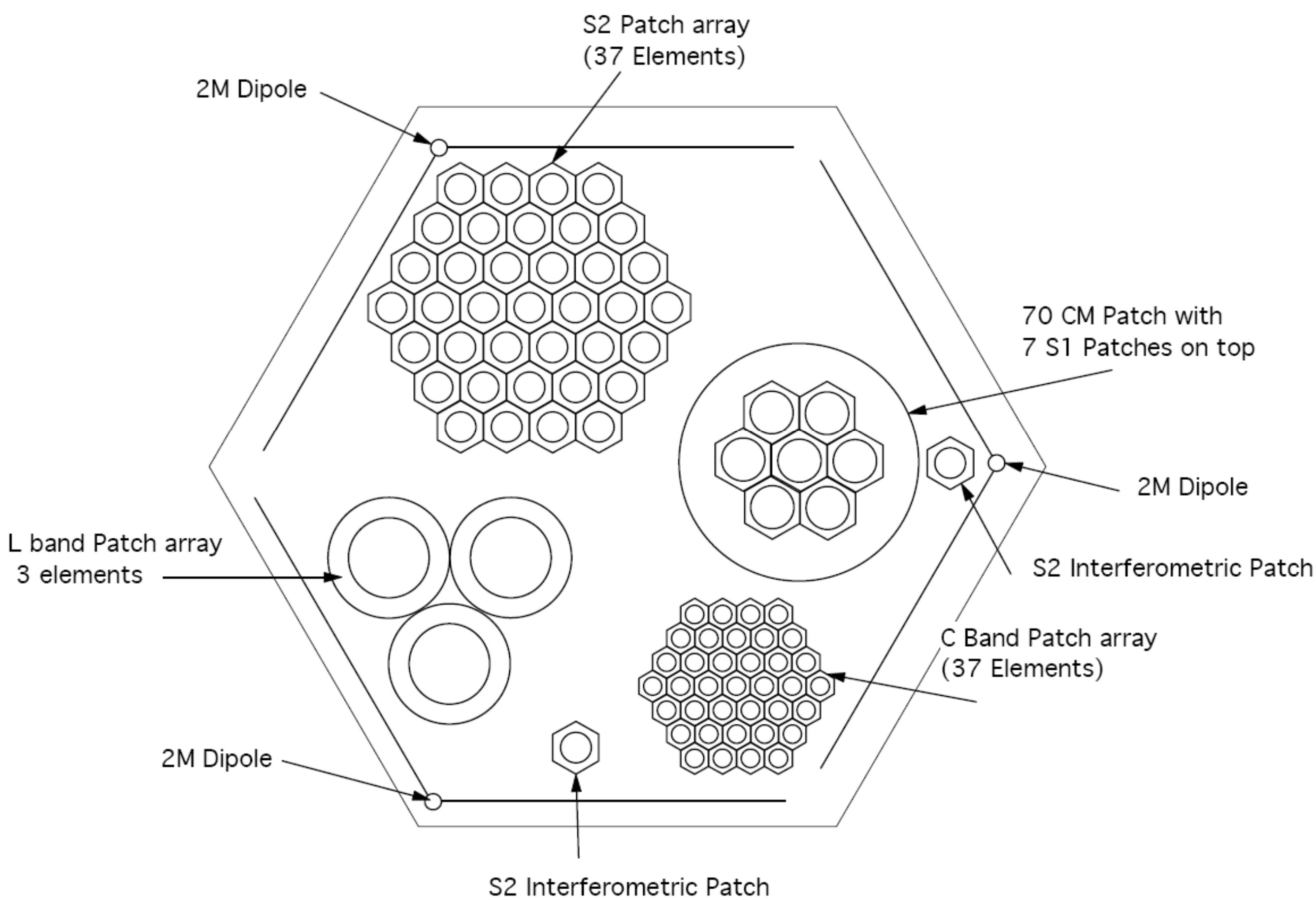
Table 1: 22.4 dBi Antenna Sizes for Microwave Frequencies

In this table, the characteristic size $\sqrt{A}$ is presented to provide an order-of-magnitude estimate of the size of the antenna needed to obtain a beam that is the size of the earth. If a dish were to be used, the dish diameter would be a factor of $4/\pi$ larger than $\sqrt{A}$.

The current baseline design for EAGLE is a hexagonal structure 60 cm on a side. Full sized, 22.4 dBi antennas for L and S1 are deemed to be too large for this size structure. The possibility of an X-band payload is still under discussion. The rest of this paper will concentrate on possible phased arrays for S2 and C-band. For both EAGLE and a possible geostationary Phase-4 mission, one of these bands will be used as a (receive) uplink, and the other will be used for a (transmit) downlink. We will concentrate on the transmitting case, but all the principles can be easily extended to the receive case.

Figure 2 (courtesy W5DID) shows one possible arrangement for the “antenna farm” on EAGLE’s 60 cm hexagon. In this case, S2 is assumed to be used for receive, and C is the transmit downlink. The S2 “Interferometric Patches” enable the satellite to accurately measure its own attitude.

Figure 2 -- A possible "antenna farm" for EAGLE



2. <u>ISN’T A PHASED ARRAY A SERIOUS COMPLICATION THAT WILL COMPROMISE RELIABILITY?</u>

I hope that I can convince the AMSAT community that the use of a phased array at microwave frequencies makes a lot of sense. We have computed link budgets for microwave payloads with a bandwidth of a few hundred kHz, and have found that the spacecraft will need a transmitter with a power output of about 30-50 watts, coupled with an antenna gain ~20 dBi (i.e. an EIRP of 3-5 kW) assuming that the target users are using ~1 meter dishes on the ground. Any less radiated power will require the user to have a bigger antenna and/or sacrifice usable bandwidth.

A reliable, high efficiency microwave power amplifier can certainly be constructed, but it would push the state-of-the-art. It would probably be made of a number of lower power modules that are phased together. An amplifier of this type would likely constitute a vulnerable single point-of-failure that compromises reliability. Valuable power would be wasted in the transmission line(s) carrying RF to the antenna(s).

The design with a phased array antenna would be very different. A number (let's say 40) of one- watt power amplifiers are distributed with one amplifier at each small element of a phased array. The amplifiers would connect directly to the antenna element, minimizing transmission line losses. It can be shown that the failure of a few isolated power amplifiers cause a gentle (non-catastrophic) degradation of array performance. Some of the elements could be intentionally turned off to help conserve power if needed.

The EAGLE spacecraft will be spin stabilized. Throughout much of the orbit, the spin axis will not point directly at the earth. With AO-40, the dropoff of the antenna pattern away from MA=128 (apogee) limited performance. In all our EAGLE design discussions, we have tried to preserve performance for off-pointing angles of ±30° (and even hopefully as much as ±45°). We have rejected any notion of mechanically pointing a dish as being well outside our capabilities (AMSAT does much better moving electrons than it does moving metal!).

3. WON'T POINTING A PHASED ARRAY REQUIRE A HUGE COMPUTER? AND WHAT IS ALL THIS INTERFEROMETER STUFF ANYWAY?

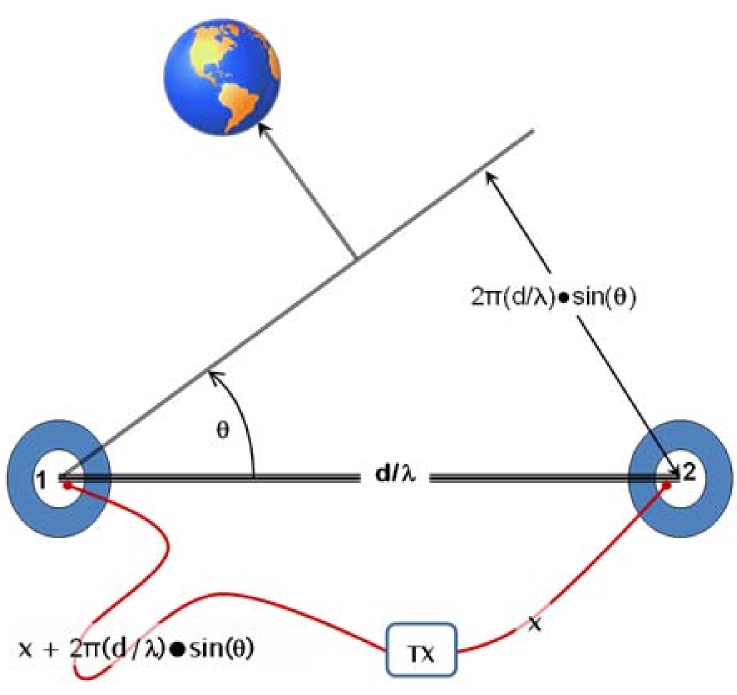


Figure 3 – A simple two element interferometer

The "root" of any phased array is the 2-element interferometer as depicted in Figure 3. We show two small antenna elements that are separated by a spacing **d** on the top of the spacecraft; we show the earth offset by an angle **Θ** from broadside (note that the angle **Θ** is the off-pointing angle we all learned about with AO-40). In order for the signal to reach antenna #2, the signal has been gone thru an extra path length of **[d·sin(θ)]** relative to antenna #1, We need to express this in units of wavelengths, so the baseline length is d/λ and the excess path delay is $[(d/\lambda)\cdot\sin(\theta)]$.

If we want our transmitter to "beam" towards the earth, then the signal to element #1 must be delayed by a inserting a phase delay of $[(2\pi d/\lambda)\cdot\sin(\theta)]$ radians in the cable feeding element #1.

If we made the baseline **d** be twice as long (or if we doubled the frequency), then the required phase shift would twice as big since d/λ has doubled. In all the following discussions, remember that phase shifts are periodic at intervals of $2\pi = 360°$, so a phase shift of 750° is precisely the same a phase shift of 390° or 30° or −330°.

Now we move the platform so that the angle θ changes. In the far-field, signals from the two elements alternately add (in-phase) and then cancel (out-of-phase) following a pattern of the form:

$$V(\theta) = \cos\left[\,(2\pi d/\lambda)\cdot\sin(\theta) + \phi\,\right] \qquad (1)$$

where ϕ is a constant phase offset that accounts for instrumental effects, cable lengths, etc.

Whenever the two elements of an interferometer are separated more than one wavelength ($d/\lambda > 1$), then the sky will be filled with multiple lobes which are usually called "fringes".

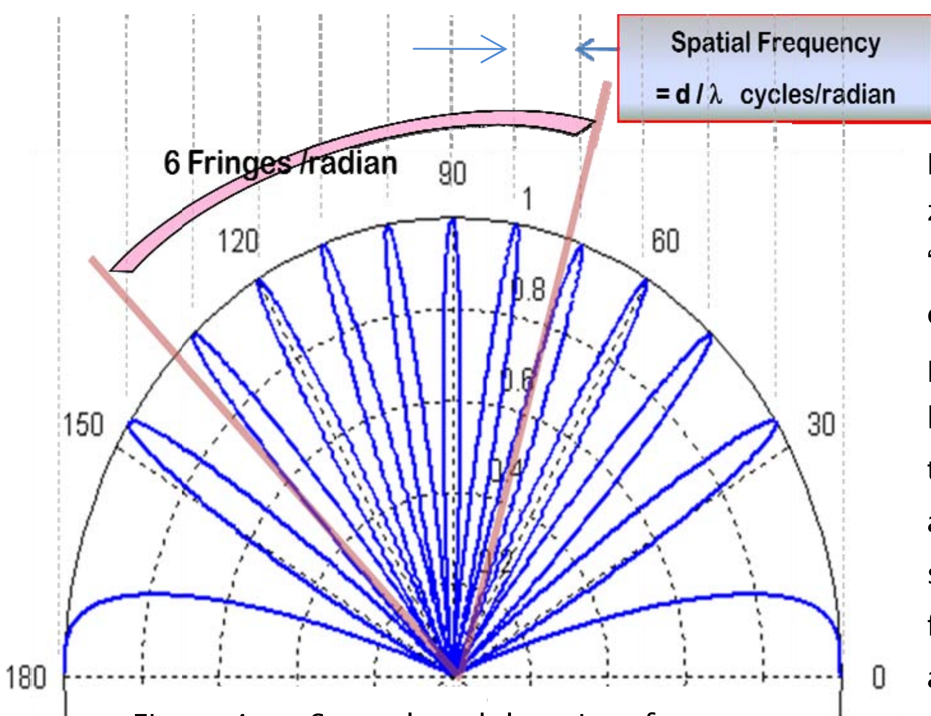


Figure 4 – a 6 wavelength long interferometer with isotropic elements

Figure 4 shows the pattern of a pair of isotropic elements spaced $d=6\lambda$. The phase offset ϕ has been set to zero when the array is "broadside" (at 90° elevation equivalent to $\theta = 0°$ off-pointing angle) so the central lobe points straight up. Since the elements have been assumed to be isotropic, the signals also add up to yield a full amplitude "endfire" beam at the horizon.

If the elements had a pattern more typical of a dipole (or patch) antenna low over a ground screen, then the pattern on the sky drops to zero at the horizon. In Figure 5 we show the case for d=10λ (therefore, we see 10 fringes/radian). Since the dipole has a null at the horizon, the response of the interferometer consists of a “fan” of fringes centered overhead in the zenith and very little sensitivity below about 30° elevation.

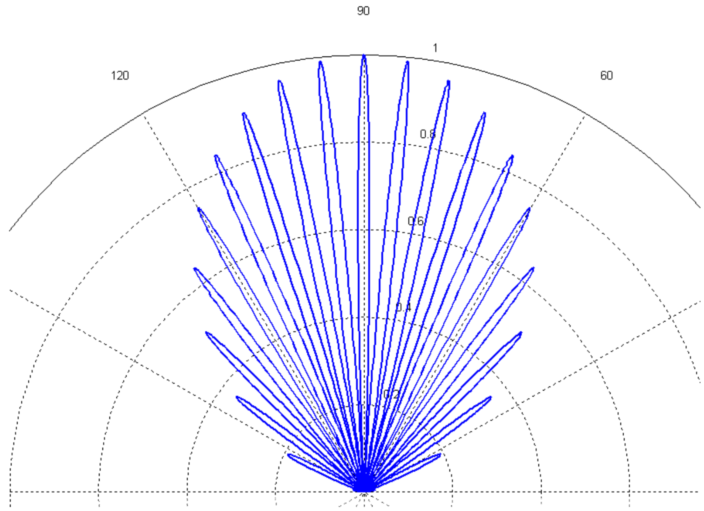


Figure 5 – a 10 wavelength long interferometer with dipole elements. Since d=10λ, there are 10 fringes/radian.

Another important interferometric concept to understand is that of ***Spatial Frequency***. When receiving, an interferometer of size d/λ responds to objects that have a spatial structure with a size of size smaller than λ/d radians. Whenever a source is bigger than ~λ/2d radians, the amplitude of the signal made by the source decreases and the source is said to have been ***resolved***.

4. A One-dimensional Phased Array:

The simplest multi-element array consists of a number (let’s pick 8 for this example) of identical elements arranged as a straight line. To simplify the discussion, let’s assume that adjacent elements are spaced by a distance **d**/λ as we see in Figure 6:

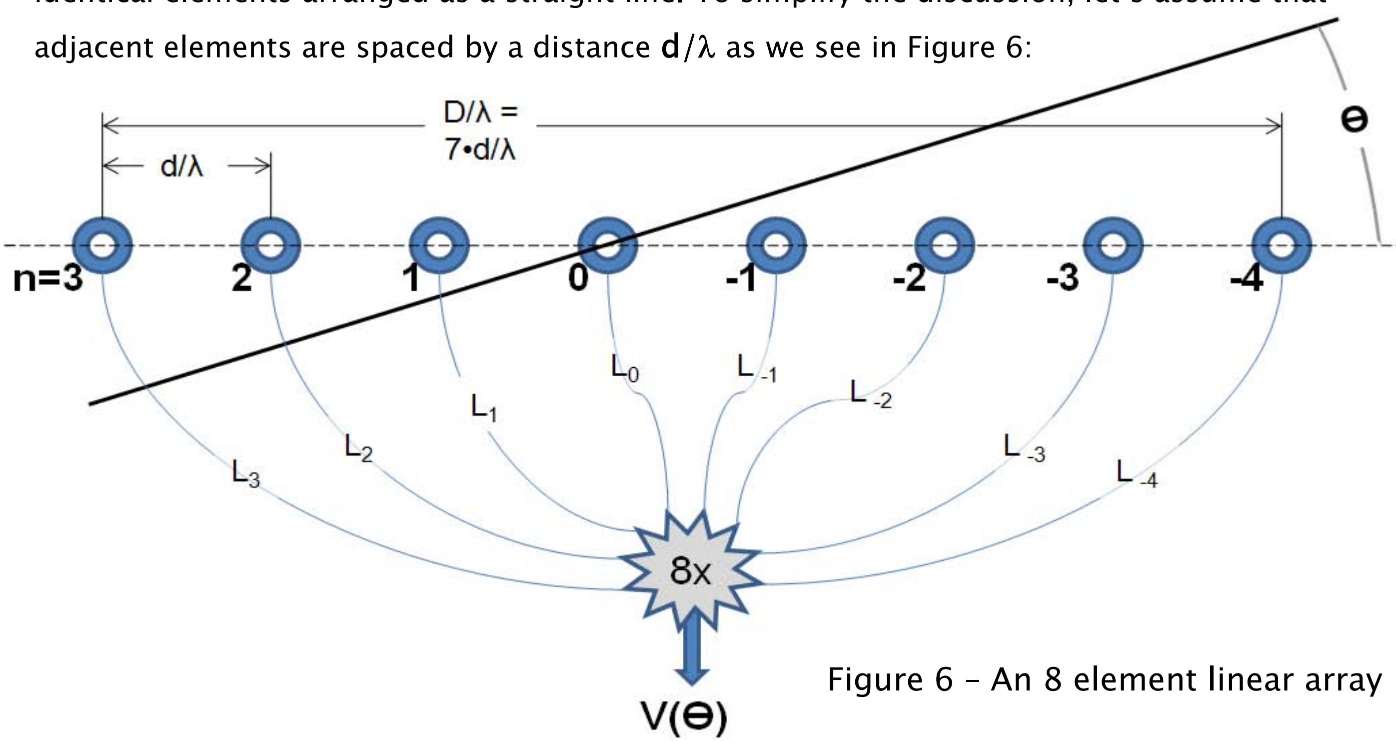


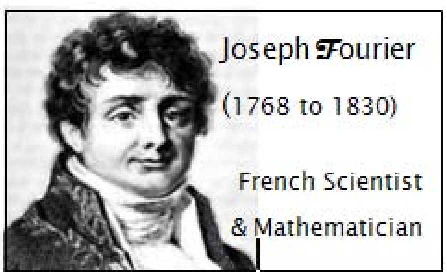
Figure 6 – An 8 element linear array

Again, we assume the same geometry as the 2-element case, with the target at an angle Θ with respect to the baseline. In order to phase all 8 elements together, each element **n** must have a phase shift with respect to element **n-1** of $\left[\frac{2\pi d}{\lambda} \cdot \sin(\theta)\right]$ radians. In this figure we arbitrarily made element **n=0** be the reference element, and the length of its feed cable = L_0.

Now we sum the signals from all 8 antennas in the summing junction denoted **8x**, after making all 8 proper length cables of length $L_n = [\ \frac{2\pi d \cdot n}{\lambda} \bullet \sin(\theta) + L_0]$ for n= [-4 to 3] and where L_0 is the length of the cable feeding the reference element #0. Finally, at the output of the 8x combiner, the signal will be of the form:

$$V(\Theta) = \sum_{n=-4}^{n=3} Vn \bullet \cos\left[\frac{2\pi d \bullet n}{\lambda} \bullet \sin(\theta) + Lo\right] \tag{2}$$

5. JOSEPH 𝓕OURIER's CONTRIBUTIONS TO ANTENNA ARRAYS:



Those of you who have become adept in the arcane arts associated with the name of Joseph 𝓕ourier and spectral analysis will immediately recognize the V(Θ) equation as being a discrete 𝓕ourier transform. Normally, we think in terms of a time series V(t) vs. its spectrum V(f).

For an antenna array we find a close analogue in the Antenna Pattern V(Θ) vs. the Spatial Frequency $V(\frac{d}{\lambda})$ distribution within the antenna array itself are summarized in this table:

𝓕ourier (& his friends)	"Frequency" Domain	Time/Angle Domain
"Signal" Series	V(f)	V(t)
Spectral Components	$V(\frac{d}{\lambda})$	V(Θ)

While the simple-minded 8-element array would have worked just fine in the direction Θ, it would require us to cut a new set of phase delay lines each time we wanted to re-point the antenna. The spectrum analysis analogue would have involved building a new set of hardware just to listen to a different frequency! The SDR folks have learned that if we gulp a sizeable time series of data into the computer, we can construct many different parallel receivers by just taking a Fourier transform. The computers we have available today can present a 50-100 kHz wide spectrum in real-time and display it as a "waterfall" at the same time we are using the same hardware and data to listen to a specific signal. In addition to fast computers, this has been enabled by efficient computational algorithms like the Fast Fourier Transform (FFT). FFTs operate most efficiently when the input series has a length of 2^n samples. We can make our 8-element phased array produce all 8 independent antenna beams at the same time. In hardware, this can be implemented in a circuit called the Butler matrix:

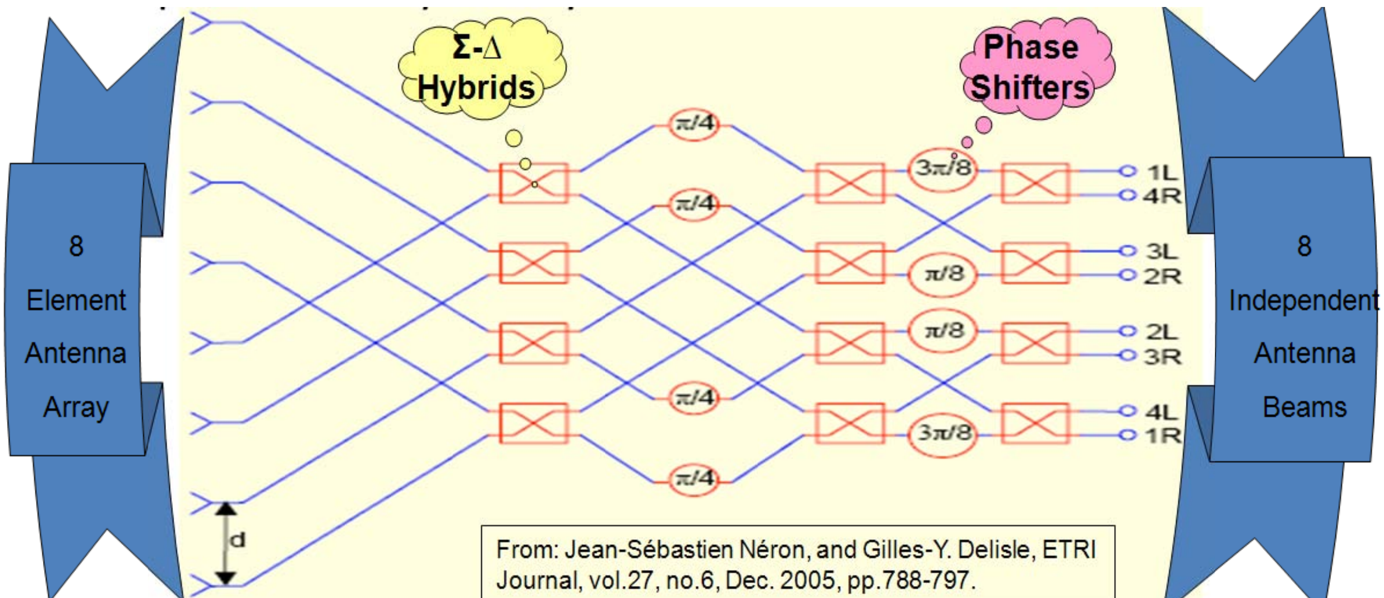


Figure 7 – The 8-Element Butler matrix is an electronic implementation of the 2^3 point Cooley-Tukey FFT algorithm to produce 2^3 independent antenna

The Butler matrix makes use of simple sum & difference (Σ-Δ) hybrid junctions and delay lines that are λ/8, λ/4 and 3λ/8 (i.e. 22½°, 45° and 67½°) in length (there is also a similar matrix that makes use of quadrature hybrids). Figure 8 shows the results of feeding an 8-element array of λ/2 dipoles, spaced λ/2 apart and λ/4 above a ground screen. The 8 antennas yields 8 beams across the sky, but beam #8 is on the horizon and is discarded.

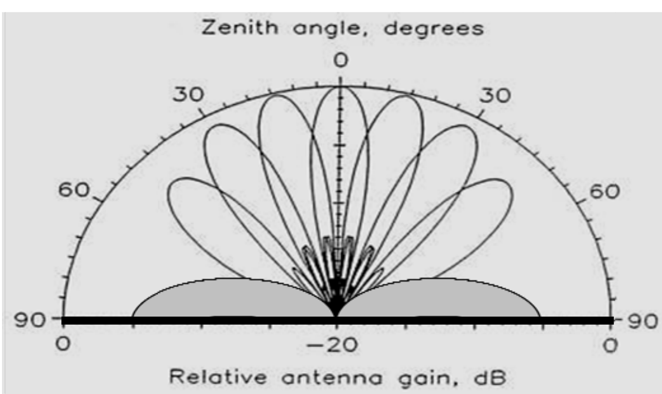


Figure 8 – The antenna pattern of an 8-element array of dipoles combined in a Butler matrix.

This 8-element linear array is a part of a 38 MHz two-dimensional 8x8 array known as SHIRE (the Southern Hemisphere Imaging Riometer Experiment) at the Australian DAVIS station in Antarctica. More details on SHIRE can be found on the web at http://www.ips.gov.au/World_Data_Centre/1/6/2.

6. An Aside – RIOMETERS and Radio Astronomy:

I digress to define the term RIOmeter and describe how it works: a Relative Ionospheric Opacity **meter** is a high stability radio telescope operating at HF frequencies (38 MHz in the case of SHIRE) that observes the cosmic background radio noise. At HF and low VHF frequencies, sky noise comes mainly from galactic cosmic ray electrons spiraling in the interstellar magnetic field, and creating synchrotron radiation. In the 10-100 MHz range we see sky brightness temperatures ranging from 10^5 to10^7 °K. This signal was first detected in 1932 at 20.5 MHz by Karl Jansky at Bell Labs. He found excess "static" with a daily signature that repeated the sidereal rate of 23^h56^m, and reached a peak when the constellations from Sagittarius to Cygnus (the Milky Way) were high in the sky. Astronomers have honored Karl Jansky for his discovery by naming the basic unit of power flux density for him (1 Jansky = 1 **Jy** = 10^{-26} w m^{-2} Hz^{-1}).

Figure 9

The first real study of the galactic cosmic radio noise was done by Grote Reber (W9FGZ) who built a 31.4ft (10m) fully steerable dish antenna in his backyard in Wheaton, Illinois. Grote built a successful receiver from scratch at 160 MHz – which is even more amazing when you realize that it was done during WW2! He is credited with the first scientific publication on radio astronomy ("*Cosmic Static*", in the Astrophysical Journal, Vol.100, page 279, 1944). You can learn more about the early days of radio astronomy on the web at `http://www.cv.nrao.edu/course/astr534/Discovery.html` and at `http://www.nrao.edu/whatisra/hist_reber.shtml`. You can visit both the Jansky and Reber radiotelescopes as reconstructed at NRAO's facility in Greenbank, WV.

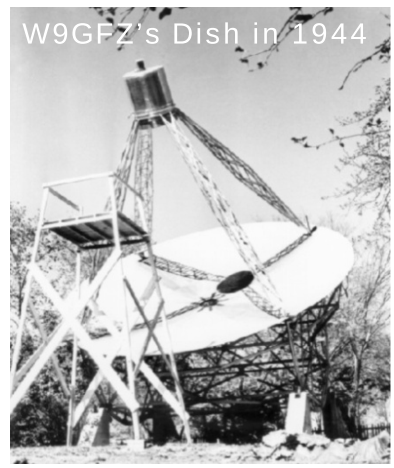


Figure 10

Returning to how a RIOmeter works -- When a solar flare occurs, it causes an increase ionization in the D-region which in turn increases the absorption and the cosmic signal decreases. This change can easily be seen by superimposing a chart of background noise from an undisturbed "quiet" day with one from a day when a major solar flare occurred. You can learn more about RIOmeters at `http://www.spacenv.com/~rice/riometer/USU/UnderstandingRiometers.htm`

7. TWO-DIMENSIONAL ANTENNA ARRAYS:

All the array concepts we have developed so far can be extended to two-dimensional arrays. Continuing our use of the Antarctic SHIRE array as an example; SHIRE is an 8x8 array of crossed diploes phased to generate both senses of circular polarization. At 38.5 MHz, the λ/2 dipoles are spaced end-to-end at a λ/2 = 3.9m spacing. The dipoles are λ/4 = 2m above a wire mesh ground screen. The ground screen is elevated about 1.5m above the local snow & ice.

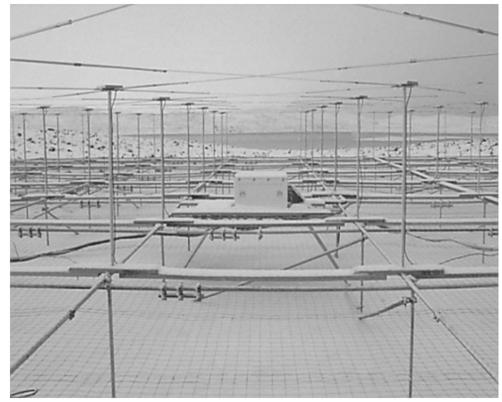


Figure 11 -Dipoles in the SHIRE array

The 8x8 dipoles feed 64 equal length transmission lines, which in turn are fed into a bank of eight rows of the 8-port Butler matrix combiners described earlier. 7 of the 8 output ports from the first bank of combiners are fan beams that look like Fig. 8; the 8th port contains the horizon beam and is discarded in a terminating resistor.

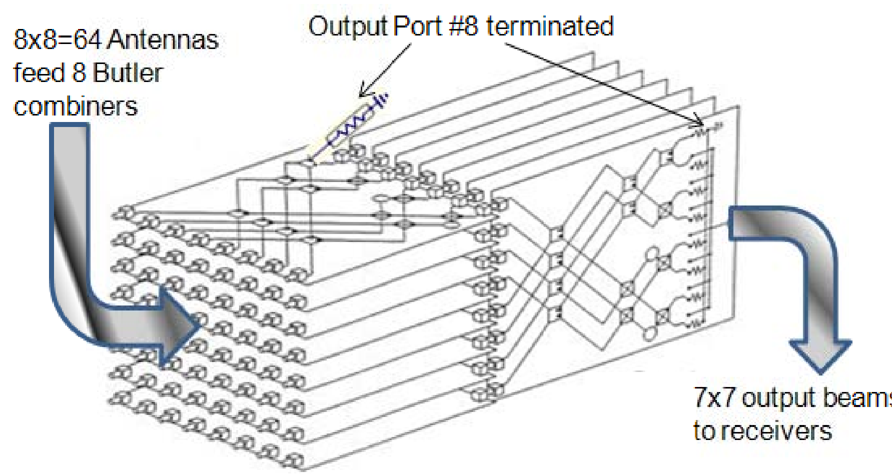


Figure 12 - 8x8 and 7x8 Butler combiners generate SHIRE's 7x7 array of pencil beams

The row outputs from the 8 fan beam combiners now feed a second bank with 7 columns of 8-port combiners. From this, SHIRE then extracts 7x7 individual spot beams (again, after discarding the 8th output) from the combiner. All these Butler combiners really are is a (very complicated!) way to take a 2-dimensional, 8x8 Fourier transform in hardware.

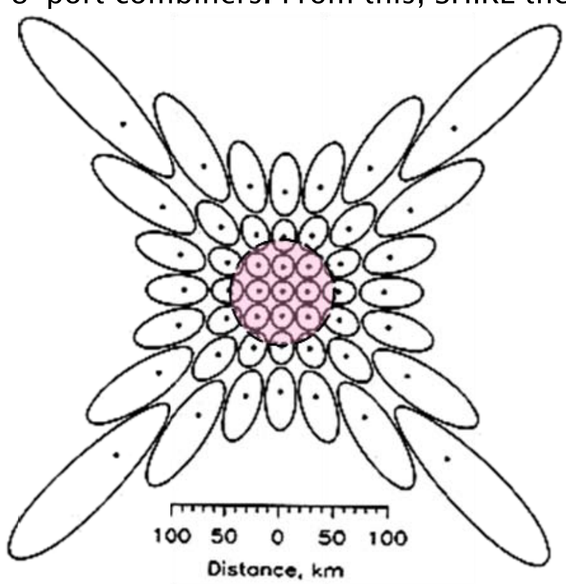


Figure 13 - 3 dB contours of SHIRE's 7x7 array of pencil beams as seen at 90 km

Putting all these bits and pieces together, Figure 13 shows the projection of the -3dB contours of all 49 simultaneous SHIRE beams onto the ionosphere at 90km altitude. The point of maximum sensitivity of each beam is indicated by a dot. The shaded circle in the centre represents the nominal (-3dB) beam of a conventional broad-beam RIOmeter antenna.

8. LET'S LOOK AT SOME POSSIBLE SPACECRAFT ANTENNAS

Since I began thinking about using a phased array antenna for CC-Rider and then Eagle, I've pondered many different possible array geometries. In Table 1 we saw that to achieve the desired ~22.4 dBi gain, we need an aperture in the 33-42 cm size range (depending on the geometry chosen) for S2 (λ=8.8 cm) or 20-25 cm for C-band (λ=5.3 cm). I now favor the use of a λ/2 circularly polarized patch about 0.15λ above the "ground plane".

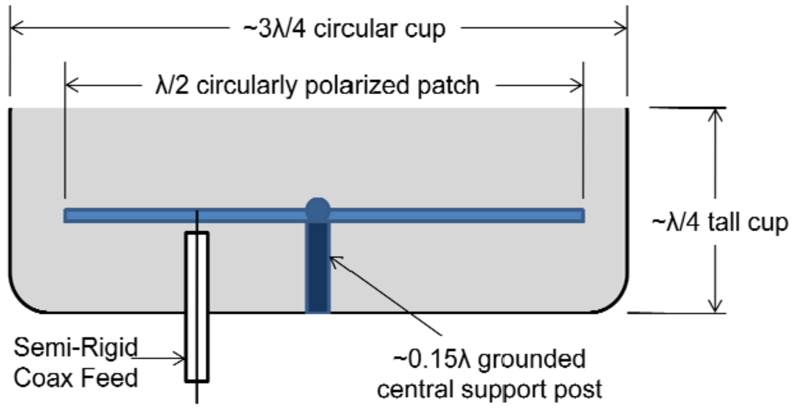


Figure 14 – A sketch of the possible geometry for the individual array elements

The patch would be centered inside a cylindrical cup with ~0.7 λ inside diameter; this size will allow adjacent elements to be spaced 3λ/4. The cup is λ/4 tall and forms a "choke ring" to improve the isolation between adjacent elements, to increase the gain of the individual elements, and to minimize the waste of power radiated towards the horizon.

With ~40 elements properly spaced, the array will provide a gain of x =16 dBi; to this is added the gain by the individual array elements. A patch antenna 0.1-0.2λ above a ground plane should provide an additional ~ 6-7 dBi of gain, so we can reach the desired total of ~22.4 dBi.

There are a lot of geometries that will squeeze about 40 elements into the physical area described in Table 1. In order to visualize the element "packing" I used a simple graphical modeling scheme. I went to the local car wash and got $11 in the form of 44 quarters. I used a quarter to denote the size (24mm) of the 3λ/4 cup seen above. The quarters provide a scale of 0.4:1 (at C-band) to 0.28:1 (at S2). The quarters were then arranged on the glass of a flat bed scanner, resulting in these photos & comments:

Figure 15a: n=36, 6x6 element square array, costing $9.00

*This geometry looks good, but it would be **very** complicated to implement two dimensional phasing.*

Figure 15b: n=37 element hexagonal array, costing $9.25

The hexagonal arrangement packs the maximum number of elements into the minimum possible space. I have not been able to devise a simple 2-D feed scheme.

Figure 15c: n=43 element extended hexagonal array, costing $10.75

This is the same as 15b, except that 6 more elements have been added around the edge.

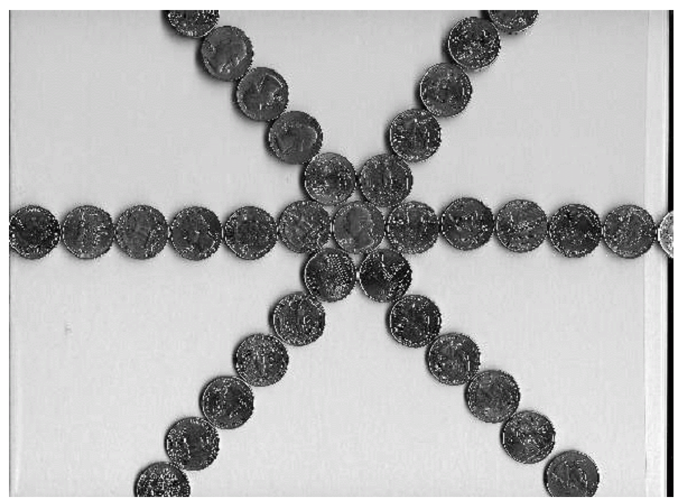


Figure 15d: n=37 element, 6-armed star, costing $9.25

This arrangement will have higher sidelobes than desired because it is too loosely packed. It makes very inefficient use of the required real estate. However, as we describe in section xx, it is the easiest to feed because the elements are equally spaced along a straight line.

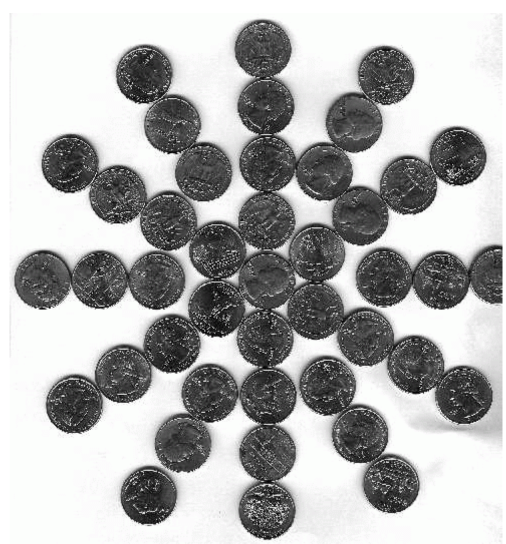


Figure 15e: n=43 element, 12-armed star, costing $10.75

This arrangement results in a more compact geometry than in 15d above, improving the sidelobe levels. The elements are also equally spaced on straight lines, making it quite easy to feed, as described in section xx. ***This geometry is my favorite.***

Table 2. Summarizing the parameters & array geometries that have been studied

Parameter	S2 (λ=88 mm)	C (λ=53 mm)	$0.25 coins (24mm diameter)
Required Array Real Estate = 3.75 – 5 λ in size (depending on shape)	330 – 440 mm	200 – 260 mm	n = 36 to 43 costing me $9.00 -- $10.75
λ/2 Patch Diameter	44 mm	26 mm	--
λ/4 Cup Height	22 mm	13 mm	--
3λ/4 Cup Spacing	66 mm	40 mm	24 mm
0.15 λ Central Support Post	13 mm	8 mm	--
15a: 6x6 Element Square	396 x 396 mm	240 x 240 mm	$9.00
15b: n=37 Hexagon	~460 mm diameter	~280 mm diameter	$9.25
15c: n=43, Extended Hex	~500 mm diameter	~305 mm diameter	$10.75
15d: n=37, 6-armed Star	~860 mm diameter	~520 mm diameter	$9.25
15e: n=43, 12-armed Star	~595 mm diameter	~360 mm diameter	$10.75
"Perfect" Dish (η=100%)	415 mm diameter	250 mm diameter	--

9. NOW LET'S DISCUSS SOME WAYS TO PHASE THESE VARIOUS ARRAYS

Case 15a: The 6x6 Element Square array is a scaled down version of the 8x8 SHIRE array. As we saw in Figure 7, each of the Butler combiners has twelve Σ-Δ hybrid junctions. To form all the 49 beams, SHIRE requires a total of 15 Butler widgets, with a total of 180 hybrid junctions plus a lot of coax delay lines. If we tried to directly phase the array at S2 or C band, the losses in these networks would rapidly eat the entire spacecraft's power budget. Of course, the phasing could be done at a lower IF and reduce signal losses, but the combiner is still complex – much, much too complex for AMSAT's spacecraft!

We might phase the array using digitally switched delay lines at each element. Manufacturers like Hittite (http://hittite.com) make chip-level programmable delay lines (like the HMC649) that are usable from 3 to 6 GHz. On the downside, these devices waste some 80-

90% (6.5-9 dB loss) of input RF power in accomplishing the phasing. We might be able to use these devices, but it would require a lot of R&D in order to come to fruition.

Cases 15b & 15c: Hexagonal arrays are mathematically beautiful as well as being very functional for honey bees. Hexagonal packing results in the maximum possible cell density. Unfortunately, I have not been able to conjure a simple phasing structure that achieves 2-D pointing, short of using switched delay lines like those from Hittite. As with the previous case, a lot of R&D is needed to make use of a hexagonal array.

Cases 15d & 15e: These "star" structures have a pair of most useful properties: All the elements lie on straight lines and are equally spaced. In section 4 we saw that this type of structure can be phased by generating a uniform phase gradient with a phase difference of $\Delta = [\frac{2\pi d}{\lambda} \cdot \sin(\theta)]$ between adjacent elements. If we could build a delay line tapped at uniform intervals L such that the desired phase gradient $\Delta = 2\pi L/\lambda$ (ignoring any 2π ambiguities), we are getting close. All we have to do is to come up with some way to make the tapped delay line out of rubber!

Figure 16 shows the conceptual design of a way to implement this for a microwave digital (BPSK) transmitter. We show a 7-element linear array. A long piece of coax is tapped at 7 uniformly spaced points with a length L between the taps. The cable is driven at one end by a VHF oscillator locked to the spacecraft's master oscillator and the "far" end is terminated to minimize reflections; DC blocks permit the cable to carry a DC bias.

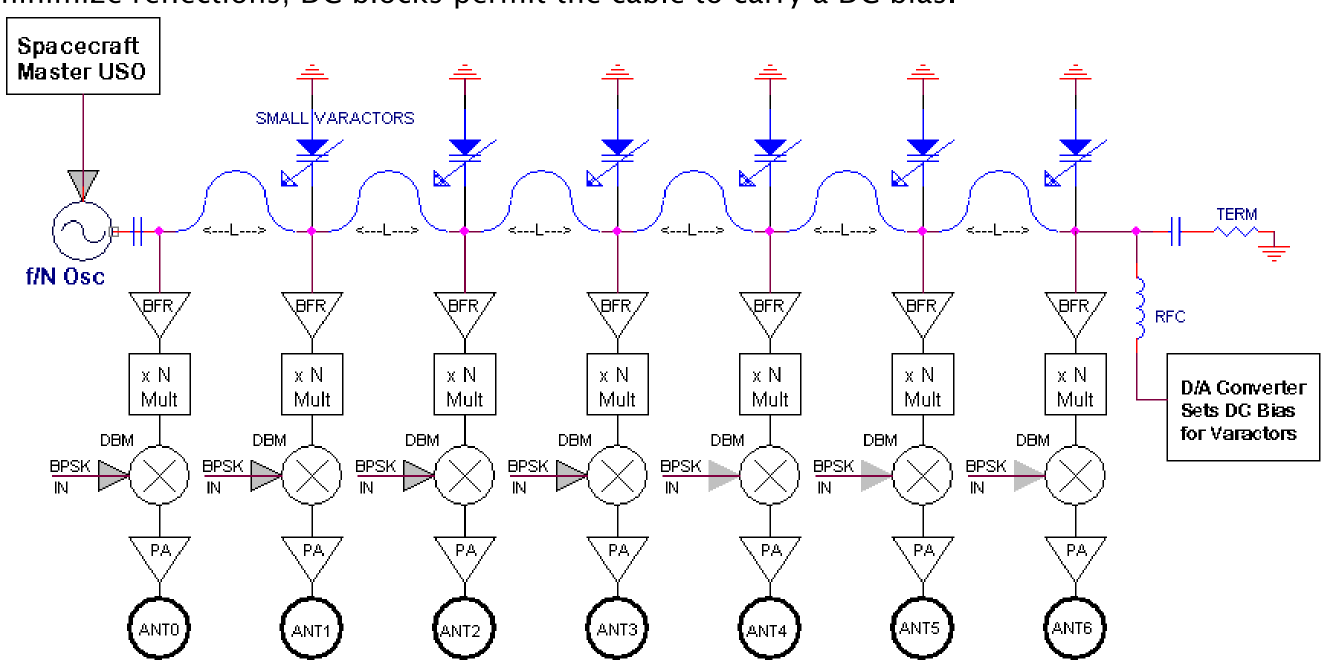


Figure 16 – The "Rubberized" delay line concept

The frequency of the VHF oscillator is been chosen to be at a convenient N^{th} sub-multiple of the final desired transmitter frequency f_{TX}. A small amount of f_{TX}/N VHF RF is tapped (lightly, to minimize reflections on the coax) at each of the taps on the delay line; the tapped signal is amplified and multiplied by N (the x N multiplier might well be implement as a PLL with a microwave oscillator and an f_{TX}/N divider). Finally, this signal (at the desired microwave frequency) drives a double-balanced mixer used as a BPSK modulator and is amplified in a high efficiency, hard limiting power amplifier driving a patch antenna.

Now let's "rubberize" the delay line. Figure 16 shows a small (a few pf) varactor at each of the taps. The varactor acts as a reactance modulator to cause a small additional phase shift. Between adjacent taps we then have the phase shift of the cable plus a small additional contribution β from the varactor to yield a "rubberized" phase shift $\Delta = (2\pi L/\lambda + \beta)$. The size of β is set by a DC Bias generated by the computer via a D/A converter; the D/A converter delivers no current since varactors operate as back-biased diodes. The same DC bias is sent to each of the taps of this arm of the linear array by the coaxial cable.

Since the VHF signal at each of the taps is multiplied by N to generate the output frequency, the phase shift on the coax needs be only $1/N^{th}$ of the phase shift (in radians) required to point the beam in the desired direction.

I asked for help in building a test version of the "rubberized" delay and Dan Schultz, N8FGV came through with flying colors! The critical need for the testing was a "pod" widget to mount the varactor and provide a buffered output; the "pod" schematic is shown in Figure 17.

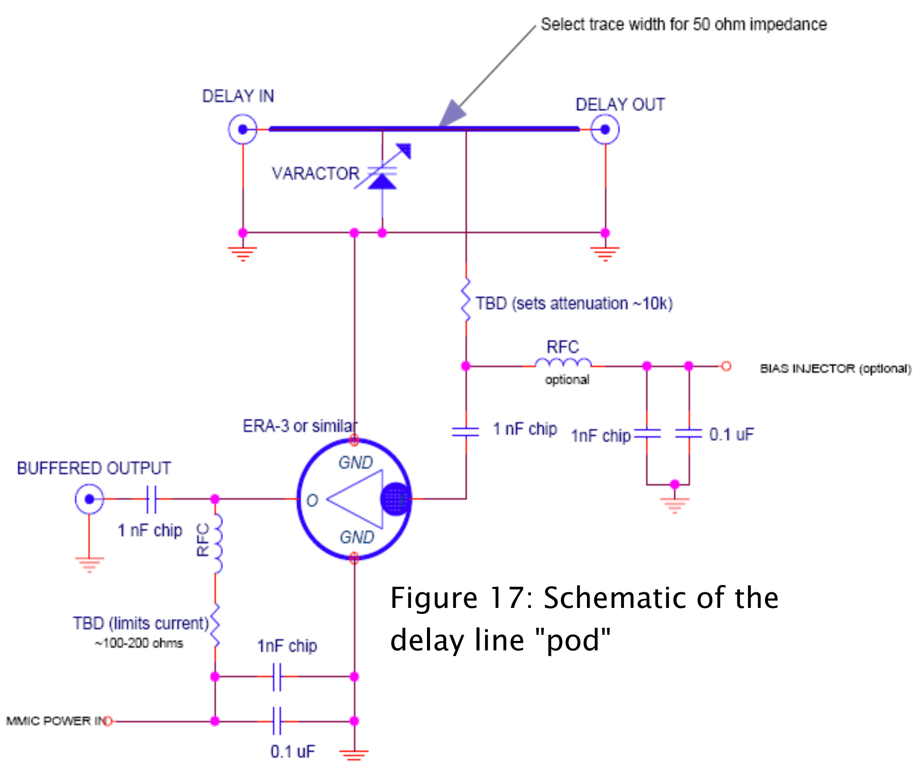


Figure 17: Schematic of the delay line "pod"

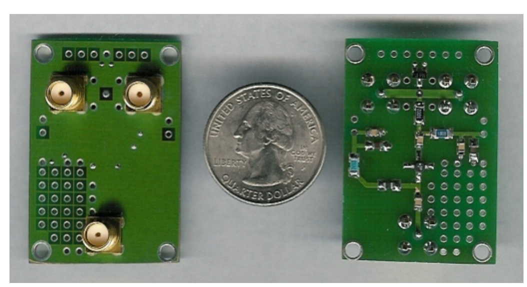


Figure 18: N8FGV's Delay Line PCB. Thanks, Dan !!

10. HOW ABOUT BANDWIDTH? DON'T WE NEED MULTIPLE DELAY LINES FOR THE BPSK MODULATING SIGNAL TOO?

The simple answer to this question is NO. Consider that we have a total signal bandwidth of B; this makes the minimum wavelength handled by the array be λ_{min}=c/(f+B/2) and the maximum be λ_{max}=c/(f-B/2). The difference in phase shift at these two extremes will be small as long as the array is small compared with the wavelength associated with the modulation bandwidth -- i.e. (array size) « $\lambda_{modulation}$ = c/B. Since the total bandwidth permitted to the amateur satellite service at C-band is 20 MHz ($\lambda_{modulation}$ = 15m), this then translates into a requirement that any C-band array must be significantly smaller than 15m – clearly the all the relevant sizes tabulated in Table 2 meet this requirement.

In the case of Radio Astronomy, arrays are called on to deliver very wide bandwidths. As an example, consider NRAO's 27-element Very Large Array (VLA) on the Plains of St. Augustine west of Socorro, NM. The 85' dish elements of the VLA are movable; at their maximum extent, the tip-to-tip extent of the array is ~40 km. The array often operates with a bandwidth of 500 MHz, so in addition to phasing the array, it is necessary to provide delay equalization to a level much better than (c/500 MHz = 60 cm).


Figure 19: The 27 element VLA in New Mexico

11. HOW ABOUT USING A PHASED ARRAY FOR RECEIVE?

Everything we have described so far is equally applicable to the receiving case. In Figure 16, we would use an f_{RX}/N VHF signal at its N^{th} harmonic to generate a Local Oscillator (LO) signal. The balanced mixer would be used to down-convert the RF signal to a convenient IF, and the power amplifier would be reversed to act as a Low-Noise amplifier (LNA). The IF signals would be summed and feed a Software-Defined Receiver (SDR) back-end. We might find it convenient to develop quadrature (I&Q) LOs with $f_{desired}$ = f_{RX} and use baseband ("zero-IF") signal processing, or we might chose to use a non-zero single channel IF f_{RX} offset from $f_{desired}$ by f_{IF}. That's an implementation design decision yet to be made.

12. AND IN CONCLUSION

While the concept may initially seem complex, the author believes that the use of microwave phased arrays actually leads to a simplification of design of a spacecraft like Eagle. Some of the reasons for making this statement are:

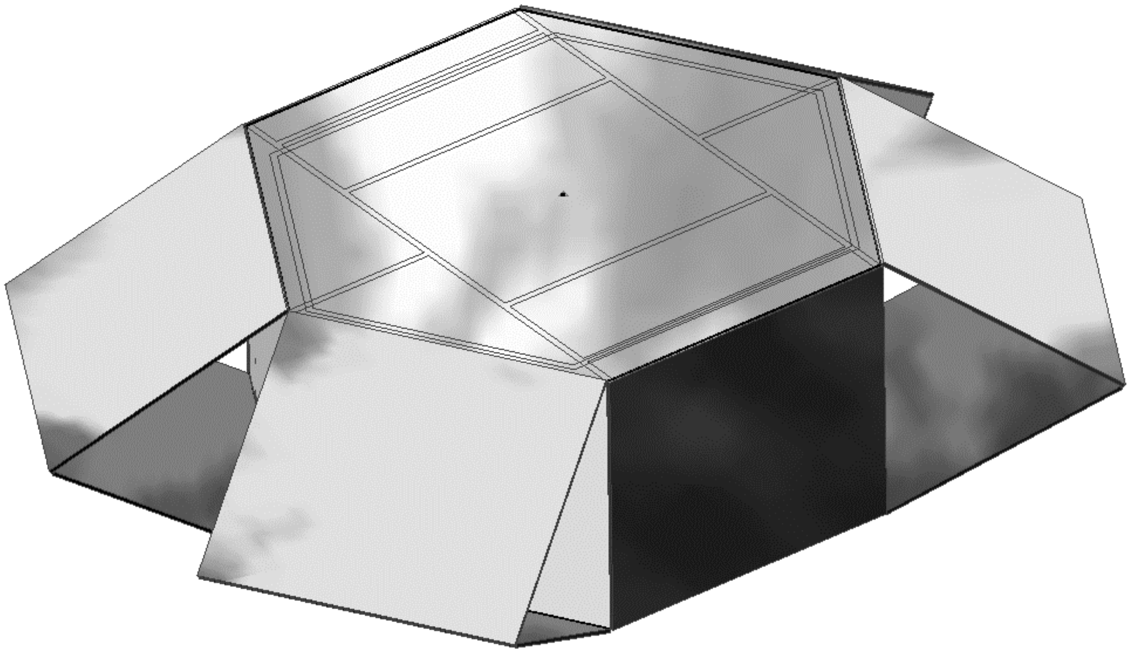
1. If no pointing is provided for a large (gain > 20 dB) antenna on a spacecraft, the beam restricts usage to a small part of a spacecraft's orbit.
2. As amateurs, we face a problem in trying to mechanically point a large antenna, either by gimballing the antenna or making the spacecraft itself be 3-axis stabilized.
3. A phased array offers the possibility of pointing a large antenna by moving electrons and not mass. This task is within the grasp of low-cost amateur technology!
4. On the transmit side, each of the N elements of an array can include a (relatively) small power amplifier. For the cases in this paper, about ~40 antennas each have a ~1 watt PA to yield ~40 watts of transmitter power.
5. With the power amplifier distributed to each antenna, the isolated failure of a few elements will do little to degrade spacecraft performance.
6. The heat loading of the PA devices is distributed across the entire array area. The individual patch antennas and their "choke ring" cups provide additional heat radiating area.
7. Individual transmitter elements could be turned off to save power and/or spread or shape the beam. Turning off ½ of the elements drops the transmit power by 3 dB and decreases the antenna gain by 3 dB, providing 6 dB of power control. A spacecraft in elliptical orbit could make use of these capabilities to further extend useful operation as the spacecraft approaches perigee.
8. We have presented a (relatively) simple phasing scheme which enables proper phasing of elements that are uniformly spaced along a line. This steering involves the use of a varactor-loaded delay line tapped at uniform intervals (figure 16). The varactors can be "tuned" with a simple D/A converter driven by the spacecraft computer. This paper describes (figure 15e) an array geometry that appears to optimize performance while minimizing complexity.
9. The same concepts can be applied to generate phase local oscillator signals for a phased receiving array.

Tom Clark, K3IO

October 2007

Mechanical Status of Eagle

By Robert Davis, KF4KSS

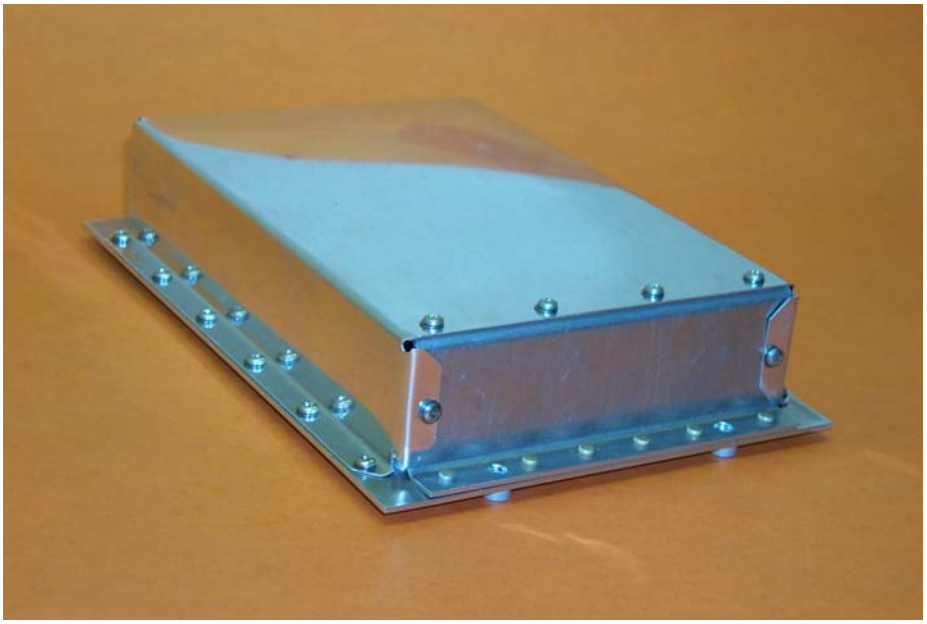


The mechanical design of Eagle changed radically two years ago, but has remained stable since. The design morphed from a smaller four-sided structure, to a larger six-sided structure for spin stabilization and other reasons. But that's old news.

Electronic Modules

Earlier this year, effort went into the prototype sheet metal module paired with the prototype U-band receiver. Several important lessons were learned through this experience.

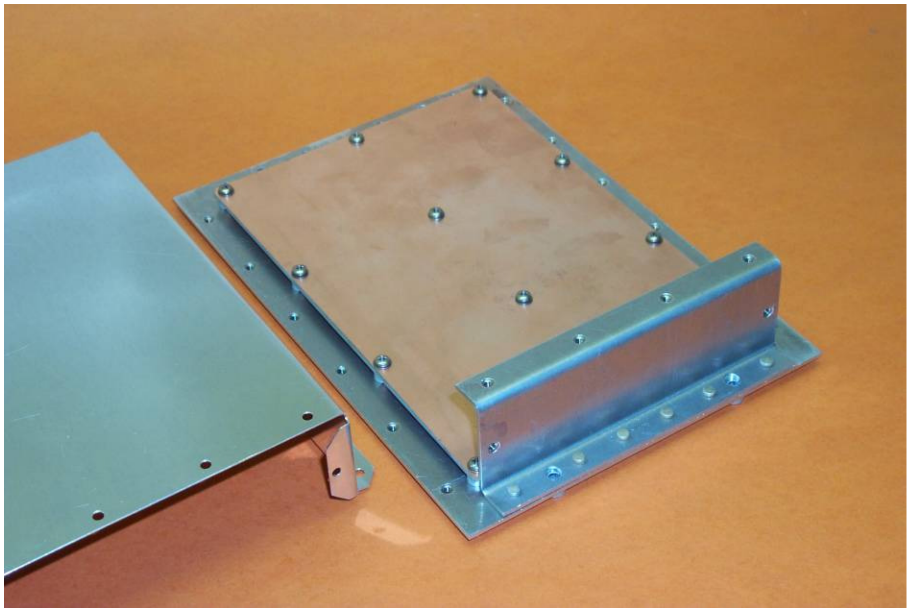
The module design is scaled for three different PCB sizes in millimeters: 125x180, 200x180 and 275x180. The prototype sheet metal module for the U-band receiver was the smaller 125x180 variant. It consists of an aluminum sheet metal Baseplate, about the same thickness as a printed circuit board (PCB). There are standoffs between the Baseplate and PCB. A connector bracket was then riveted to the Baseplate. This connector bracket was customized with any D-sub or SMA connectors required for that specific module. A thinner aluminum sheet metal cover was then placed, which also provided the walls for three of the sides of the module. This design provided substantial access to the top of the PCB, was very lightweight, and flexible for placement of heat sinks and connectors. The substantial effort into this mechanical and thermal design by Dick Jansson KD1K must be acknowledged.



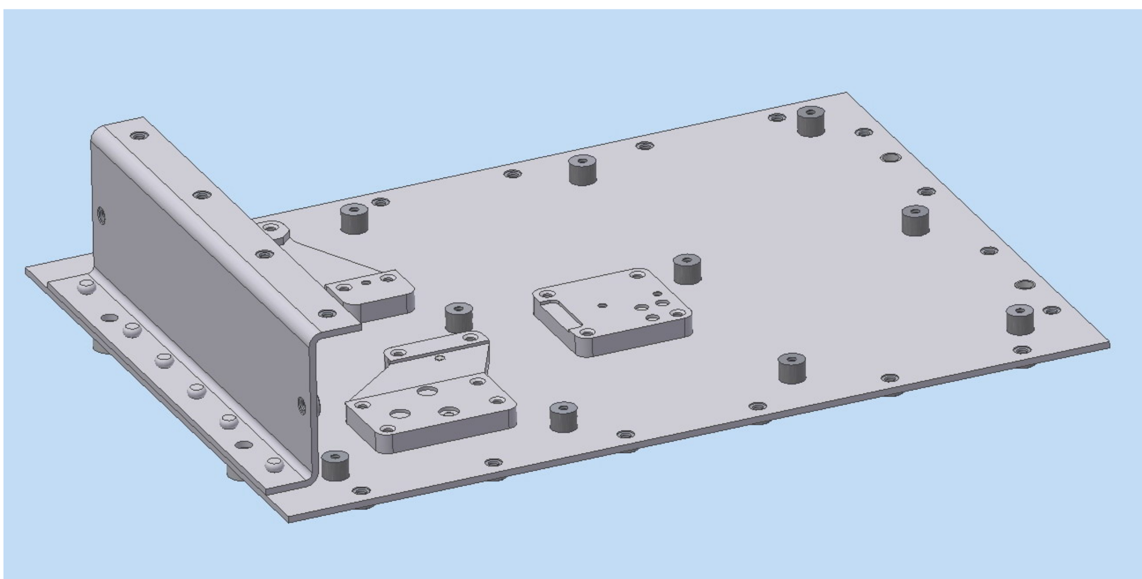
A number of lessons were learned from the first fabrication, and then from the first assembly with a PCB.

First, the stiffness of the sheet metal module is derived from the bent sheet metal Cover, not from the Baseplate. This creates a problem when attaching the PCB to the Baseplate. Both the PCB & Baseplate are of equivalent stiffness, and either can have residual stresses that cause bowing, or even a downright bend (as in the prototype). Then, attaching a bent sheet metal Cover with its own tolerances for bends can then stress the PCB-Baseplate combination. In fact, scrutiny of a couple Covers led to discovering that several would rock on two corners. The Cover contained ten bends. Approximately half of these bends formed that three walls of the module, and were very susceptible to length differences. Significant effort was put into the fixture which strived to very accurately place the sheet metal in a small bender. This extra effort in locating the bend locations was in fact needed to prevent the screws installing the Cover from "sucking" the PCB out of shape.

Second, the accuracy of the 90 degree bend in the Connector Bracket that meets the Baseplate becomes increasingly important when you consider stresses on soldered pins on the PCB. To address this, we decided to solder the connector(s) only after the PCB is mated to the Baseplate and Connector Bracket. This minimized stresses on the solder joints.
This soldering operation then required access to the bottom of the PCB, which was not previously provided. So, plans were put in place for a very large access hole in the Baseplate (of what is now an assembly fixture) large enough for soldering the pins of any connectors.



Third, height of the heatsinks under a PCB must be well matched to the length of the Commercial Off The Shelf (COTS) standoffs. Any difference in height will likely stress the PCB, which is poor. Vice Versa, if a screw location is unable to “suck” out the gap in a short standoff, then this gap may cause an unwanted thermal condition.



Fourth, we did find instances of the captured hardware on the Baseplate becoming loose (able to spin). This will be watched in the future, and that hardware may be replaced. We must plan these modules to be “flight ready” even after many cycles of assembly and disassembly of PCBs.

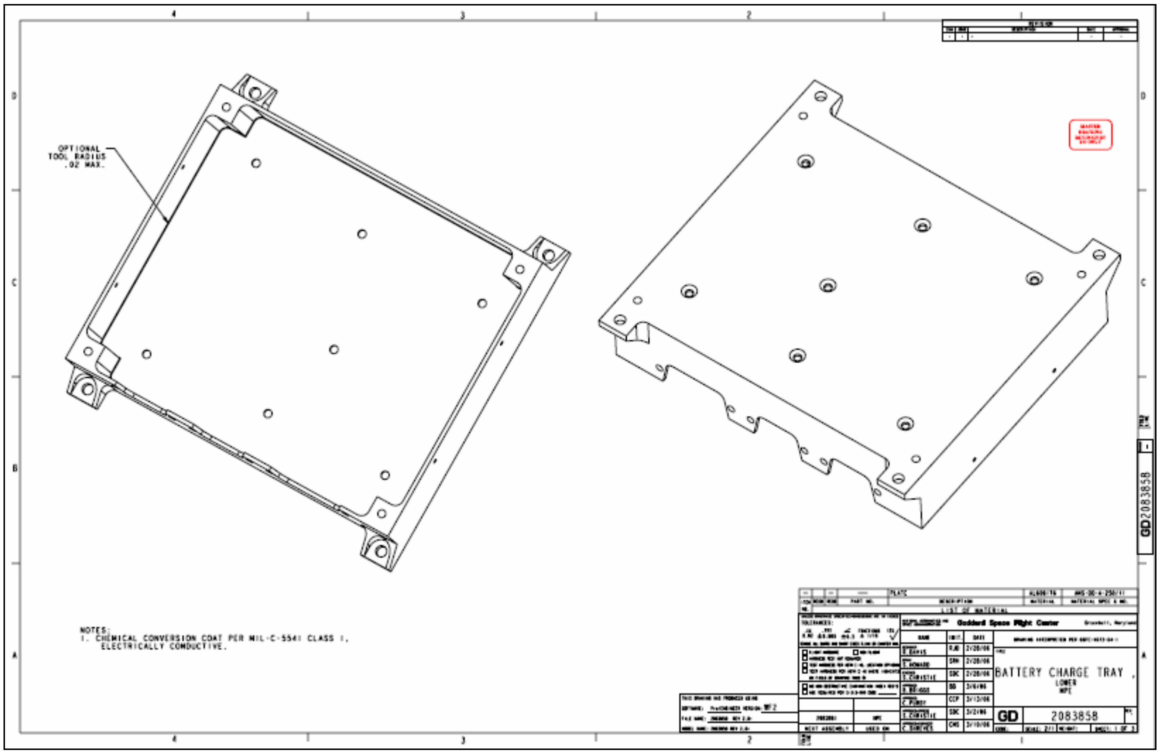
Fifth, after first use of a module and PCB also demonstrated the problem of self-compatibility. In this instance, there was interference between the CAN-DO widget and the U-band receiver. This issue can be solved by eliminating the source, bolstering the receiver, or by separating the two (either with foil or placing each in their own compartment). For flexibility, all three of these solutions are being addressed.

Sixth, there are screws along “front” of the module for attachment to a spacecraft structure. This screw placement can potentially be under a connector backshell. Although it is probably not good practice to have a module connected to a harness and THEN mechanically attached, the apparent convenience should be accommodated.

To address the first and largest mechanical issue of Baseplate stiffness, we began talking about a module Baseplate that is milled from a thin piece of plate. This is cheap since the milling operation is minimal (not full height of the module). This minimal height milled Baseplate still had a bent sheet metal cover, albeit shorter due to the thickness of the walls on the Baseplate.

After a long period of arguments for and against full-height milled modules, I believe the appropriate action now is full height milled modules. One of my longstanding arguments against full height modules is that this may now be an activity that we have to outsource. However, perhaps this is not significantly different than outsourcing PCB fabrication. My concern is that our volunteer organization doesn’t have a line going around the block of machinist who are volunteering their time, skill & tools. Fred Parker KF0AK has been so generous so far, but he cannot solely carry the burden of machining (our new lab in Pocomoke, MD will help too!). A milled module also removes the uncertainty of the angle of the bent Connector Bracket, and of walls of the bent sheet metal Cover.

Below is a sample full-height milled module from a project at NASA Wallops Flight Facility. I’ve used this style for two different projects with fairly good feedback. It also has the advantage of convenient stacking of modules, if the need was to arise and the thermal design can accommodate.



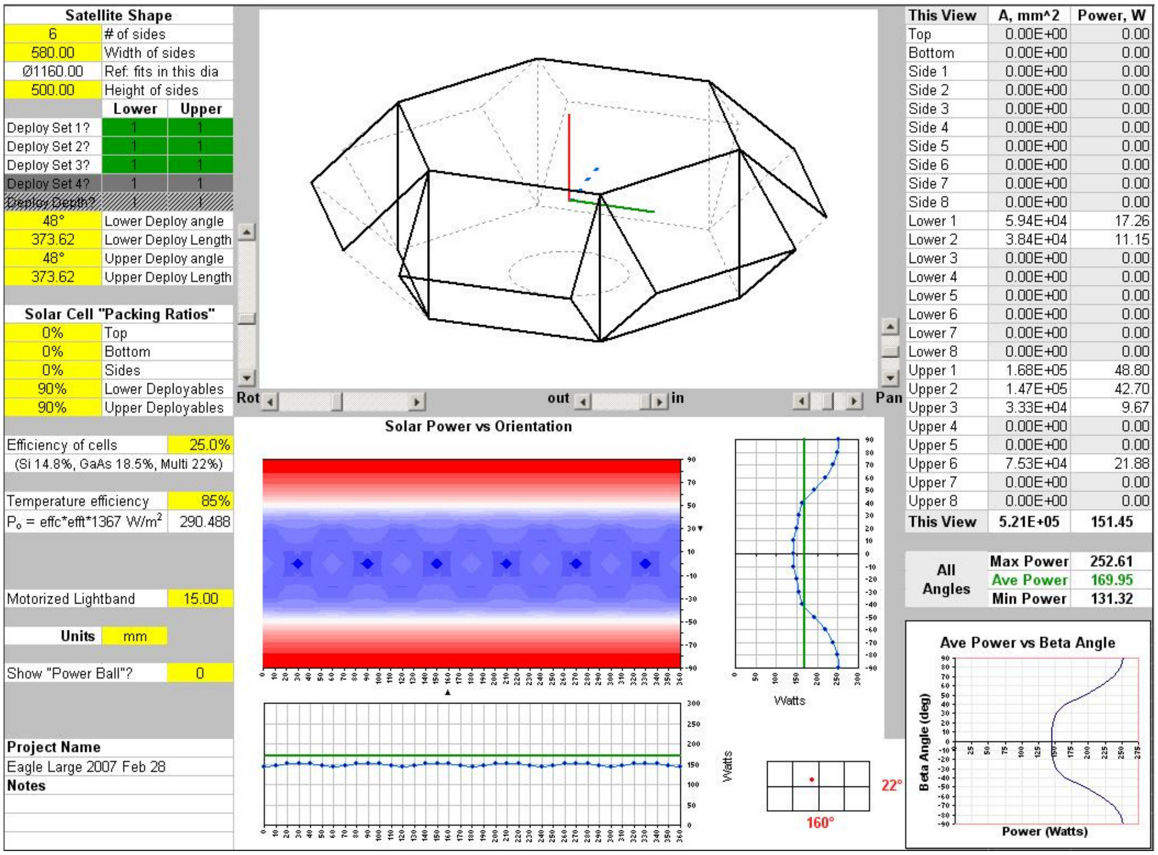
The process of requirements development, technical design, peer review, prototyping, and testing has improved the robustness of the mechanical design. The requirements development for the mechanical design have been lagging, and this is my next little push.

Eagle Model

Just prior to the Dayton Hamfest this year, we produced a 1:2 scale model of the Eagle spacecraft. Although this was only a simple model, and not indicative of the flight structure, it's a good aid in discussing the solar panels, antenna configuration, and more. This model now resides in the new AMSAT lab in Pocomoke, MD hosted by the Hawk Institute for Space Sciences.

Solar Panel Sizing

At the Dayton Hamfest, Bob McGwier N4HY, Lou McFadin W5DID and I sat down to discuss the solar panel sizing of Eagle. I made an Excel spreadsheet to help visualize the solar panels, and provide at least a rough estimate of the instantaneous, maximum, minimum, and Beta-angle average solar power generation. If you look close enough (put on your reading glasses), you'll see our current plans for dimensions and power.



Stiffness of Launch Vehicle Adapter

Dick Jansson KD1K performed a Finite Element Analysis (FEA) in Cosmos DesignSTAR of a simplified Eagle structure, with specific attention to the interaction between a proposed central fuel tank and the interface to the launch vehicle (assumed to be a 15” diameter clampband or similar). This particular spacecraft component is of interest since its stiffness most affects the stiffness of the large clump mass (fuel & tank), and the stiffness of the spacecraft structure. Launch vehicles require a minimum stiffness, or else the low frequency modes during powered ascent can transfer significant loading to the spacecraft.

Dick’s modeling and analysis showed several things in the preliminary analysis. First, the fuel tank may be of similar diameter as the launch vehicle interface, making a thin wall cylinder (or slightly conic cylinder) very attractive for stiffness. Second, the attachment of a milled ring in the honeycomb panel between the tank ring and the launch vehicle will be a tricky design. Third, in this preliminary assessment, the concept provides sufficiently highly natural frequencies (the tone of the loud noise it would make if it were rung like a bell or placed on a launch vehicle that induces vibration). In the picture below, the two shaded components would be the launch vehicle adapter plate and the ring supporting the fuel tank. The fuel tank is the transparent cylinder in the middle. The box around it represents the major structural box of the spacecraft. Avionics would be mounted exterior to these panels, and additional panels would be present but are not shown here because they are not load bearing. So, Eagle is actually six sided though you only see a box here.

Plans for Coming Year

The coming year will see a number of very visible advances in the mechanical design:

1) New revision of prototype module
2) Fabrication of flight and ground modules
3) Continued support of antenna configuration
4) Finalization of structure design
5) Finalization of solar panel design
6) Fabrication of solar panel engineering unit for assembly-level testing
7) Fabrication of engineering unit of spacecraft structure to appropriate fidelity

I expect that the new Pocomoke, MD lab will play a major role in these tasks. These plans can become reality with continued support of the Eagle design team, not just the mechanical team but all disciplines! To help the mechanical team, please contact me at KF4KSS@amsat.org. To help the project, please contact Jim Sanford W4GCS.

Thermal Design of Eagle Modules

Presented by

Dick Jansson, KD1K

Abstract

The cooling of high-density electronics for Eagle modules presents problems not previously seen in prior AMSAT High Earth Orbit (HEO) Amateur Radio satellites. Localized power densities of the modern circuit elements are quite high and the U Band Receiver effort has illustrated this issue. This requires machining special aluminum block heat sinks that are attached to the module baseplate, which provides a mounting of the printed circuit board assembly (PCB) to provide the conductive cooling of these circuit areas. More and more this is seen as an inherent characteristic of these electronics. The solutions to these issues required the creation of some thermal analytic models, and other tools, to evaluate these situations.

One down to earth example of the high power density issue is seen in the designs of new, high powered desktop computers, with some major efforts placed in cooling of these electronics by employing closed-loop liquid cooled heat exchangers followed by compact liquid-to-air heat exchangers.

About the Author

Dick Jansson, KD1K (formerly WD4FAB), has participated in the design aspects of AMSAT spacecraft since the late 1970's during the design of the ill-fated P3A mission. His principal expertise is that of heat transfer and thermal design of the spacecraft, which has been his professional occupation as a Thermal Design Engineer. He has been professionally involved in the thermal design activities of spacecraft and cryogenic devices since 1958 and performed his first satellite computer thermal analysis (using punched cards and run on an IBM 7090) in late 1963.

As a trained Mechanical Engineer, being involved in the mechanical design of devices is seen as a natural aspect of Dick's thermal design interests. This led to the AMSAT positions of the mechanical design and thermal design of the Microsat Project, the P3D Project (AO-40), and followed by the design work of the Eagle Project.

Dick also has been very involved in the amateur satellite communications, and VHF, UHF, and microwave communications in general, and has garnered many operating awards in those activities. Now, due to a change to apartment living, Dick enjoys HF operations using a non-descript magnet-wire loop antenna strung through nearby trees outside of his office window, maintaining a low-visibility for the antenna.

1 Introduction

This paper shows that designers of Eagle electronic modules must pay closer attention to the thermal aspects of their designs so that these electronics will see proper temperatures for the safe operation of the intended circuits and functions. Compounding this picture is the fact that electronic elements created in recent years have become much smaller and more complex. As a result, the power densities of these elements have dramatically increased. Power densities seen in these elements are demanding much closer attention to the thermal details. Presented is an example to illustrate the problems and solutions for the conditions presented. Compounding the issues is the fact that designers do not have convective cooling effects of air, normally available for their circuits. All cooling must be done through both thermal radiation and direct conduction to the spaceframe.

2 Overview

The Eagle satellite is an orbiting platform for Amateur Radio communications, and carries numerous electronic modules for these communications. Shown in Figure 1 is one side of the first configuration of Eagle. One solar panel has been removed to show the six modules mounted below the panel. The modules shown are of the (drawing number) E05 20 design, which consists of a printed circuit board, PCB, with dimensions of 125x180mm. Modules are sometimes called by their PCB dimension which in this example is a 125x180 module.

Modules mounted in Eagle follow a mounting scheme that has been long tested in other AMSAT high-earth-orbit, HEO, satellites. This plan employs conductive thermal isolation in the mounting. This allows the module temperatures not to be highly coupled to the thermal vagaries of the spaceframe. Such an arrangement is brought about through the use of a fiberglass-epoxy molded channel, as seen supporting the modules in Figure 1.

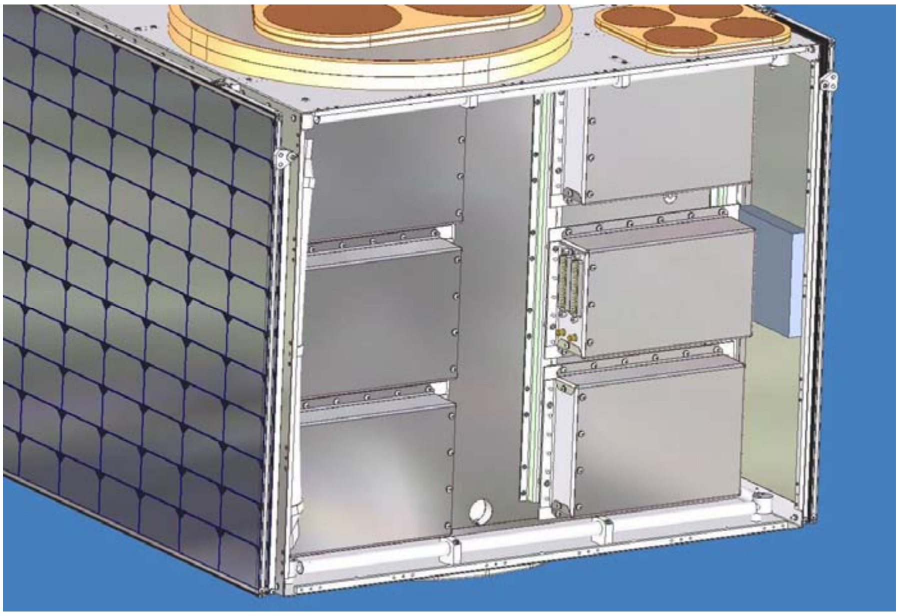


Figure 1: An Eagle satellite with one solar panel removed, showing internal modules.

This arrangement provides thermal isolation by forcing the module heat removal to be principally through radiant heat transfer, a thermal process that provides only low heat transfer rates and thus the desired thermal isolation. An electrical equivalent of this thermal arrangement is that of a high impedance input RC low-pass filter. Module temperature control is performed by controlling the thermal emittance of the module housing, as will be discussed.

3 Solutions

Operational Eagle modules are typified by the U Band Receiver. To start, the basic cooling for almost all Eagle electronics is through radiant heat transfer, either directly from the module housing, or indirectly through both the module housing. Some of the heat is directly conducted to the spaceframe, but this is held to a minimum, as is shown later. For the basic module radiant cooling, the suggested module power dissipations are shown in Table 1. This information is only for the module design that is expected to be most widely used, the E05 20, 125x180 Module shown in Figure 2. The computed conditions assume a module mean (shell) temperature of 20°C in a 0°C spacecraft.

Figure 2, E05 20, 125x180 Module, shown with CAN connector.

Mean Emittance, ε	Allowable Power Dissipation, Q
0.045	0.4 W
0.15	1.3 W
0.45	3.9 W
0.91	7.9 W

Table 1: Mean Emittance, vs. Allowable Power Dissipation

The thermal emittance, ε, of the module's coating provides the control for the radiant heat transfer of the module to the spaceframe. The fabrication of the module cover is from AlClad aluminum sheet. This material has a thin layer of pure, low-emittance aluminum on its surfaces, providing a principal emitting surface for the module. This low emittance property is inherent to pure aluminum. Controlling the module emittance, to higher values than that offered by the AlClad coating is done through the application of space-rated pressure sensitive (PSA) tapes or paints of suitable properties and patterns on the module exterior surfaces.

Modules with higher power dissipations, such as transmitter power amplifiers, need internal heat sinks applied to their power devices, or to the higher power density areas of the PCB. Modules with the power dissipation levels of 7.9W, or greater, need to use E05 25 Heat Sink Module designs that employs a large internal heat sink mounted to the exterior of the module and mounted to the spaceframe. This method of conductive cooling of power electronics was successfully used on the AO-40 satellite.

We can now address the E05 20 modules, with power levels less than those needing the large internal heat sink of the E05 25 module. This dissipation from the PCB is in the following illustration: If we limit the PCB temperature rise to a further 20°C rise in a 20°C module, or a PCB temperature of 40°C total, then the PCB dissipation would be 4.8W, somewhat less than the 7.9W allowed in a 20°C module. This discussion assumes modest and somewhat uniform distribution of power elements on the PCB. Modern electronics are quite compact with many functions compressed into very small packages. Designers may often create functional clusters on a PCB. This can result in a locally dense power area of concern. It is these local areas that in a vacuum are of great concern and require special treatment, as in the U Band Receiver in this study.

Working with this one Eagle module shows that PCB dissipated power is not (ideally) uniformly spread over the PCB, but has concentrations of power in localized areas by circuit functions. To alleviate the problems caused by these localized high power concentrations require the use of specialized conductive heat sinks mounted internally, shown in Figure 3. Please note that three such machined aluminum blocks are mounted on the baseplate (one of these is only partially visible). By using screws, the PCB is mounted to both the heat sinks as well as the standoff posts. These attachments insure that the areas of concern in the PCB are thermally coupled to the E05 21 Base Plate where the heat is distributed and radiated to the spaceframe.

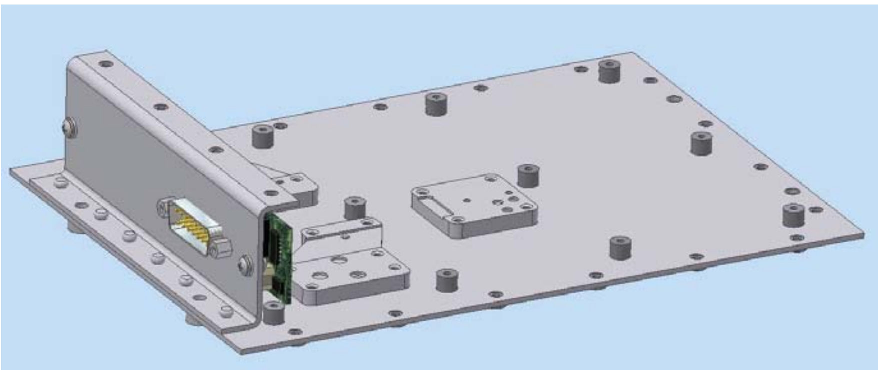


Figure 3, E05 20 Module for the U Band Receiver with a E05 50 heat sink base plate.

Operating such PCB designs without heat sinks in free air should be done with caution, as these concentrations of devices have a high enough power density to be of a concern. An example is the power regulator area, which dissipates about 1200mW (typical) in a 29x29mm area, or 0.207W/cm². A power density that high would provide some thermal problems for those devices without added heat sinks.

Providing a conductive heat sink to the power regulator area of the receiver greatly improves the removal of the excess heat. If left untreated and allowed to only radiate through the module cover, the effective thermal resistance of this area is: $\Theta_R \approx 56°C/W$.

Placing the devices of this section onto the heat sink directly attached to the baseplate provides a mounting thermal resistance of: $\Theta_m \approx 3$°C/W. This is greater than an order of magnitude improvement cooling of the electronic elements and is typical of the several areas of the PCB that are of a concern in this study.

4 PCB Analysis

In addition to designing the heat sinks for the concentrated power dissipations of the U Band Receiver, the temperatures expected in four-layer PCB assemblies have been analytically studied to reveal how PCB materials respond. The model consists of a 40x40mm PCB section with only a small amount of copper on the top and bottom faces and a contiguous 1oz (0.0014in thick) ground plane in the second layer. The dissipating device has a 2x 2mm soldered pad area with just three plated through holes in the PCB, all mounted in the center of this PCB. The model PCB area was divided into a 5x5 matrix (8x8mm element size) for each of four layers over the 40x40mm model area.

While expecting unfavorable results from this analysis, the end results were somewhat surprising. None of the intermediate power levels are detailed in this report, only the 250mW dissipation model ($\approx$ 0.016W/cm^2 or 3.5W for an entire E05 20 module PCB) is discussed. The PCB was considered to be coated with some form of organic material, such as a conformal coating. Organic coatings of this type are inherently of a high thermal emittance, such as $\varepsilon \approx 0.85$. The PCB was also only cooled by thermal radiation to a "black" total enclosure (module housing) operated at +20.0°C. These conditions resulted in a mean PCB temperature of just 34.9°C (+14.9°C above the enclosure) with the device mounting surface at +36.0°C and the coolest edges of the PCB at 31.4°C, showing a PCB gradient of only 4.6°C. This model has been closely examined, including a back-of-envelop sanity check and these are supportable results.

What makes these results possible is the ground plane. This is despite being very thin and without any heavy copper surfaces on the top or bottom of the PCB. It is clear that such heavy copper layers are not needed. It is also imperative that a 1 oz copper ground plane be included in the design of the PCB. Such ground planes are as electrically useful, as they are thermally.

5 Assembly

Assembling a module, such as this U Band Receiver, must be done with the use of heat sink thermal compound, used to eliminate non-conducting gaps between the PCB and the heat sink. For space flight the compound to be used is the NuSil Technology CV-9042, a thermally conductive, controlled volatility silicone grease. This material is space-rated and was used on AO-40. Only 50 grams of this pricey material was purchased. Small vials of this compound were distributed to experimenters for assembly of flight units. This CV-9042 material is not for use on non-flight assemblies as the more conventional Wakefield silicone thermal, heat-sink compound is very suitable for non-space applications.

6 Low Power Command Modules

A departure from this discussion of heat sinking techniques is now provided regarding a few of the spacecraft and mission critical modules. There are some particularly critical modules that must be of a low power design. These are those involved in the ultimate commanding of the spacecraft, for instance the command receiver, decoder and the IHU. The reason for this notation is that the cooling effects of the spaceframe during the unavoidable eclipses will also affect this equipment. There is a need to maintain the command-loop equipment in operational condition regardless of the radical eclipse cooling of the spaceframe. During a 2-3hour eclipse, the spaceframe can cool to as low as -80°C or lower. These conditions have been observed in telemetry from prior P3 spacecrafts. Obviously, the command electronics cannot be allowed to become that cool and still maintain their functionality. Low-power electronic modules have been shown, by experience, to barely get to 0°C under these conditions through the use of the low-emittance coatings of the module housing and the conductive thermal isolation afforded the mounting of modules on the fiberglass channels built into the spacecraft.

7 Conclusions

This paper has shown that by paying close attention to the finer details of the thermal design of an electronic module, operating temperatures of the components have been controlled to desirable levels. This assurance provides the confidence that component-degrading conditions can be avoided in this assembly and for all other Eagle modules. The Thermal Designer thoroughly studied the schematics and component ratings of the receiver, and designed the needed thermal treatments of these components and component groupings. Electronic Designers, in turn, have had to modify some components and their arrangements on the PCB to be able to take advantage of the heat sink capabilities of this design.

The studies and information generated by this effort, reinforces the need that all electronic designers must work closely with the Eagle Thermal Designer - as closely as he does with the system engineer who commissioned the work. Module design cannot be done in a “vacuum” as it must be a cooperative, multi-technology effort. It is imperative that a designer is knowledgeable of all the appropriate papers and documents and fully understands the system requirements.

Where's the Launch?
Getting Phase 3 Satellites into Orbit

Lee McLamb, KU4OS
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Abstract:

Several existing and potential future options for launching Phase 3 satellites will be explored. In addition this paper addresses the constantly evolving business environment in which secondary payloads must find launches. To be successful AMSAT and all the supporting volunteers must adapt their philosophy with respect to how satellite projects are supported and managed.

In the past amateur satellite projects have frequently not had the benefit of full financial and volunteer support until a launch date was identified. When I've manned the AMSAT booth at various hamfests I have often heard people say that they'll start supporting a satellite project once the launch has been identified. Similar sentiments have also been expressed in electronic forums such as AMSAT-BB. While waiting until the launch opportunity or date was set has worked in the past, it also created numerous problems and is no longer a viable option due to changes in the launch market. As a result AMSAT's Eagle project needs your support **now** if we are to be prepared to take advantage of launch opportunities once they are identified.

Today's Launch Vehicle Market

As experience with and confidence in today's modern rockets has grown, the length of time it takes to plan and integrate space launch missions has shrunk. The result is lower price launches for the primary payloads. While this is an advantage in the commercial market it creates a great challenge for those who are looking for secondary payload opportunities as the time available to identify and respond to an opportunity is also diminished. One of the large contrasts between commercial satellite programs and traditional amateur satellite programs has been when the investment in significant development and construction starts.

Commercial satellites are typically in construction long before a contract for launch is ever signed. As the satellite progresses toward completion, at the appropriate point in the schedule a launcher is put on contract. For commercial launches the contract is signed typically only about twelve months before launch. Some launch providers, such as Lockheed Martin Commercial Launch Services (LMCLS), advertise a capability to launch as soon as four months after signing a contract.

The 2006 launch of Atlas V/Astra 1KR is a good example of the volatile and rapid changes that can now take place in the commercial launch market. Astra 1KR was initially contracted in April 2004 for launch on an Ariane V. Part of that contract required that Ariane V ECA conduct two successful qualification flights plus two successful commercial flights prior to Astra 1KR. Since Ariane couldn't meet that requirement by the needed launch date, the contract was given to ILS in February 2005 for launch on a Proton M rocket. In order to meet the contracted launch date, ILS swapped the Astra 1KR payload from Proton M to Atlas V in December 2005 and finally launched on April 20, 2006.

Because of these short time horizons the old amateur satellite program model of "wait for an identified launch" is simply no longer viable. Instead we need to follow the lead of the commercial programs and make the commitment to building our satellites up front so that we are prepared to use launch opportunities when they finally arise. Fortunately the development of standardized secondary payload adapters for both Ariane V and the Evolved Expendable Launch Vehicles (Delta IV and Atlas V) has also made this more feasible than in the past.

There are other benefits to getting an early start as well. First, amateur satellites could often have benefited from additional time for more thorough testing so that problems can be found and fixed on the ground instead of being worked around once in orbit. Complete and detailed testing will greatly reduce the risk of failure after launch. Another benefit that also reduces the risk to our precious spacecraft is avoiding over-work and burn out by the volunteers doing the actual construction. Many of them have stories of sixty to eighty hour weeks being worked to meet certain critical dates. While their heroics are certainly appreciated, it is really an unfair burden to place on volunteers and creates too many opportunities for error due to fatigue or lack of time for review and verification.

TANSTAAFL

With apologies to Robert Heinlein let me say right up front, There Ain't No Such Thing As A Free Launch[1]. The cost of paying for even a secondary launch opportunity is fairly daunting. As a result I'm frequently asked about getting another "free launch" like we had for earlier satellites. While AMSAT may not have directly paid a fee for an earlier launch, there are always some fairly substantial costs involved with adding a secondary payload to a mission due to the additional engineering and analysis involved. These costs get paid by someone. So while there's no "free" launch, there may be groups who would see the benefit in helping AMSAT's Eagle satellites get into orbit. One of the key aspects in gaining the support of outside groups is the perceived viability of the project. We must be able to demonstrate that we have both the technical and financial resources to see a project through to completion. These potential supporters want to know that their efforts will be productive and not lost on a project which never reaches completion.

In addition to the costs, there is also now much greater competition for the limited secondary payload opportunities that do arise. In this aspect AMSAT has become a victim of its own success. Sixteen to thirty years ago AMSAT was a pioneer in demonstrating the usefulness of small satellites. Now the ability of small satellites to perform useful missions is becoming widely recognized as evidenced by a 2004 presentation made by SpaceDev forecasting 693 small satellites that will be needing launches between 2002 and 2011. Other studies[2] have also identified hundreds to potentially thousands of small satellites that could be launched if inexpensive launches were available and that this small satellite market has proven to be fairly constant over the last several years. As a result an entire industry has now grown up around small satellites with which we now compete for launch opportunities.

Existing Launch Capabilities

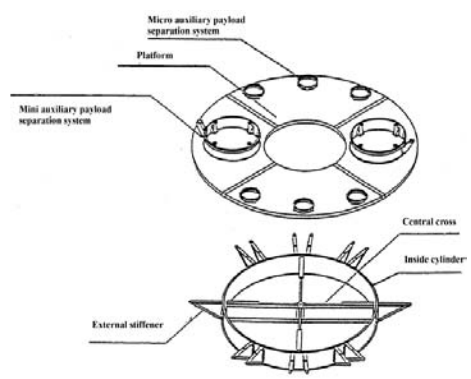
One of the benefits of the growing market of small satellites is that there are an increasing number of options being provided for launching secondary payloads. In addition the definition of “small satellite” continues to evolve in both the larger and smaller directions. This results in a greater range of options into which we might fit amateur radio spacecraft. One of the specific challenges with launching the Phase 3 spacecraft such as AMSAT-DL's P3-E and AMSAT-NA's Eagle is that due to power, antenna and stability requirements, they are larger than most amateur spacecraft destined for low Earth orbit. In addition, the energy required to reach the highly elliptical orbit which give the long access durations means that these satellites must fly on the larger launch vehicles.

Delta II - Dual-Payload Attach Fitting

Photo Credit: Boeing

The Delta II Dual-Payload Attach Fitting (DPAF) allows a single Delta II rocket to carrier to spacecraft into orbit[3]. The DPAF is available in two versions, DPAF, shown left and a reduced height version, RHDPAF. Each is capable of supporting a spacecraft weighing 362.9 kg or 308.4 kg respectively. The RHDPAF allows a lower dimensions of 151.7 cm (60 in.) in diameter and 131.5 cm (52 in.) in height. These dimensions provide sufficient volume for the Eagle spacecraft but would require deployable 2m antennas for P3-E.

Ariane V - Ariane Structure for Auxiliary Payload



Drawing Credit: Arianespace

As Ariane has transitioned from their early fleet of launch vehicles to the Ariane V, they have also updated the capabilities of the Ariane Structure for Auxiliary Payload (ASAP) which is now offered as the ASAP5[4]. The new ASAP5 can include mounting locations for both “mini” and “micro” sized spacecraft. As defined by Arianespace, a microsat can have a mass of up to 120 kg while a minisat is between 120 kg and 300 kg. The ASAP5 is available in three different configurations:

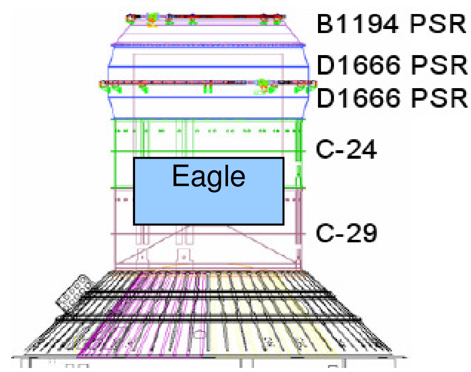
- a combined configuration of up to 2 minisats and 6 microsats (shown above)
- a configuration of up to 4 minisats
- a configuration of up to 6 microsats

Due to their larger size the minisat positions are of interest for Phase 3 satellites. While the microsats allowed for a cube of only 600 mm, the minisat locations permit the mounting of spacecraft that fits within a 1.5 m cube. This volume would easily accommodate the Eagle spacecraft. Making P3-E fit would require adapting the 2m antennas so that they could be restrained and then deployed once on orbit.

Future Capabilities

Atlas V – Internal Payload Carrier

At the 2007 Small Payload Rideshare Workshop, the Boeing/Lockheed-Martin partnership known as United Launch Alliance (ULA) provided an update on their available secondary payload capabilities utilizing the Atlas V and Delta IV launch vehicles. One example of the Atlas V Internal Payload Carrier (IPC) is shown at the right with a representation of how the Eagle satellite would fit. By adding an additional payload separation ring (PSR), the internal volume of the combined C-24 and C-29 spacer rings is then exposed allowing deployment of an additional payload.   This internal volume would accommodate a payload of 121 cm (48 in.) O.D. x 152 cm (50 in.) high. While this volume is adequate for Eagle, P3-E's 132.7 cm structure plus antennas would not fit.

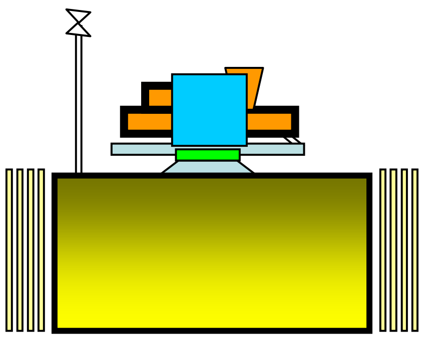


Drawing Credit: ULA

In addition to the IPC and other secondary adapters being developed, ULA is also developing a Secondary Payload Integration Lap (SP-SIL) in Denver. The purpose of the SP-SIL is to allow for the complete checkout of mechanical and electrical interfaces prior to arriving at the launch site for integration onto the launch vehicle. This is seen as significantly enhancing the likelihood of success for the secondary payload by eliminating last minute surprises during the launch campaign. Likewise it reduces risk for the primary payload, by providing earlier assurance that the secondary is in fact “as advertised”.

Intelsat

Several interesting concepts were presented by Intelsat Satellite Services at the 2007 Small Payload Rideshare Workshop. These included options for both carrying



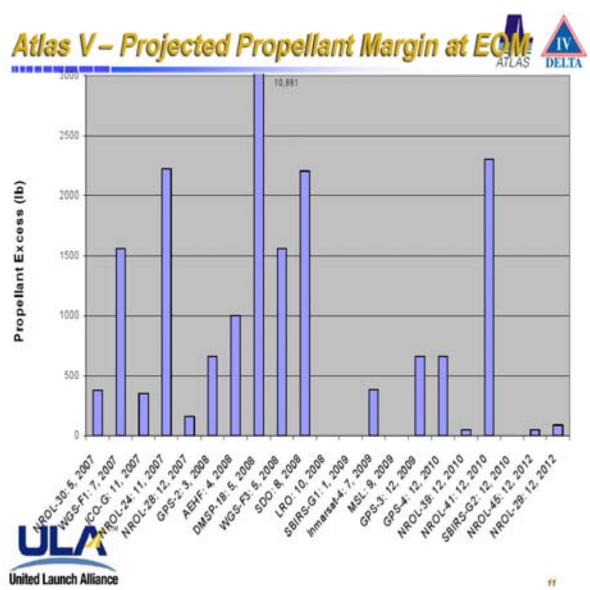
Drawing Credit: Intelsat Satellite Services

a separating satellite of up to 150 kg or an equipment platform on an Intelsat satellite. The drawing to the left shows how each might be integrated onto the nadir face of the host satellite. The box on top of the cone shown in the drawing represents a notional satellite interface using Planetary System's 15 inch motorized LightBand separation system. While the dimensions shown suggest a much smaller volume than would be needed by P3-E or Eagle, this could provide an option for future follow-on Phase 3 satellites. The benefits of being integrated onto the primary payload are significant and include:

- Advance knowledge of launch opportunities based on a predictable commercial satellite replacement schedule. This is probably the most significant advantage in that it synchronizes the amateur secondary payload development time with the commercial satellite. Instead of needing to be ready once a launch is identified at less than a year, a more predictable 2-3 year project can be planned.
- Lower mass penalties to the overall launch mission due to the elimination of most of the secondary payload adapter mass.
- Shock exposure during launch is significantly reduced due to attenuation by the host satellite structure.
- As a part of the primary satellite the costs, coordination and documentation issues at the launch site are reduced.

Finding Upcoming Launches

As was mentioned earlier in the article, the current short launch vehicle integration cycle makes finding secondary launch opportunities difficult. One approach is to look for cases where a constellation of satellites are going to be launched. In this way a longer-term insight can be gained regarding launch capabilities. The chart to the right was presented by ULA at the 2007 Small Payload Rideshare Workshop and shows the expected excess propellant in pounds at the end of the Atlas/Centaur mission. Two satellite programs stand out as potential candidates, Wideband Global Satcom (WGS) and Advanced



Extremely High Frequency (AEHF). Both are planned to be constellations of geosynchronous satellites and have 1500 lbs and 1000 lbs of expected excess capacity. Having identified promising candidates, AMSAT is now engaged in discussions to determine whether adequate volume margins exist to support the additional hardware to include Eagle as an IPC mission.

Conclusion

The marketplace in which AMSAT must compete for launch opportunities is constantly changing. New competitors for launch availability as well as new launch vehicle capacity are emerging on an on-going basis. Waiting to support large complex amateur satellite programs such as the Phase 3 satellites until the launch opportunity or date was set no longer a viable option. The Eagle and P3-E projects needs your support **now** if we are to be prepared to take advantage of launch opportunities once they are identified.

References:

1. Originally, "There ain't no such thing as a free lunch" by Robert A. Heinlein in *The Moon Is a Harsh Mistress (1966).* ISBN 0-312-86355-1

2. Marco Carere, "Tracking nontraditional satellite customers", *Aerospace America Online*, October 2003

3. Boeing Launch Services Inc., *Delta II Payload Planners Guide*, July 2006 http://www.boeing.com/defense-space/space/delta/docs/delta2_ppg_2006-07.pdf

4. Arianespace, *ASAP5 User's Manual*, May 2000 http://www.arianespace.com/site/images/ASAP5-manual.pdf

The New AMSAT Spacecraft Lab in Maryland!

By Robert Davis, KF4KSS

Last year in late 2006, AMSAT-NA and the Hawk Institute for Space Sciences (HISS) began talking about cooperative activities. HISS is my employer in Pocomoke, MD and a non-profit division of the Maryland Hawk Corporation, which is affiliated with the University of Maryland Eastern Shore (UMES). HISS was planning a new facility, and of course AMSAT has been considering lab possibilities for the upcoming Eagle amateur satellite project. This led to the agreement that HISS will offer space in the new HISS facility for AMSAT's lab. In exchange, HISS can also use AMSAT resources like the clean room for their own projects on a space-available basis. A marriage is born! The announcement of the signing of the Memorandum of Understanding (MoU) with between AMSAT and HISS, and separately between AMSAT and UMES was on the AMSAT website (www.amsat.org) and publicized in the AMSAT Journal.

Hawk Institute for Space Sciences

HAWK INSTITUTE FOR SPACE SCIENCES

A Division of Maryland Hawk Corporation

Flight Log

November / December 2006

UMES & Hawk Institute Sign Agreement with AMSAT-NA to Build Satellite Projects on Maryland's Eastern Shore

The University of Maryland Eastern Shore community welcomes AMSAT-NA to the Eastern Shore as the two groups agree to work jointly on satellite and related technology projects in the region. The Hawk Institute for Space Sciences (HISS), through its parent company Maryland Hawk, has signed a Memorandum of Understanding with AMSAT-NA to host AMSAT spacecraft integration lab at the HISS facilities located in the Mid-Atlantic Institute for Space and Technology (MIST) building in Pocomoke City, Maryland.

AMSAT-NA, formally known as the Radio Amateur Satellite Corp, is a non-profit 501(c)(3) volunteer organization whose mission is to design, build and operate experimental satellites carrying amateur radio payloads and promote space education. AMSAT has designed and built over 30 satellites carrying amateur radio equipment since its founding in 1969.

The agreement with Maryland Hawk gives AMSAT-NA essentially no-cost access to the HISS facility in return for sharing its equipment and ideas with HISS. The agreement also allows for AMSAT's portable clean room and other resources to be located at the HISS facility. Hawk and UMES will provide volunteer labor for the AMSAT Eagle satellite project, and AMSAT will share their spacecraft technology with the University community.

UMES has signed an independent Memorandum of Understanding with AMSAT-NA to work collaboratively to identify opportunities to develop appropriate satellite and related technology projects, as well as working with UMES students and faculty to enhance hands-on studies and dissertation research. AMSAT-NA scientists and engineers may receive Adjunct status at UMES.

Jerry Redden, Worcester County Director of Economic Development, says "this agreement is a win-win for everyone involved."

"It opens doors to the aerospace for our native sons and daughters. We've been working with area high school and college students to excite them in science, technology, engineering and math, and this partnership provides opportunities to students on the Eastern Shore to enter the knowledge-based economy," says Redden.

AMSAT-NA includes the United States and Canada, and other AMSAT organizations exist throughout the world. Membership in AMSAT-NA is approximately 4,000 individuals.

See http://www.amsat.org for more information about AMSAT-NA. If you would like to be a volunteer on AMSAT-NA's next satellite project, named Eagle, contact Bob Davis at rjdavis@mdhawk.org.

University Officials Meet with AMSAT-NA Directors

Front row (L to R): Rick Hambly, President of AMSAT-NA and member of the AMSAT-NA Board of Directors; Dr. Thelma Thompson, President, University of Maryland Eastern Shore; and Quentin R. Johnson, Executive Assistant to the UMES President; Back row (L to R): Dick Jansson, volunteer AMSAT-NA engineer; Bob McGwier, Vice President of Engineering for AMSAT-NA and member of the AMSAT-NA Board of Directors; Dr. Ronald G. Forsythe, Vice President for Planning, Assessment, Technology and Commercialization for UMES; Ron Bettini, Executive Director of Hawk Institute for Space Sciences; Tom Clark, member of AMSAT-NA Board of Directors; and Robert Davis, engineer with HISS and volunteer AMSAT-NA engineer.

Hawk Institute for Space Sciences is a Division of the Maryland Hawk Corporation, an affiliated 501 (c) (3) non-profit organization of the University of Maryland Eastern Shore, a Historically Black 1890 Land-Grant University.

Over the 2006 Christmas / New Year's holiday, we descended on the Orlando storage unit which held the AMSAT property which previously composed the AMSAT Orlando, FL lab, and to a facility near Kennedy Space Center which held the disassembled AMSAT clean room. Several days of packing the three 24' rental trucks was made possible by Andrew Glasbrenner KO4MA, Lou McFadin W5DID, Stan Wood WA4NFY, Lee McLamb KU4OS, and Bob McGwier N4HY. Then, Andrew, Bob McGwier and I hit the road for Maryland.

When we arrived in Pocomoke, MD, we were met by a large crew for the unpacking: Rick Hambly W2GPS, Tom Clark K3IO, Paul Shuck N6TX, Dan Schultz N8FGV, Rob Renoud K3RWR, Dave Bern W2LNX, and several others. The shipment consisted of the eight air handlers for the clean room (final interior size is 20’x20’ and 8’ high), a variety of electronic test equipment, RF gear, spares and equipment from AO-40, and tons of stuff (imagine your garage but it’s an office, fabrication area, and amateur radio spacecraft lab).

We immediately set forth on the task of inventory and organization. The piles became organized piles, then rows. Preparing the clean room air handlers for assembly became a several month long task for Rob Renoud K3RWR, JC Taylor W3JCT, and Ray Fantini KA3EKH. First, there was the washing. Then, there was the stripping. Next, there was sanding. And when we thought it was almost over, there was the scraping, sawing, chopping, flipping, moving, and identifying.

Finally earlier this year, we assembled the air handlers using a fork lift, more volunteers and a bunch of sweat. We still have more work on light fixtures, paint, the clear plastic "soft walls" and filters before it's really a clean room. When complete, it will again be a wonderful resource, capable of exceeding the spacecraft industry norm of clean room air cleanliness of class 100,000 (particle or dust measurement).

Concurrent with all these AMSAT volunteer Saturday events, HISS was continuing the construction of the 7,500 sq ft Pocomoke office, which includes the office, break room, restrooms, a large lab area and machine shop. The HISS office is conveniently located between UMES in Princess Anne 15 minutes north and NASA Wallops Flight Facility in Virginia 15 minutes south. The walls, lights, power, A/C, paint, floors and doors are finally done. Recently, the remainder of the AMSAT property entered the new facility. It finally looks like home!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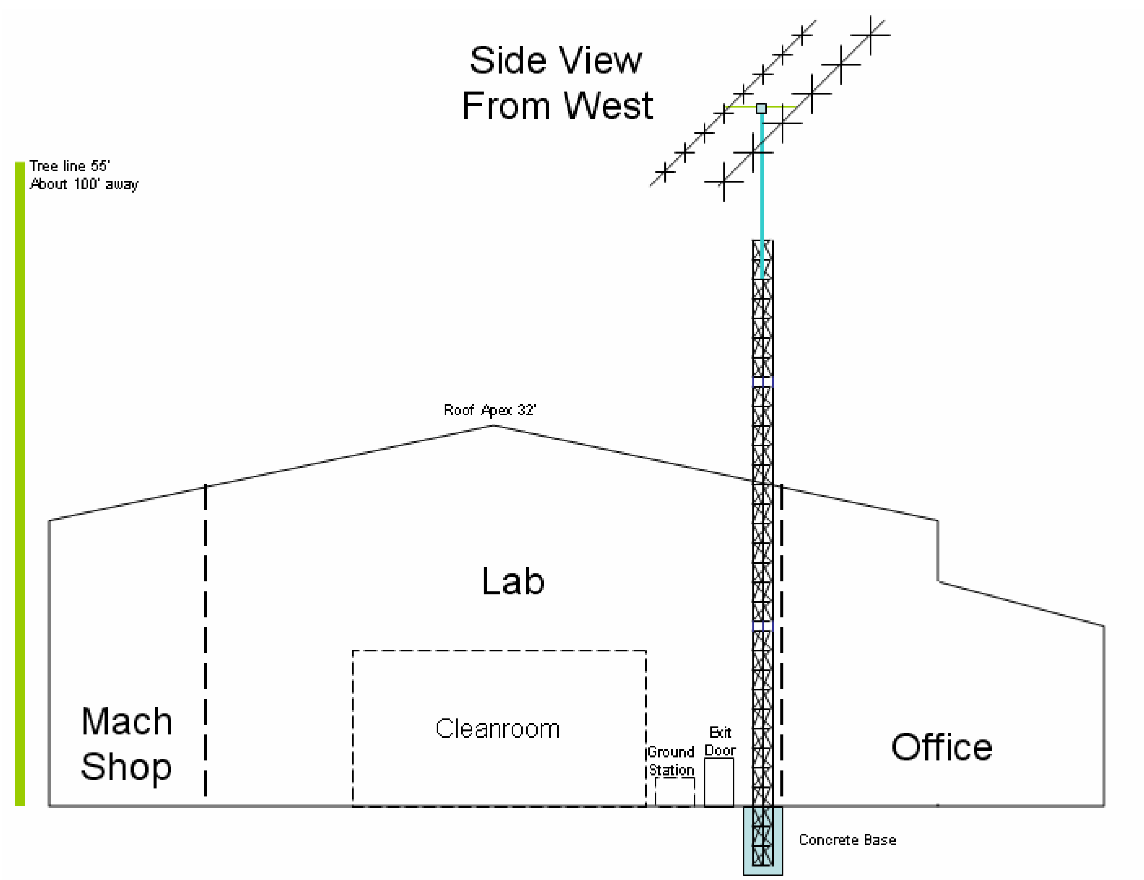
The immediate tasks now are the sprinklers, the HEPA filters which have a 6-week lead time, and wiring up the clean room lights and fans. After the interior and walls are complete, then a final wipe down is in order before the filters can be installed.

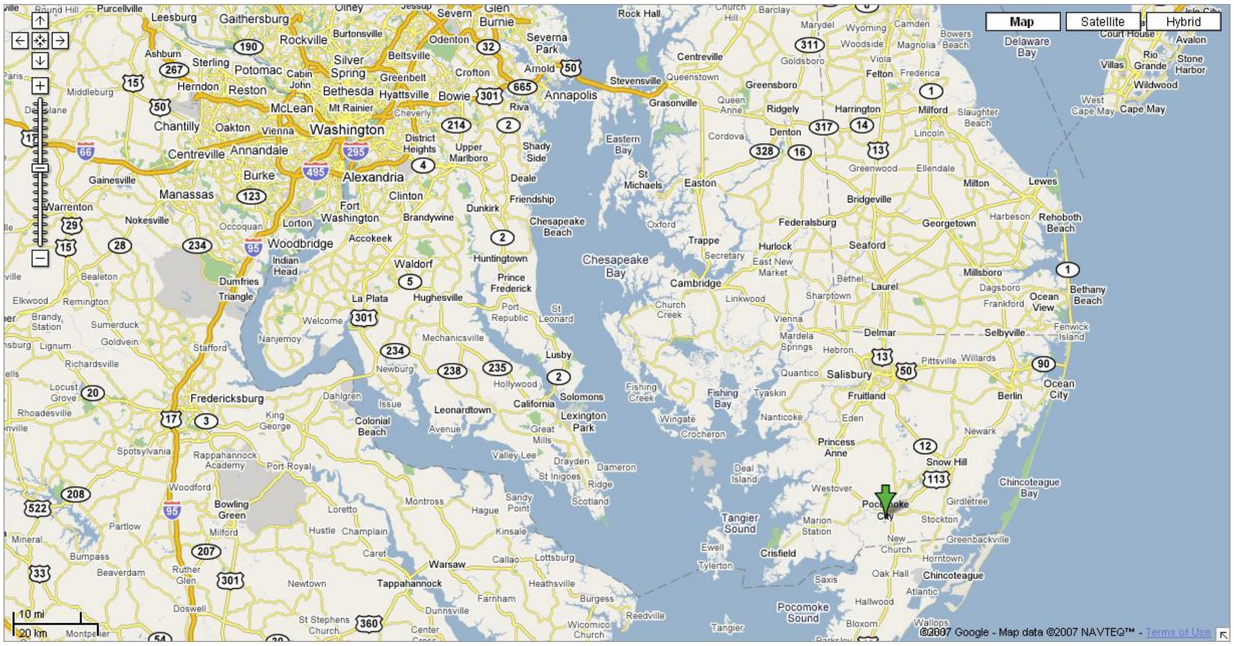
And, we're itching to get the ground station up and running. Our immediate plans are raising a tower next to the building for U & V band yagis. The AMSAT owned Icom 910H and PC will be paired with the HISS owned M^2 U & V band yagis and Yaesu rotor. We are in the final stages of getting the tower installation approved by the property owner. Also on the list is an APRS station and reserving some of the yard for other projects, possibly including a dish.



So, by the end of 2007 we should have a very fine facility that's lacking only two things: project Eagle (and other AMSAT initiatives), and more volunteers! And of course, donations (tax deductible) of test equipment and other lab equipment would also be appreciated.

Eagle is progressing, and the Pocomoke lab will be ready with a capable machine shop, the electronics test area, and clean room. Additionally, HISS has access to more resources at NASA Wallops Flight Facility through our Space Act. NASA is only 15 minutes south and has other resources like thermal vacuum chambers, anechoic chambers, vibration tables, and of course there's a launch vehicle range!

The Pocomoke lab is only a place to go, but with volunteers it becomes a capable spacecraft integration lab. There are volunteer opportunities with project Eagle, and at the lab. If you find yourself near the lab and are interested in either volunteering, contact me at KF4KSS@amsat.org. Pocomoke, MD is less than three hours south east of BWI airport in Baltimore (but there's a closer airport).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Bowers Beach
Delaware Bay
Cape May Court House
Avalon
Rio Grande
Stone Harbor
Villas
Wildwood
West Cape May
Cape May
Ashburn
Sterling
Potomac
Cabin John
Silver Spring
Beltsville
Greenbelt
Crofton
Bowie
Odenton
Burtonsville
Herndon
Reston
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St Michaels
Easton
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Tangier Sound
Marion Station
Ewell
Tylerton
Crisfield
Saxis
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Wallops
Tangier
Elkwood
Remington
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Sumerduck
Bealeton
Goldvein
Stafford
Richardsville
Locust Grove
Rhoadesville
Fredericksburg
King George
Dahlgren
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Newburg
Issue
Avenue
Great Mills
Valley Lee
Drayden
St Inigoes
Ridge
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Bumpass
Beaverdam
Ruther Glen
Doswell
Loretto
Hustle
Champlain
Caret
Montross
Hague
Sandy Point
Kinsale
Callao
Lottsburg
Heathsville
Warsaw
Tappahannock
Newtown
Farnham
Burgess
Reedville
Wicomico Church
Dunnsville
St Stephens Church
Center Cross
Montpelier
10 mi
20 km
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AO-51 Power Generation, Storage and Transmitter Power

Gould Smith, WA4SXM

An amateur satellite is a self-contained system. It must generate, consume and regenerate power – keeping the system in balance. As the satellite components age in space this balance is altered. Determining what is changing and how to restore the balance is the exciting and challenging job of the command stations. This is part of that story.

AO-51 Background

- AO-51 (Echo) was launched 29 June 2004
- 12 kg (26.4 lbs), 9.5" cube satellite
- Built in cooperation with SpaceQuest, Ltd of Fairfax, VA
- Launched by ISC Kosmotras from their Baikonur Cosmodrome in Kazakstan
- Dnepr rocket put Echo into a polar, sun synchronous orbit.
- 4 dual channel 2 M receivers plus an SQRX multiband, multimode receiver
- 2 UHF transmitters plus a S-Band transmitter
- Capable of dual UHF transmitter operation
- Open for general use, 30 July 2004
- Operated in multiple mode combinations during the last three years

AO-51 Modes

AO-51 is a very versatile satellite. Numerous combinations of inputs and outputs afford multitude operational modes. The AO-51 Operations team has taken advantage of this versatility and provided most of the available operational modes to the ground based amateur satellite users worldwide.

- **V/U 145 MHz FM uplink/ 435 MHz FM downlink**
- **V/S 145 MHz FM uplink/ 2.4 GHz FM downlink**
- **L/U 1.268 GHz FM or SSB uplink / 435 MHz FM downlink**
- **L/S 1.268 GHz FM or SSB uplink / 2.4 GHz FM downlink**
- **SQRX*/U SQRX uplink / 435 MHz FM downlink**
- **SQRX*/S SQRX uplink / 2.4 GHz FM downlink**

* 10 MHz to 1.3 GHz FM and SSB receiver

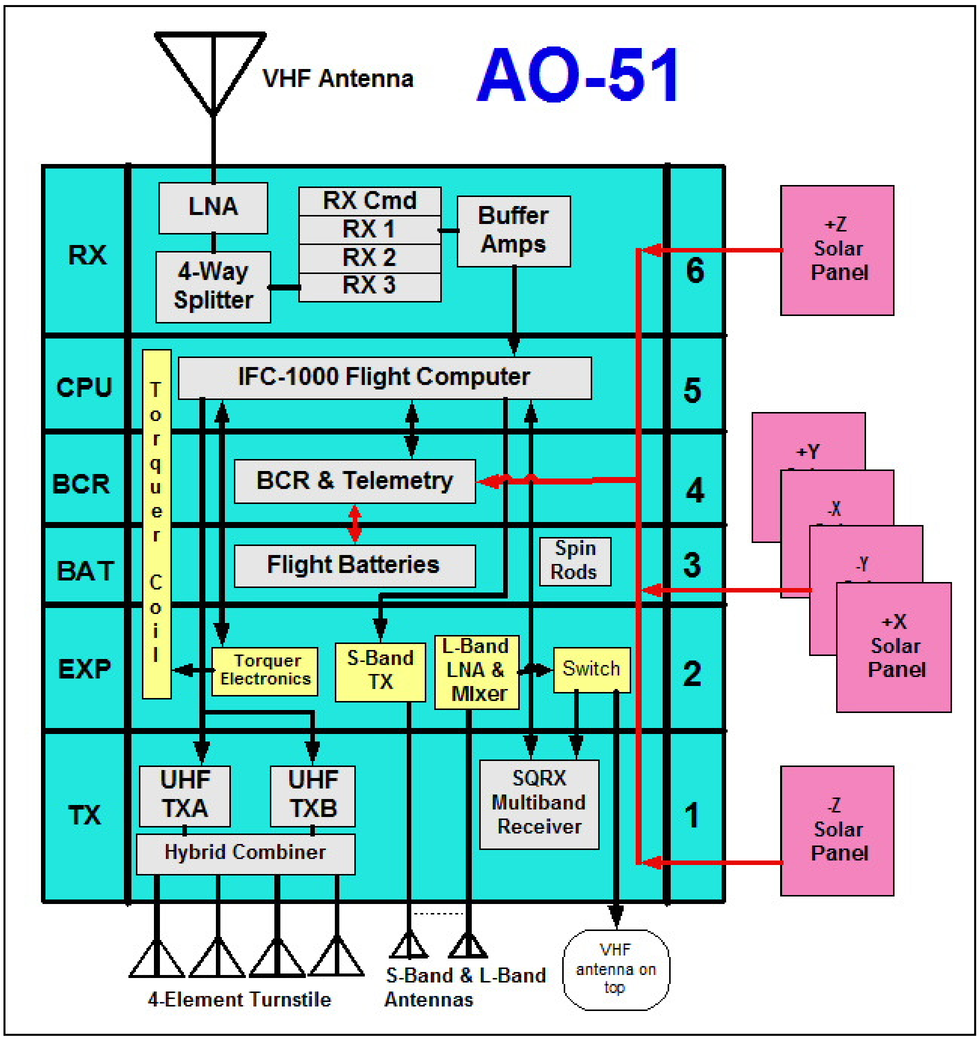
Generally we run two UHF transmitters at about 900-1000 mW total output. The S-Band transmitter has about 960 mW of power. The L-Band uplink uses the SQRX receiver and a dedicated L-Band antenna. The user digital mode also used the SQRX receiver and the 2M vertical on top of the satellite. The SQRX receiver can only use the 2M or L-Band antenna. So, although the receiver is quite versatile, the available antenna selection reduces the receive capabilities.

AO-51 Power Generation

The AO-51 power system is one of the key systems in the satellite. In fact, the power system occupies most of the exterior of the satellite and 1/3 of the internal volume. The three main parts of the power system are:

- Solar cells
- BCR (Battery Control Regulator)
- Batteries

Figure 1. AO-51 System Trays

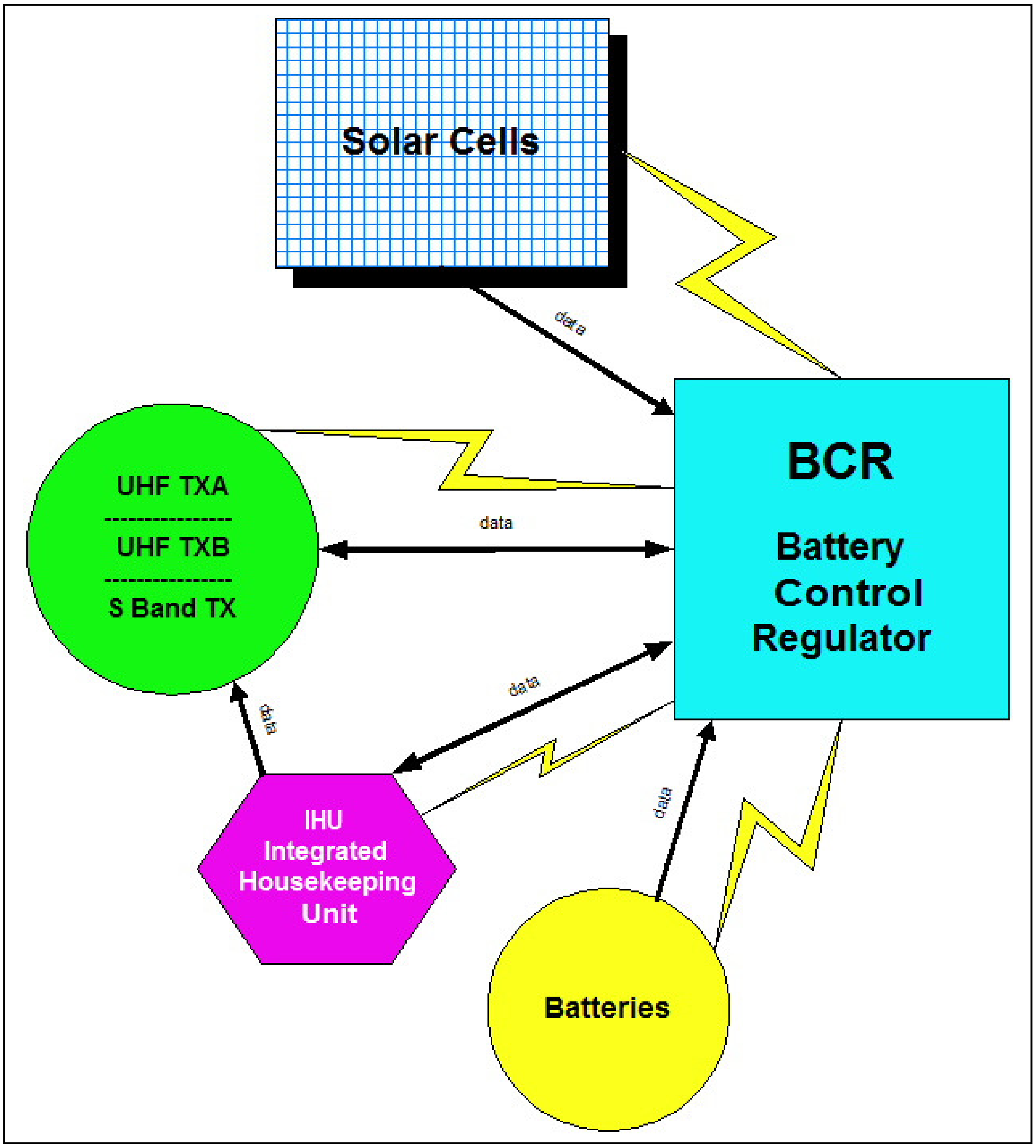


The AO-51 power system involves a close relationship between these three main elements.

When in the sun the solar cells generate power to the BCR. The batteries also supply power to the BCR to supplement the solar cells or supply all the power when the satellite is in eclipse. The BCR controls and regulates the power to the various satellite systems.

The power and data communication are shown in Figure 2. The solar cells and the batteries supply power to the BCR which decides how much power to use from each source and then convert this power to various voltages and supply power to the various systems. The BCR also recharges the NiCd batteries during sun periods.

Figure 2. Simplified AO-51 Power and Communication System

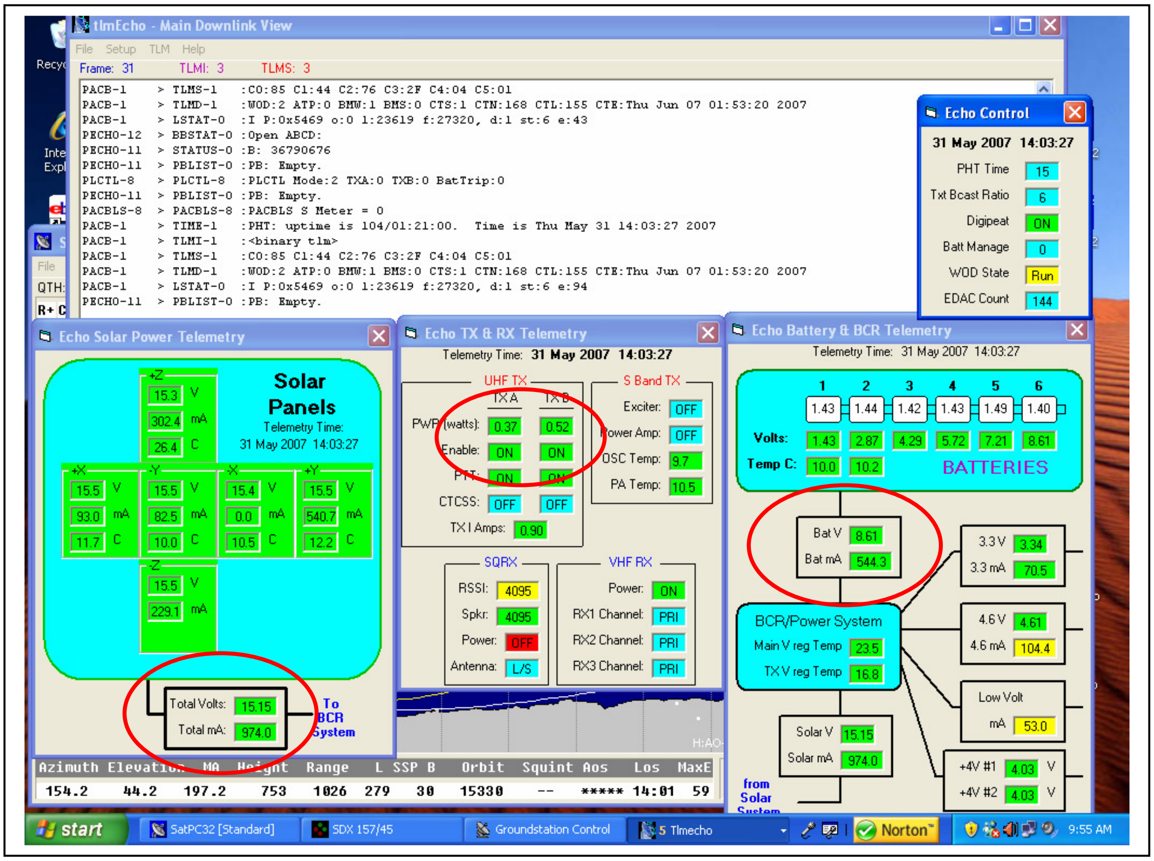


Current, voltage and temperature data all go through the BCR to the IHU. Transmitter settings and power levels are sent via ground command to the IHU.

AO-51 Telemetry

We humans use the satellite telemetry to see what is happening aboard AO-51. The realtime telemetry is important, but currently only available during the local 12-15 minute pass windows. See Figure 3. The more important data is the long term WOD (Whole Orbit Data) which are selected telemetry channels stored in a file and downloaded from the onboard file system. The problem with this is that this data is usually 12 -24 hours out of date. Fortunately, things usually change slowly enough on AO-51 that we are able to correct things before they become a problem.

Figure 3. Realtime AO-51 Power telemetry from the TlmEcho program



The WOD file format was changed in January 2007 by Jim White, WD0E and Michael Kingery, KE4AZN to allow selected channels to be stored in the file. For the first 2.5 years, all the channels were stored. Over a 24 hour period and at a 10 sec storage rate, this would produce a very large file. Many of the channels were status and generally did not change except from a command from one of the command stations. This software change made it possible to collect the most important channels at a faster rate and keep the file size down. This made it easier to download a complete WOD file during a 13 minute pass. The file format is the start date and time, sample rate and list of channels, then 70-170k of data bytes. A program converts the raw WOD data into a csv (comma separated variable) format that can be imported into Excel and other spreadsheets.

The original telemetry data was stored in files named: we010500 or we010501
This format is mmddff, month, day, file
The final 01 means this is the second file generated on Jan 05. Keeping track of the years is the responsibility of the ground stations organizing skills.

The new telemetry data files are named: wd081400 and wd081401
The same month, day and file structure is maintained. The 'wd' at the beginning distinguishes this new format.
The most common sample rate is 30 seconds. I generally collect data for 650 minutes (10.8 hours) or 1440 minutes (24 hours). About every two weeks I change the sample rate to 5 sec, about the fastest it will work, and get data for one orbit. This is used to determine the eclipse rate and look closely at how fast things are changing. I am going to see five additional data points every 30 seconds as opposed to the standard 30 second sample rate.

The AO-51 telemetry is stored in the new AO-51 telemetry archive found at:
http://www.amsat.org/amsat/sats/ao51/

Here you can download the raw data or the csv data since the beginning. Except for a few Excel macros, all of the telemetry analysis is done manually. Colin Hurst, VK5HI has been a great help with the telemetry analysis. His experience as an AO-40 command station gives him good experience. His dedication and interest have highlighted a number of interactions onboard AO-51.

New Telemetry Demodulator
Douglas Quagliana, KA2UPW has developed a 9600 bps soundcard demodulator program- Willow. This opens up the reception and decoding of the AO-51 telemetry to all. No longer is a dedicated modem required. This will also work to receive GO-32 digital data. In addition, those stations receiving realtime data can stream it via TCP/IP. When his server software is complete, this will allow people around the world (including the command stations) to receive realtime telemetry data from AO-51.

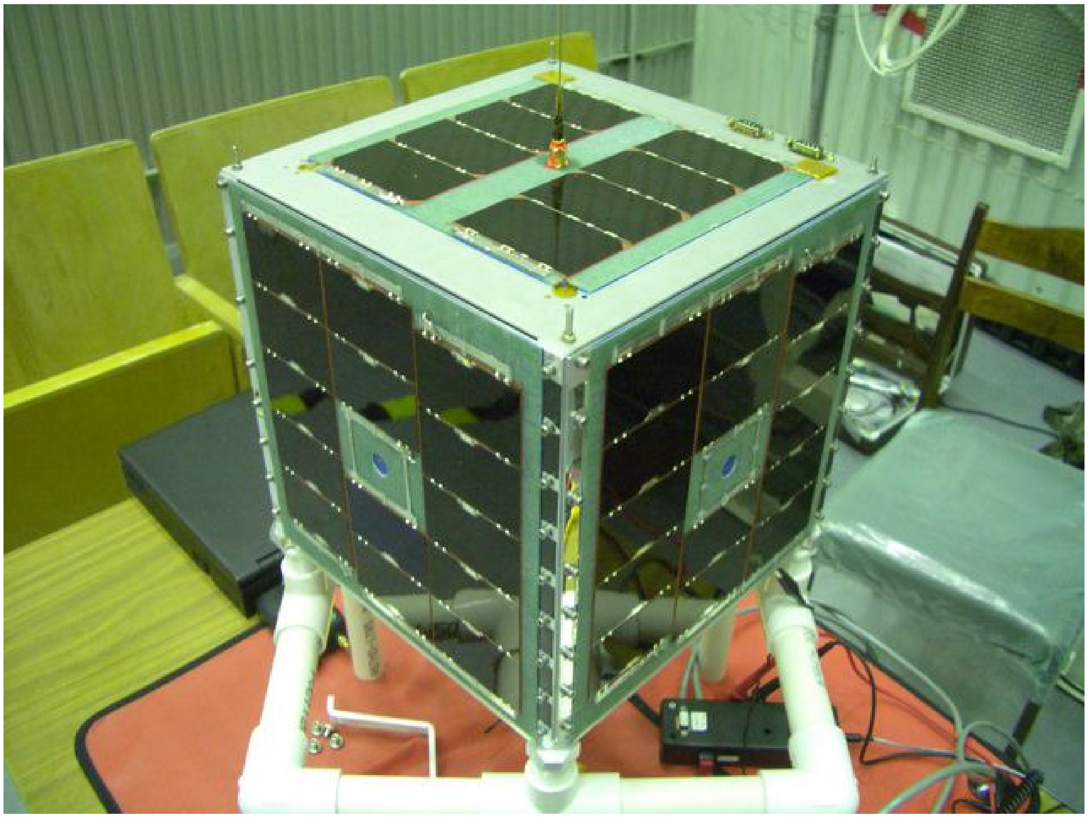
Another useful program Douglas has produced is Sabins, which will display the AO-51 telemetry data. It also plays back telemetry data collected during the pass, a packet at a time. This is a great help to the command stations, since they didn't have an easy way to access the realtime data once the pass was over. This software is an excellent teaching tool as well. This standalone software can also use stored data and allow teachers to demonstrate how the satellite systems change as it rotates and goes in and out of eclipse.

Let's examine the three power system components individually.

AO-51 Solar cells
AO-51 uses state of the art, triple junction GaAs (Gallium Arsenide) cells. They are an astounding 27% efficient. In full sun these cells can produce approximately 20 Watts,

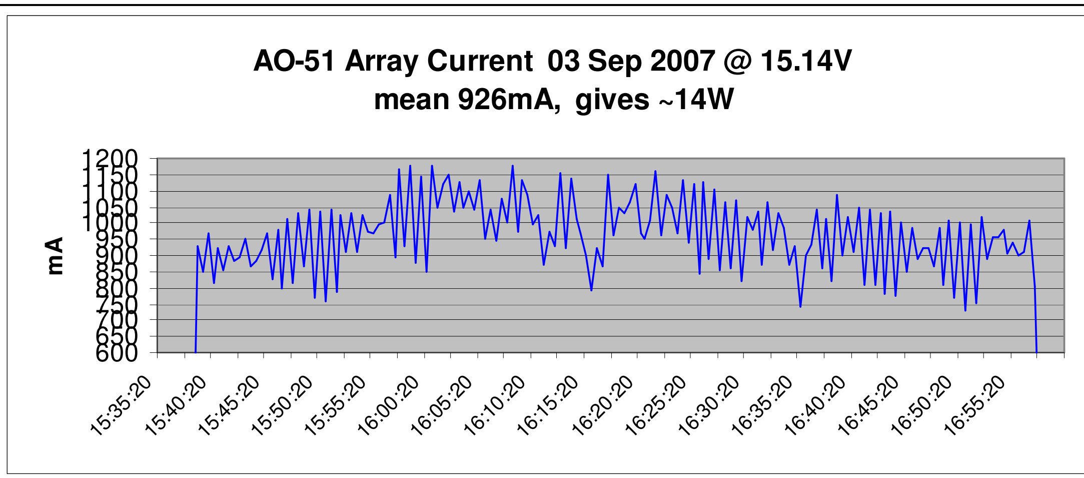
12-14 W per side. The four sides contain 14 cells each, while the top and bottom each have eight cells. The cells cost about $20,000. See Figure 2.
The spin rate of the satellite and the angle to the sun determine the actual amount of power generated by the cells.

Figure 4. AO-51 Solar cell arrangement – 14x4 and 2x8



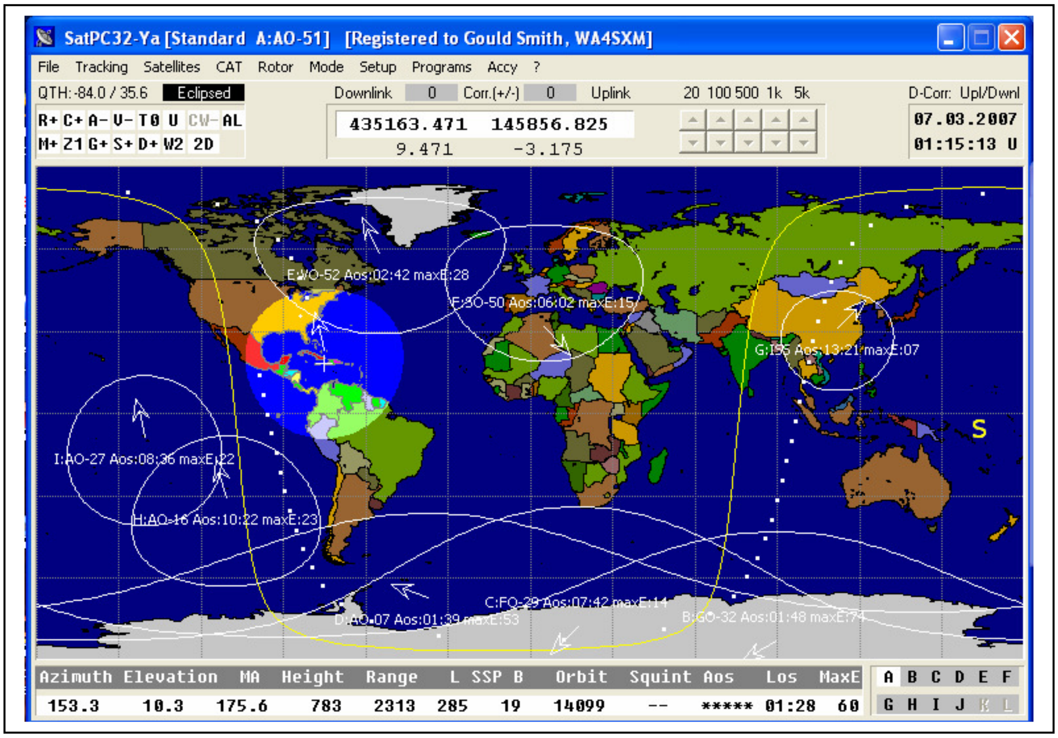
The typical solar panel generation pattern is for the voltage to quickly go to 15.x V when in the sun (or earth reflection), but the current is used to tell us when the satellite is getting full illumination. Currently AO-51 is rotating about 2.3 rpm.

Figure 5. Typical AO-51 solar panel power generation for one orbit



The drop off at the edges in Figure 5 is due to the satellite being in eclipse. A sun synchronous, polar orbit means that AO-51 closely follows the sun's grey line, on both sides.

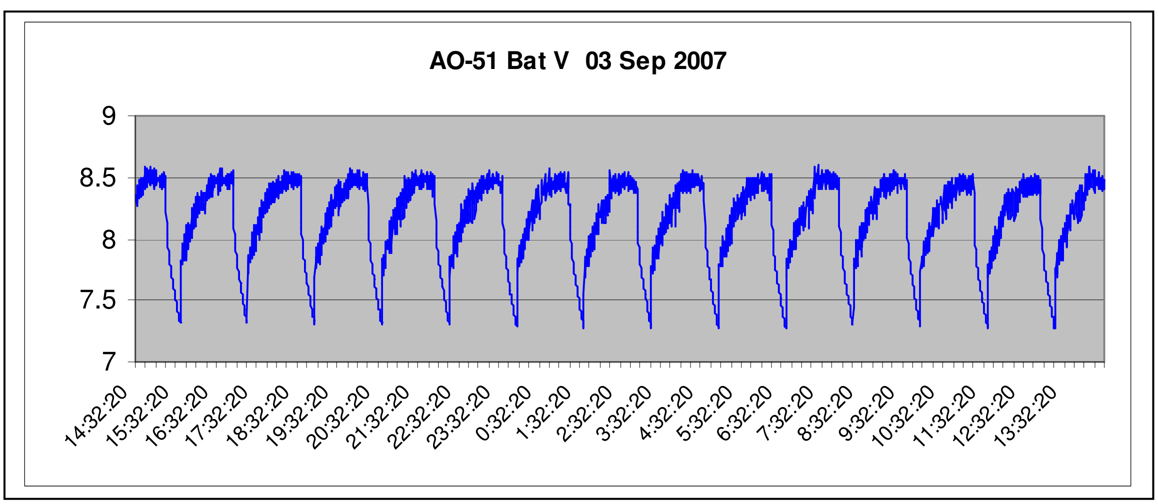
Figure 6. SatPC32 showing AO-51 during eclipse



AO-51 Eclipse cycle

One of the more important things I monitor is the eclipse time of AO-51. For during this time the satellite is totally dependent upon the battery system for supplying power.

Figure 7. Typical AO-51 Battery voltage cycle for 24 hours



In Figure 7 you can see that there is a consistent pattern of charge and discharge during this 24 hour cycle. We get about 14 charge/discharge periods each day. The main goal in controlling this cycle is to make sure that the batteries charge completely during the illuminated period and do not discharge too far during eclipse. Figures 8 and 9 show the battery voltage for one orbit and its associated eclipse time.

Entering the eclipse period we want the batteries fully charged and we want the power consumption during the eclipse period to discharge the batteries enough to prolong their lifetime, but not low enough to reach the battery setpoints. Setpoint #1 will turn off the S-Band transmitter, Setpoint #2 turns off the S-Band Transmitter and TX B. Setpoint #3 turns of the S transmitter, B transmitter and sets TX A (most commonly the digital data transmitter) to a low TX power level.

Figure 8. AO-51 single orbit eclipse cycle

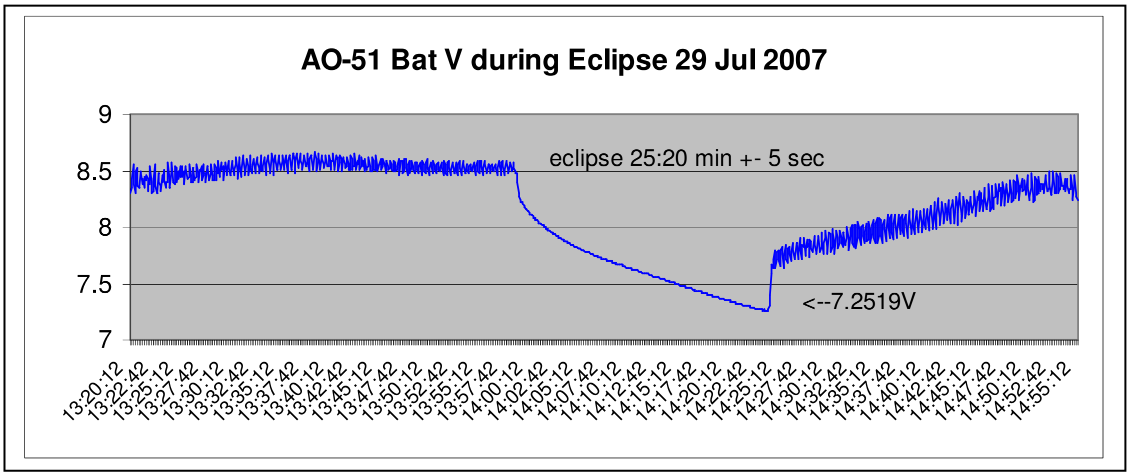
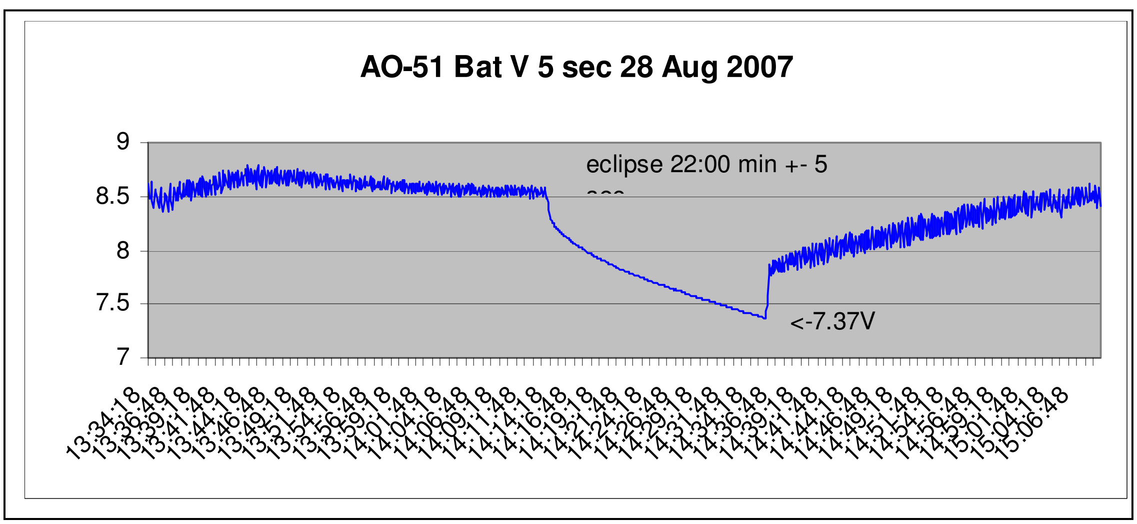


Figure 9. AO-51 eclipse cycle one month later

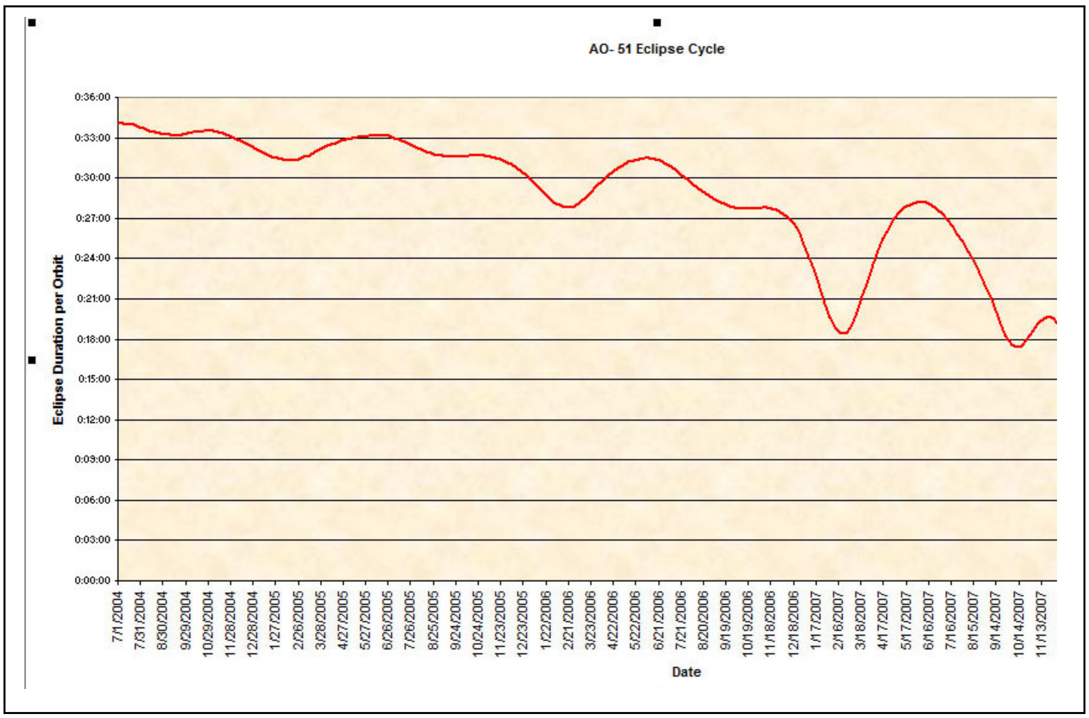


Control of the satellite power usage is mainly done by changing the transmitter power output. The eclipse times for AO-51 have ranged from 18 minutes to 33 minutes. In July 2007 we were seeing a medium length eclipse time and running TXA at 360 mW and TXB at 540 mW, with the SQRX receiver off.

Looking at Figures 8 & 9 you can see that it takes a little more than half the sun period to get the batteries fully charged to about 8.6V. During the illuminated periods the satellite is run from a combination of the solar cells and the batteries all controlled by the BCR.

Notice that in Figure 9, one month later that we have about 3 minutes 20 seconds less time for the batteries to solely power the satellite. As such, I can run the transmitters at a higher level. Note that the minimum battery voltage during eclipse is higher also, which will later prove interesting.

Figure 10. AO-51 eclipses July 2004 – 2007, from VK5HI using W4SM program



Battery Control Regulator

The BCR (Battery Control Regulator) board takes up an entire tray in AO-51. The AO-51 telemetry control system is also on the BCR board. The telemetry control receives voltage, current and temperature values from the satellite systems and sends them to the IHU for system operational decisions, storage and transmission. As seen in Figure 2 this board handles the voltage control for the satellite. It takes power from the solar cells when illuminated, power from the battery and provides multiple regulated voltages to various satellite sub-systems. Another main function of this board is the battery charge and discharge control. When the solar cells are generating voltage, the BCR uses this to recharge the batteries. It also arbitrates how much of the solar cell energy is used to power the system and how much of the battery power goes into powering the satellite. Although NiCd batteries can be charged slow or fast, it is important not to overcharge them. They tend to heat up and eventually produce gas. So the critical job of controlling the recharging of the batteries is a major item that must be handled well.

BCR Features

- Battery charging circuit
- Multiple voltage sources and regulators
- Autonomous operation, no control software
- Telemetry control

Figure. 11. AO-51 BCR board

AO-51 Power usage

- BCR - Input 12-28 V Solar cells and 8 volts Batteries
  - Output 3.3 V, 4.6 V, 7.5 V, 5 V
- IHU – 3.3V
- VHF receivers – 4V
- SQRX – 5V
- UHF Transmitters – 7.5 V

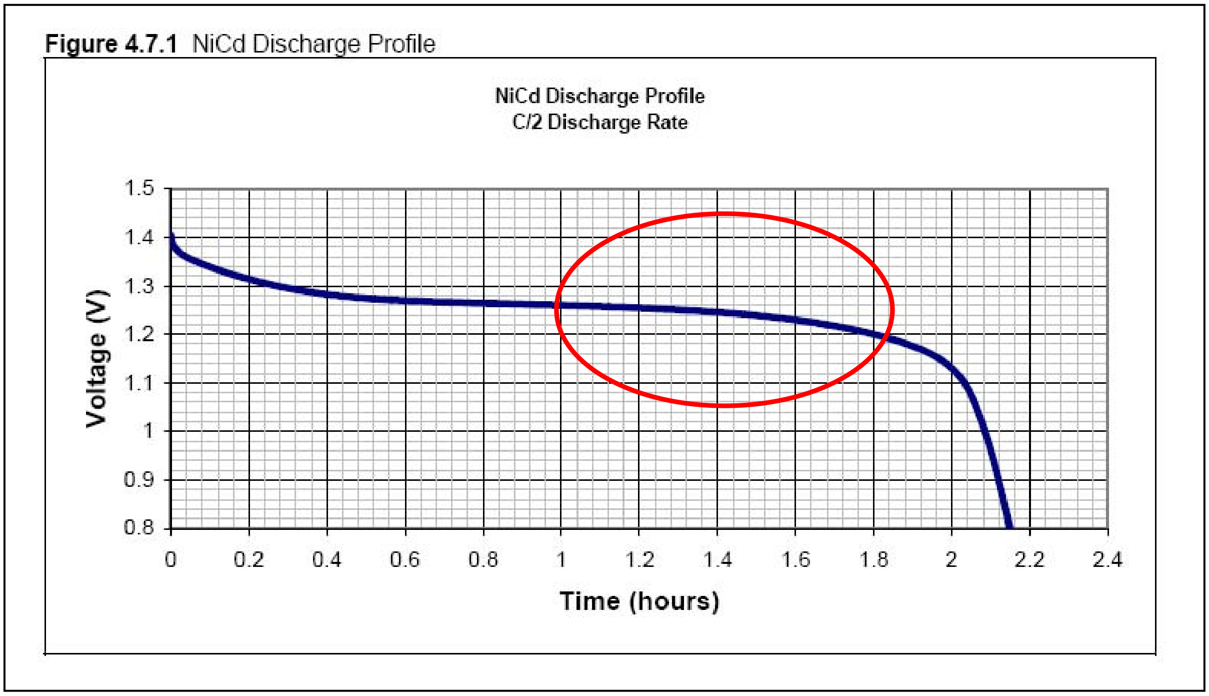
NiCd batteries

I have spent a great deal of time over the last year learning about NiCd (Nickel Cadmium) batteries. I was fascinated to discover that NiCds are one of the earliest materials used to make batteries, as far back as 1899. My folder has grown to more than 2" thick and due to their popularity and good fit for so many applications there is quite a bit of information about them.

Benefits of NiCd batteries for satellite usage

- Tested in space and proven extremely reliable
- Low weight for given amount of energy
- Long cycle life
- Good charging efficiency
- Little voltage change during discharge
- Low internal resistance (high current delivery)
- Non-critical charging conditions

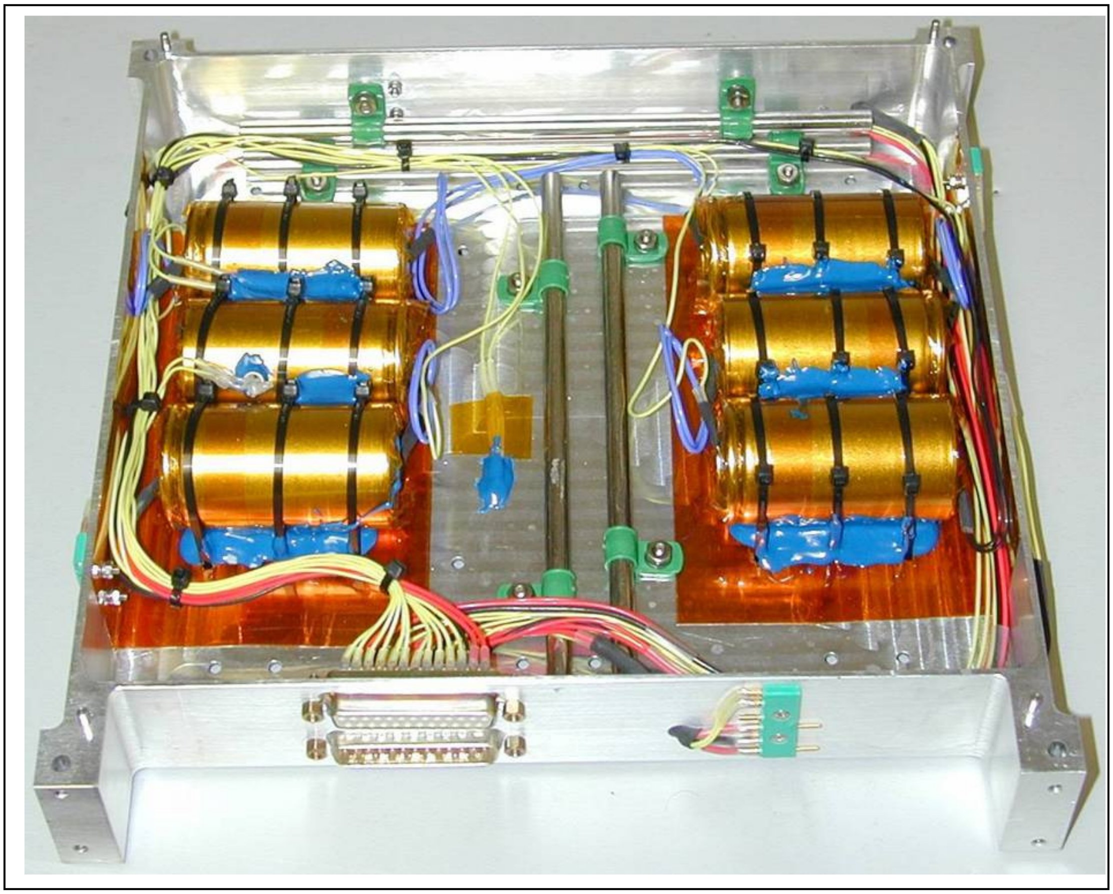
Figure 12. NiCd discharge profile



Each of the six NiCd cells in AO-51 has a nominal operating voltage of 1.2V. You can see in Figure 12 that the initial voltage starts out at greater than 1.2V but quickly moves to 1.2V, and stays there until it reaches the 'knee' and then quickly drops off.
The AO-51 batteries give us a working voltage of about 7.6V mid discharge.

NiCd Discharge Rate
The main thing to consider when describing a battery discharge profile is the amount of current used at a particular time. Whether the current is spiking or constant, and how much current is being drawn effects the discharge curve. The load on the AO-51 batteries is constant while in eclipse, unless something happens. To quantify the discharge rate of batteries the term 'C' is used to describe the discharge rate on a battery. A 1C rate means that a 1000mAh battery will provide 1000mA for one hour. The same battery discharged at 0.5C or C/2 will provide 500mA for two hours. AO-51 has 4 Ah batteries.

Figure 13. AO-51 NiCd battery tray



Depth of Discharge
The amount of discharge that a battery experiences before being recharged, effects its lifetime. The deeper the discharge each cycle, the shorter the lifetime.

Some representative numbers for standard ground based cells are:

- 150-20 cycles at 100% depth of discharge
- 400-500 cycles at 50% depth of discharge
- 1000+ cycles at 30% depth of discharge

The AO-51 cells are rated at 50,000+ cycles.

So, 14 cycles/day * 356 days/yr = 5110 cycles/yr, and 50,000/5110 = 9.78 years.

Batteries reaching their lifetime are traditionally one of the main failure in satellites, so we have many years of battery life left for AO-51.

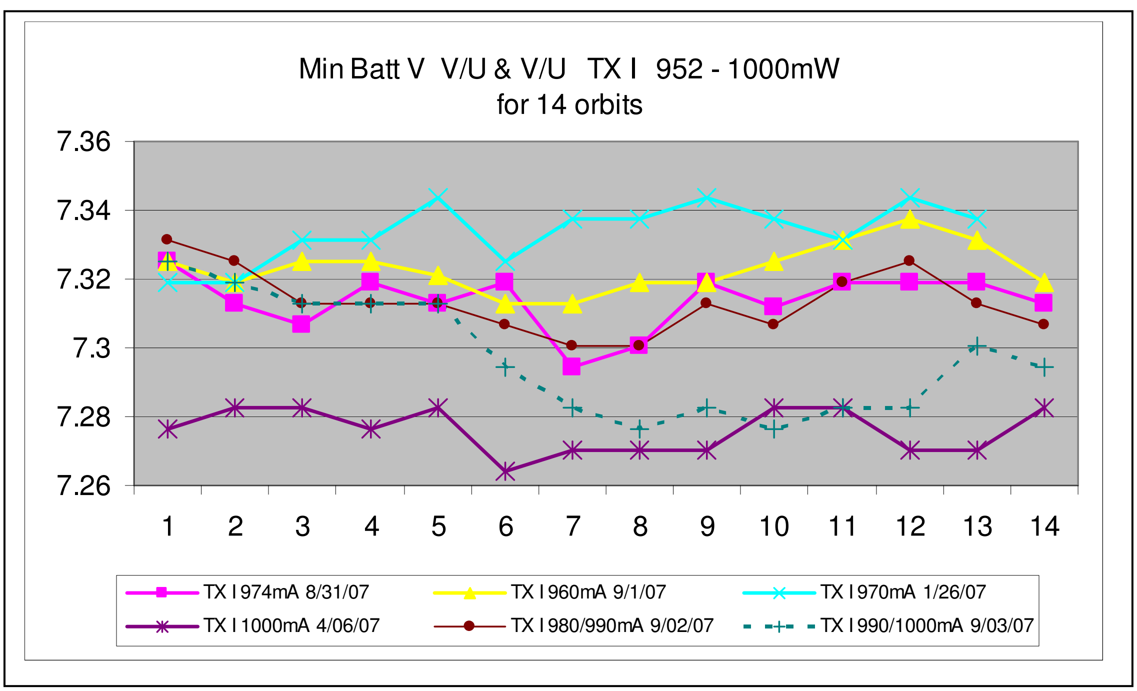
We ran AO-51 at about a 20% depth of discharge for the first 2.5 years. Current information from other AMSAT groups say 35-50% might be a better discharge level for satellite batteries. As such I have adapted the depth of discharge for AO-51 this year. Currently the depth of discharge is managed by changing the total transmitter current.

NiCd Memory?

NiCd batteries have been labeled with a "memory effect." It has been noticed especially in satellites, which have constant shallow discharge levels. The effect is accused of causing the batteries to quickly drop to this constant level and not get a satisfactory discharge. A good deal of the literature confirms observing the effects, but there are different opinions as to the cause.

I have been discharging the AO-51 batteries to different levels on a weekly basis and then a few times a year I do a deeper discharge (reconditioning) down to 50%.

Figure 14. AO-51 depth of discharge graph



AO-51 Transmit Current

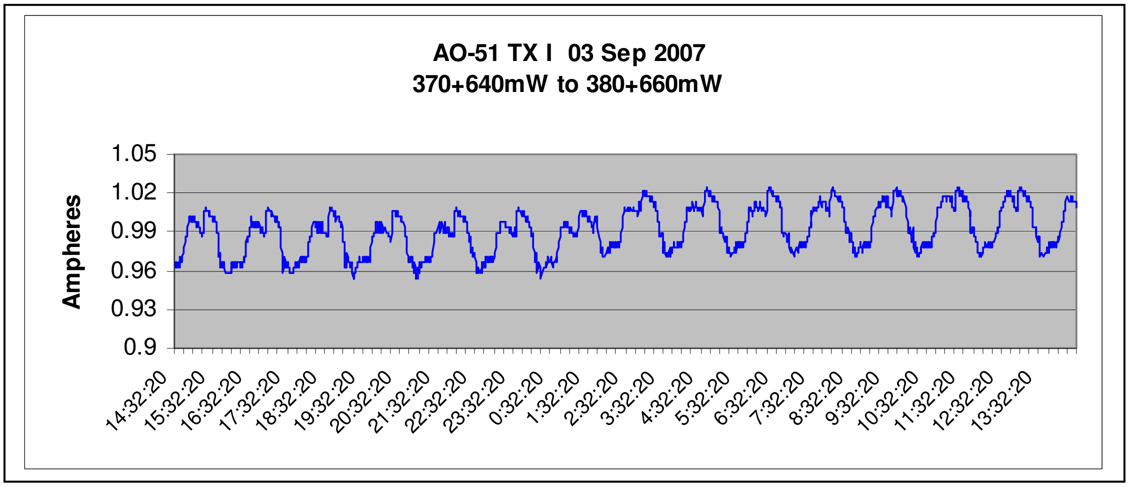
The AO-51 satellite can run multiple transmitters at the same time, but the limiting factor is the current consumption during eclipse. As you can see in Figure 15 the transmitter current is pretty stable. The TX I during the first half of the graph was :

TX A 370 mW + TX B 640 mW (no SQRX) = 1010 mW → ~ 980 mA

About twelve hours into the pass the transmitter output was increased.

TX A 380 mW + TX B 660 mW (no SQRX) = 1040 mW → ~ 1000 mA

Figure 15. Basic TX I graph for one day

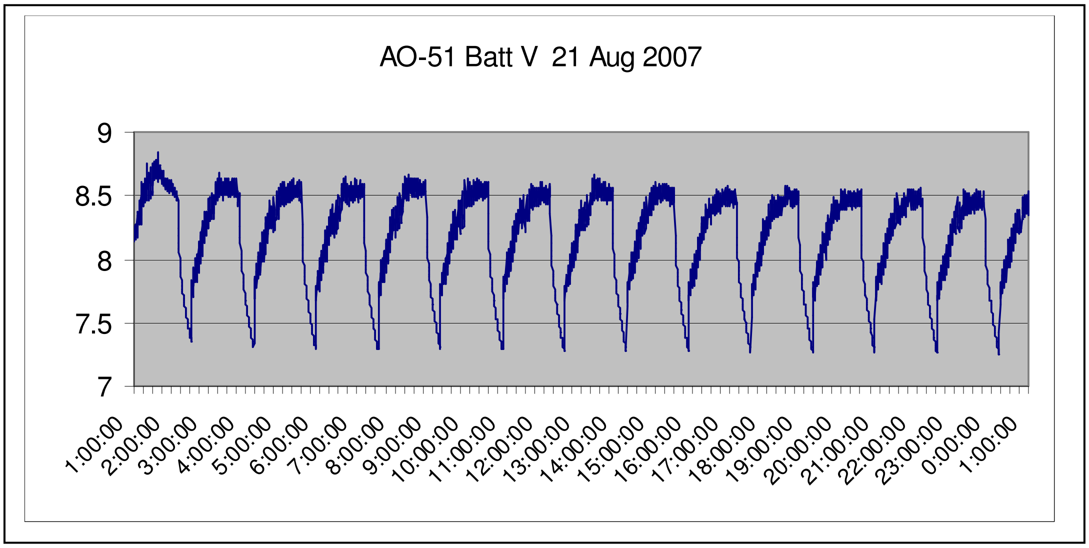


August learning event

On August 21st 2007 I switched AO-51 into V/U and L/U modes with the SQRX on. I had made adjustments to the transmitter output power to compensate for the power used by the SQRX. I cannot see the telemetry output when TX A has the analog mode of the SQRX receiver connected to it without switching out of that mode and into digital operation. I generally take one pass every couple of days and download some telemetry to keep an eye on the satellite. I can send commands to the satellite to start WOD (Whole Orbit Data) storage, but don't have any feedback that it actually received the command and started the telemetry file. Experience has shown me that I have a very high success rate doing this, so I assume that it happens. I got telemetry from AO-51 after about 24 hours and it looked OK on a cursory examination. See Figure 16.

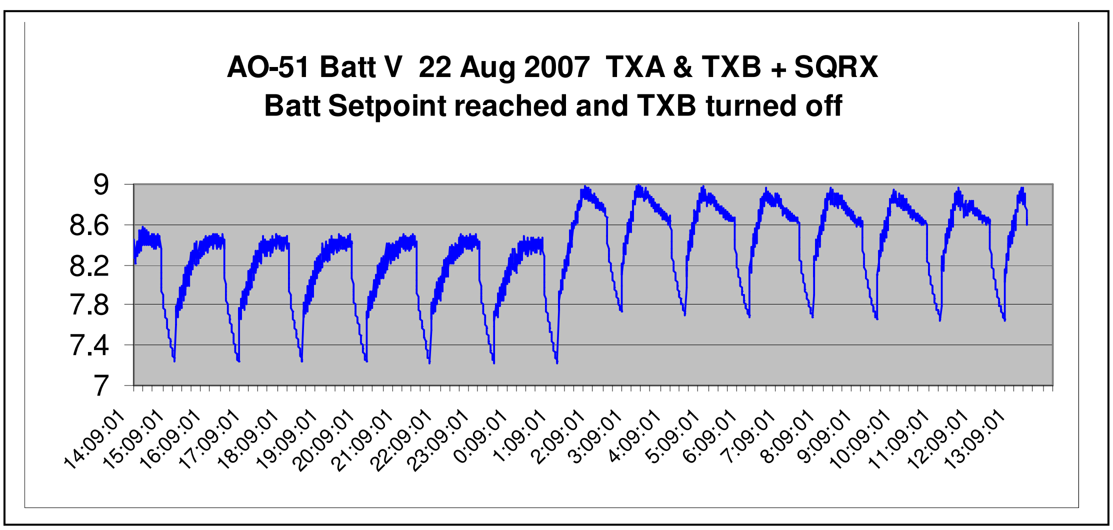
Figure 16 shows a standard looking Battery Voltage graph like Figure 7. What I had not picked up on was the slow decrease in minimum battery voltage and the slow decrease in maximum battery voltage – i.e. a fully charged battery.

Figure 16. AO-51 battery voltage 20 Aug 2007



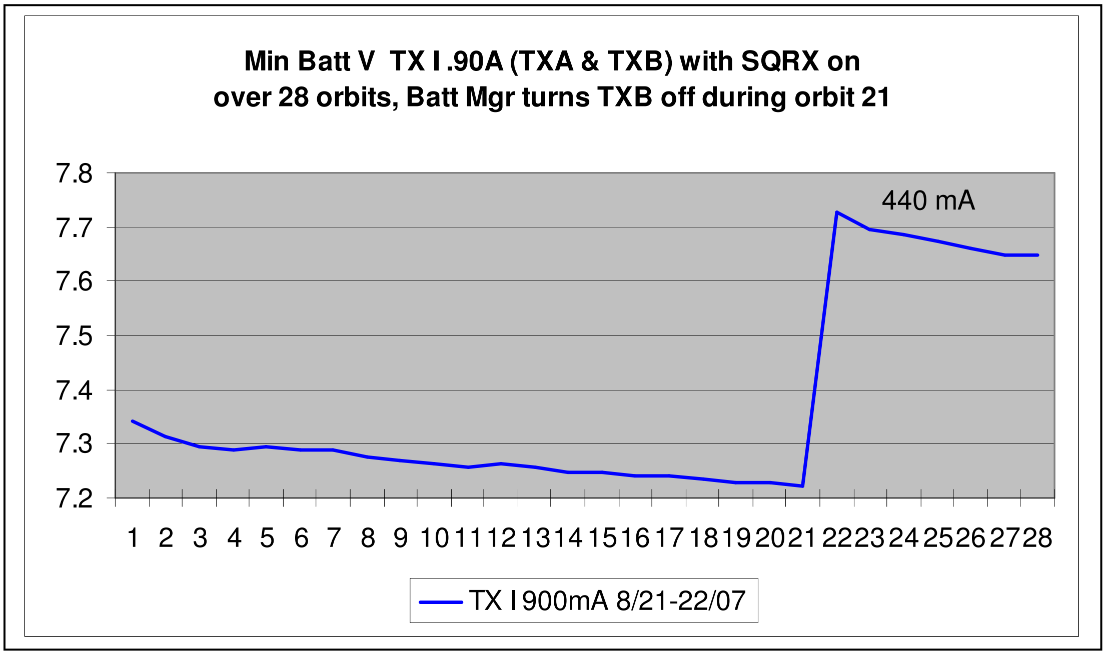
So, as the minimum battery voltage decreased over 36 hours it finally reached Setpoint #2 and turned off TX B. This caused a number of things to happen in addition to stations on the earth not being able to use the normal V/U repeater. As you can see in Figure 17 the minimum battery voltage was now around 7.7 volts rather than 7.28 where I like to keep it. The other thing that jumps out is that the maximum battery voltage now goes up to almost 9 volts. Looking more closely at Figures 17 & 18, you can see that the minimum and maximum battery voltage is still slightly decreasing each orbit.

Figure 17. AO-51 battery voltage 22 Aug 2007



In reviewing this event I tried to determine where my calculations had gone wrong, so as not to repeat the mistake. I graphed the minimum battery voltage for two days on a single graph. The pattern then became obvious. See Figure 18.

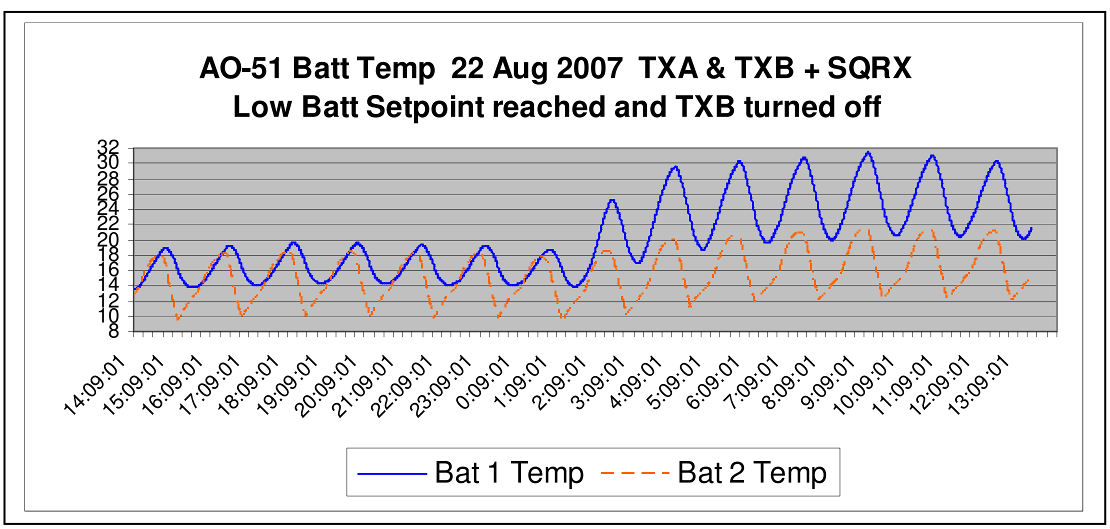
Figure 18. AO-51 minimum battery voltage 21 – 22 August 2007



Relationship between TX Power and Battery Temperature

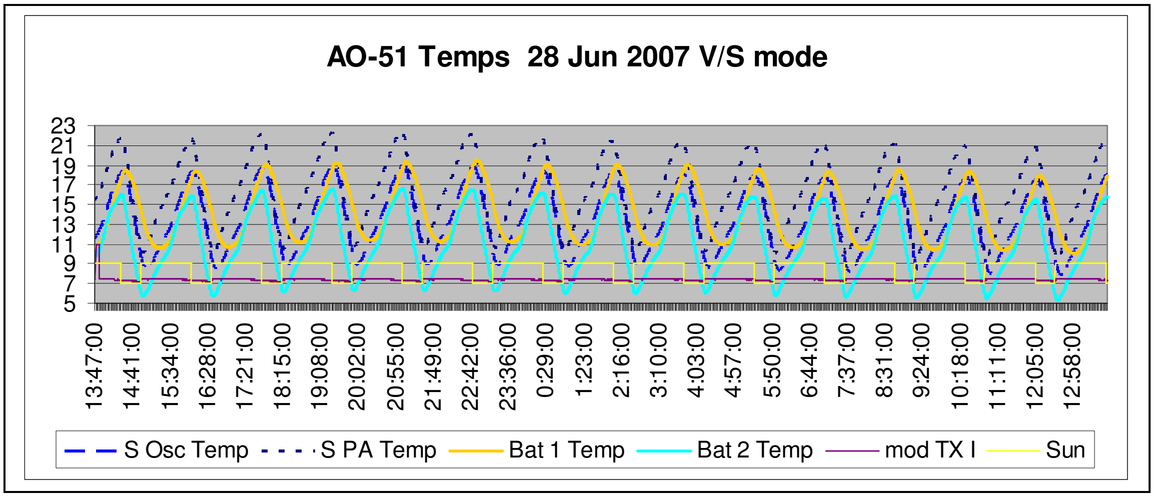
One of the important things to look at during low transmit power is the battery temperature. Historically it tends to rise. Just as expected the battery temperatures rose. During the early part of Figure 18 TX A was 360 mW and TXB was 500 mW (860 mW total). When TX B went off the total TX power was 340 mW. The maximum battery temperatures went from 19 ºC to about 31 ºC. Another thing to notice is that the temperature swing is much greater with Bat 1 after the power decrease.

Figure 19. AO-51 battery temperatures during different TX power levels



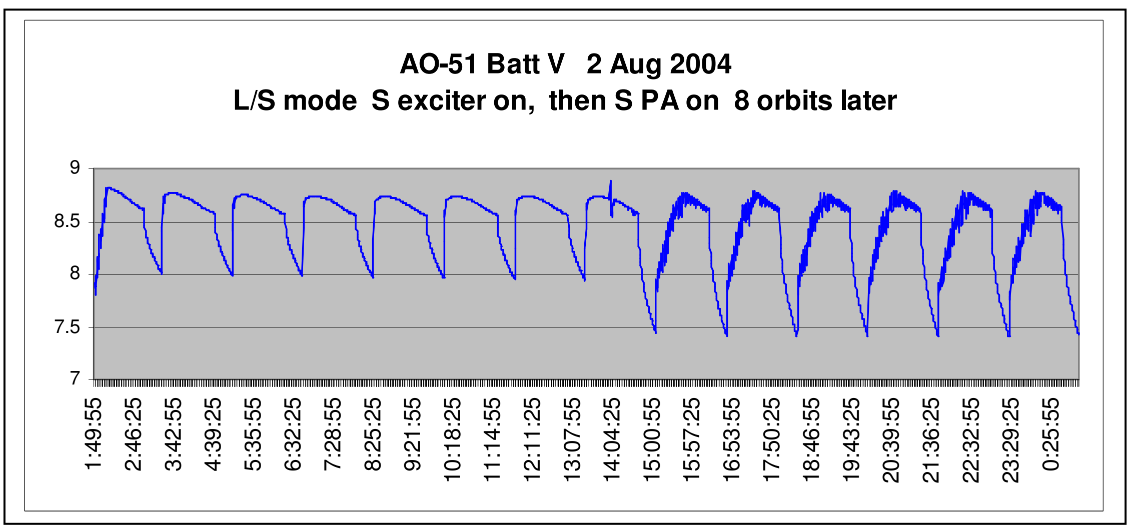
The S-Band transmitter is said to produce 960mW of power. In mode V/S the SQRX is off and the transmitter current is 746 mA, the minimum battery voltage averages about 7.32 V. You can see in Figure 20 that the temperatures all look good in this mode. Even the S Power Amplifier temperature is not bad. All the temperatures are in the standard teens to low twenties.

Figure 20. Battery voltage and temperature during V/S mode



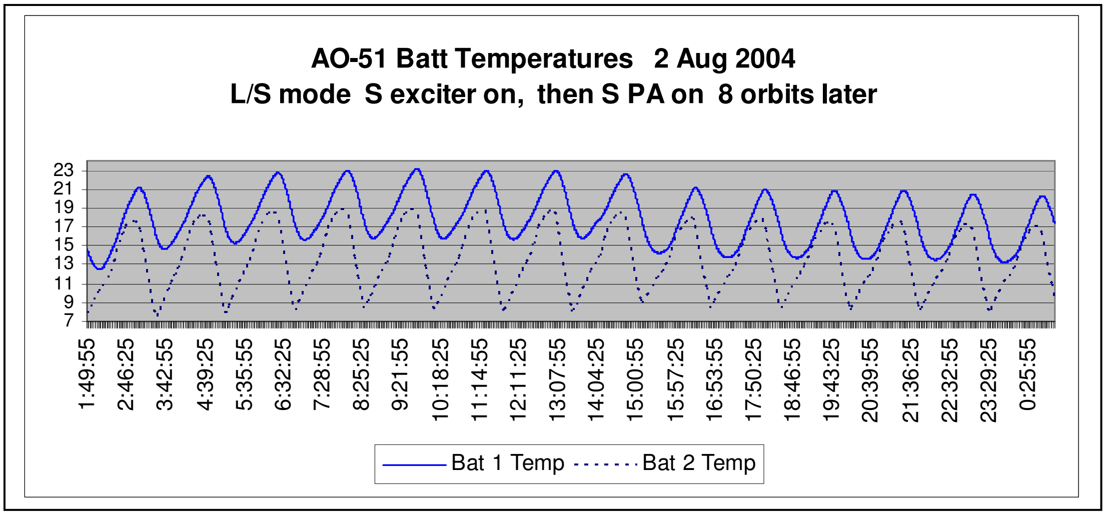
Back on 2 August 2007 I didn't get the S-Band power amplifier turned on before the satellite got too low. The result was that the very low power S-Band exciter and the SQRX and the system were the only things using power in the satellite.

Figure 21. AO-51 battery voltage during S exciter and S exciter and PA operation



The transmitter current goes from 25 mA to 730 mA during this time. The obvious question is what happened to the battery temperatures during this event?

Figure 22. Battery temperatures during S exciter only and S exciter with PA operation



Surprisingly the battery temperatures are normal. With very little TX power the system does not get as warm as when it is in the intermediate TX power range of 300-400 mW. Once it is 730 mW or more the battery temperatures are normal. The worst case seems to be when the power is in this intermediate range.

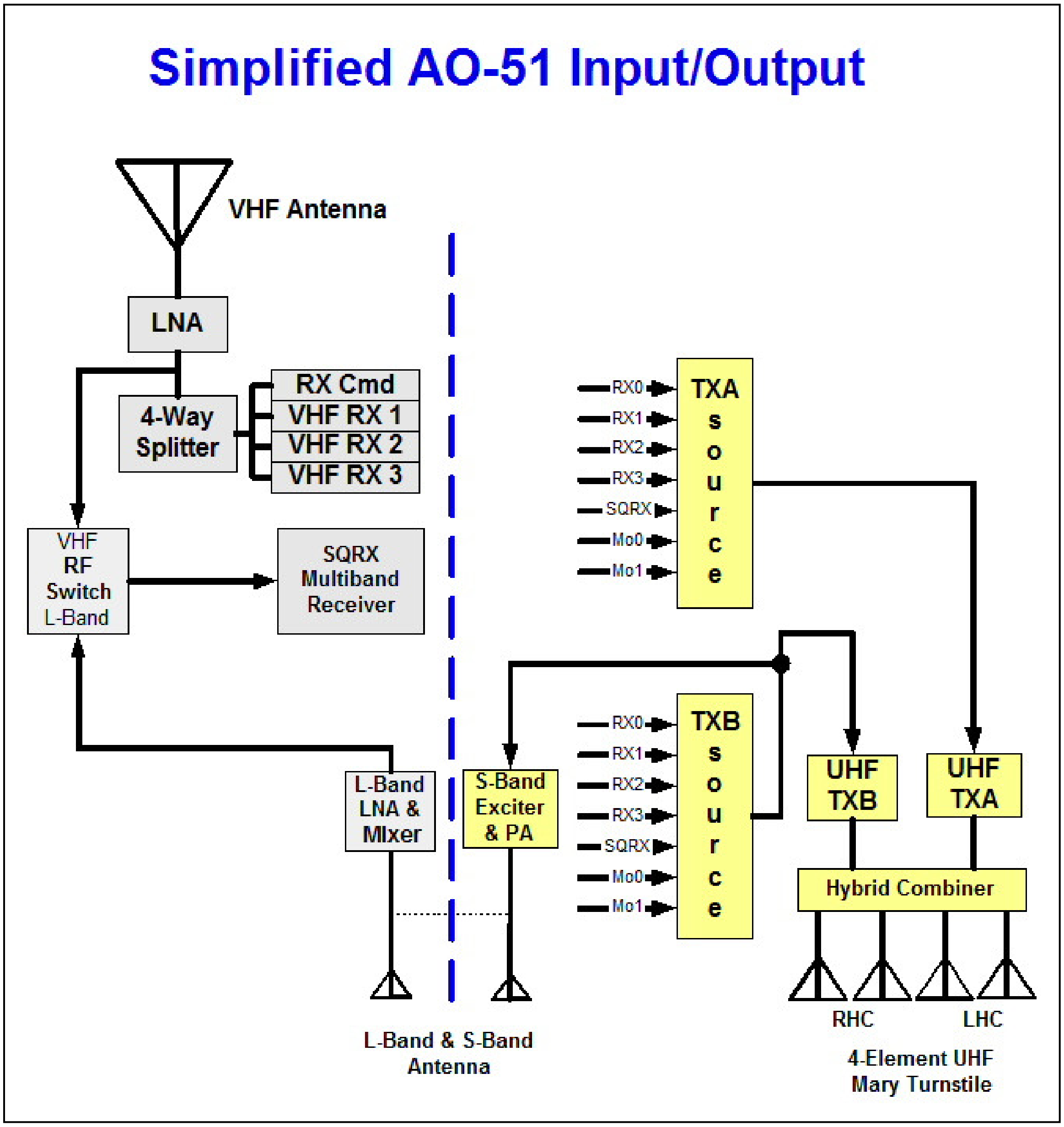
AO-51 Operating Modes

At the beginning of this paper I listed the basic operating modes of AO-51. This is a very versatile satellite in that it can have two U band transmitters operating simultaneously, U and S-Band transmissions simultaneously and have either 2M or L-Band signals for an uplink. The SQRX is capable of many frequencies, but the available antennas limit its use of these frequencies.

We have a number of modes and frequencies that we can use with this satellite. I have been quite pleased that there is more and more activity on our special modes. The AO-51 Operations team have been scheduling a number of interesting modes the last few months and attracting a good deal of interest. We are also seeing more requests for these modes.

Figure 23 is a simplified diagram of the various inputs and outputs that AO-51 is capable of . The operations team welcomes your suggestions about new modes. Send them to ao51-modes@amsat.org and we will certainly make an effort to try to schedule it.

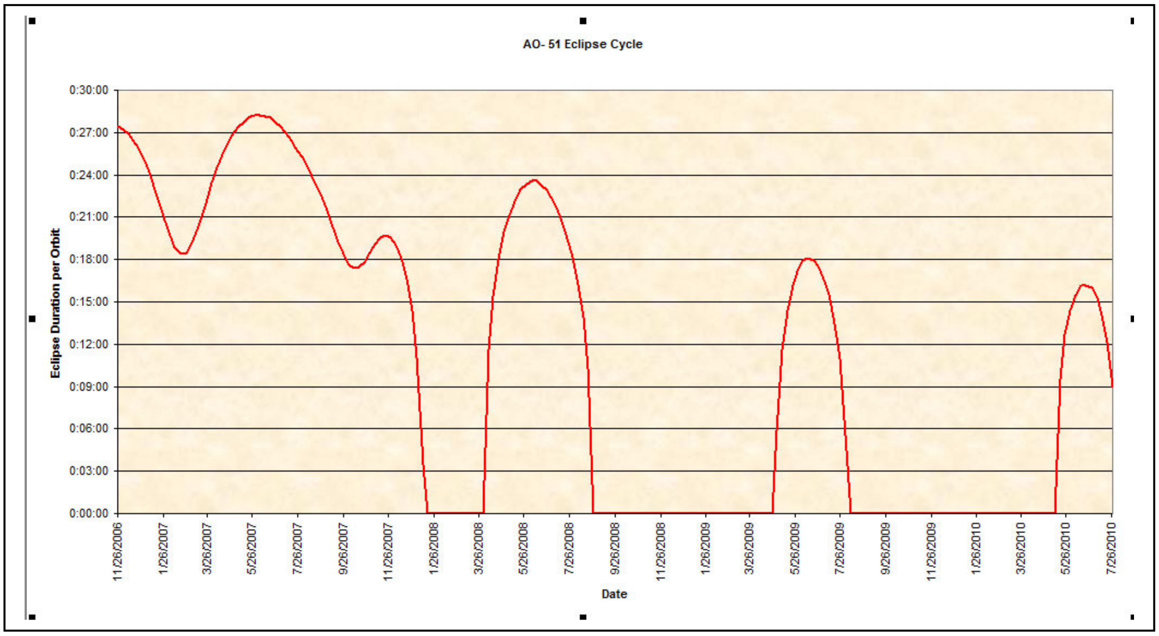
Figure 23. AO-51 RX/TX Matrix



A New Operating Environment for AO-51

Looking ahead a few months, we see that AO-51 will experience a new operational environment. AO-51 will enter a period of no eclipse in January 2008 for about three months, then return to eclipse for about 3 months then back to no eclipse for about 8 months. This is a common occurrence for polar orbiting satellites, but a first for AO-51. The Engineering, Operations and Command teams are all looking at a number of strategies to best maintain the satellite. SpaceQuest had been through this with similar satellites and assures us that AO-51 will be fine.

Figure 24. AO-51 future eclipse cycles



Summary of AO-51 Battery and Power Management

- Manage the TX output power levels to get through eclipse
- Use high power or no power to keep the battery temperatures under control
- Monitor the satellite eclipse time
- Optimize the transmit power levels during no eclipse period
- Develop configurable auto transmit power control software

References

Buchmann,Isidor; *Batteries in a Portable World;* http://www.buchmann.ca

CBA II (Computerized Battery Analyzer) , West Mountain Radio

Dong, Shuonan; *International Space Station Nickel Hydrogen Extended Battery Discharge Model Analysis;* MURJ, Volume 11, 2004

http://www.batteryuniversity.com/print-partone-16.htm

Jaycar Electronics Data Sheet, NICADS.pdf; *Using and Charging NI-CAD Batteries*

Mason, G.E.; Daman, M.E.; Waller, J.S.; Hayden, J.W.; *Lunar Prospector 5 Ah Super NiCd battery performance characteristics*; Battery Conference on Applications and Advances, 1998., The Thirteenth Annual, Volume , Issue , 13-16 Jan 1998 Page(s):103 – 106

Smith, Gould, WA4SXM; *AO-51 Development, Operation and Specifications*; V1.0, AMSAT, January 2005

SpaceQuest, Ltd.

Timmerman, Paul J.; *An Improved Theoretical Ni-Cd Battery Performance Model*; AIAA-94-4039-CP

Suitsat-2/Radioskaf-2: The second Amateur Radio Space Suit project and stepping stone to future small amateur satellites.

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ABSTRACT.
This paper describes the plans for the second Suitsat satellite. The first Suitsat captured the attention of people the world over including many who were not radio amateurs. The second Suitsat will make many improvements as well as serving as a test bed for future satellite systems.

SuitSat-1/Radioskaf-1 caught the attention and fascination of the world, garnering a large amount of newspaper, magazine, radio and TV reporting. Even more importantly, SuitSat-1 captured the imagination of students and schools! Amateur astronomers strained their eyes and cameras to get a glimpse of the eerie sight of SuitSat-1/Radioskaf-1 floating in space. Amateur radio operators listened for hours to hear its signals. Many sightings and signal reports were posted to a special web site proving that sparks of excitement were coming from the public over the space program. SuitSat/Radioskaf-1 attracted nearly 10 million hits to the suitsat website during its mission!

The little satellite was such a success that plans were developed to produce a second SuitSat/Radioskaf. To do this, the international Amateur Radio on the International Space Station (ARISS) team discussed it at their delegates meeting in October 2006. Architect of Suitsat-1/Radioskaf-1, Sergey Samburov, RV3DR, discussed this idea with the ARISS team and everyone was enthusiastic about the potential of a second SuitSat/Radioskaf.

SuitSat-1/Radioskaf-1 was a simple satellite made from a surplus Russian *Orlan* spacesuit fitted with a single beacon amateur radio transmitter that ran on Russian spacesuit batteries. It had no capability to receive commands and was destined to live only a short while because it had no solar panels to replenish its batteries.

SuitSat-2/Radioskaf-2 is based on SuitSat-1 successes but there are many enhancements, such as amateur radio transponders, being made.

The intent is that a future ISS Expedition crew will release SuitSat-2/Radioskaf-2 during a space walk. The suit will have a voice ID in a number of languages plus telemetry and these will be transmitted along with images as it orbits Earth. The unusual spacecraft's radio signal will be heard around the globe.

It is hoped that SuitSat-2/Radioskaf-2 can be launched during a spacewalk to possibly commemorate an occasion such as the 125th birth anniversary of Robert Goddard and the 150th anniversary of the birth of the famous Konstantin Tsiolkovsky, the great-grandfather of Sergey Samburov.

Enhanced Capabilities of SuitSat-2/RadioSkaf-2

SuitSat-2/Radioskaf-2 has a special new job added to it's mission that is considered very important to the amateur satellite community. That new addition to it's mission is to be a prototype and test bed for testing new concepts in building amateur satellites.

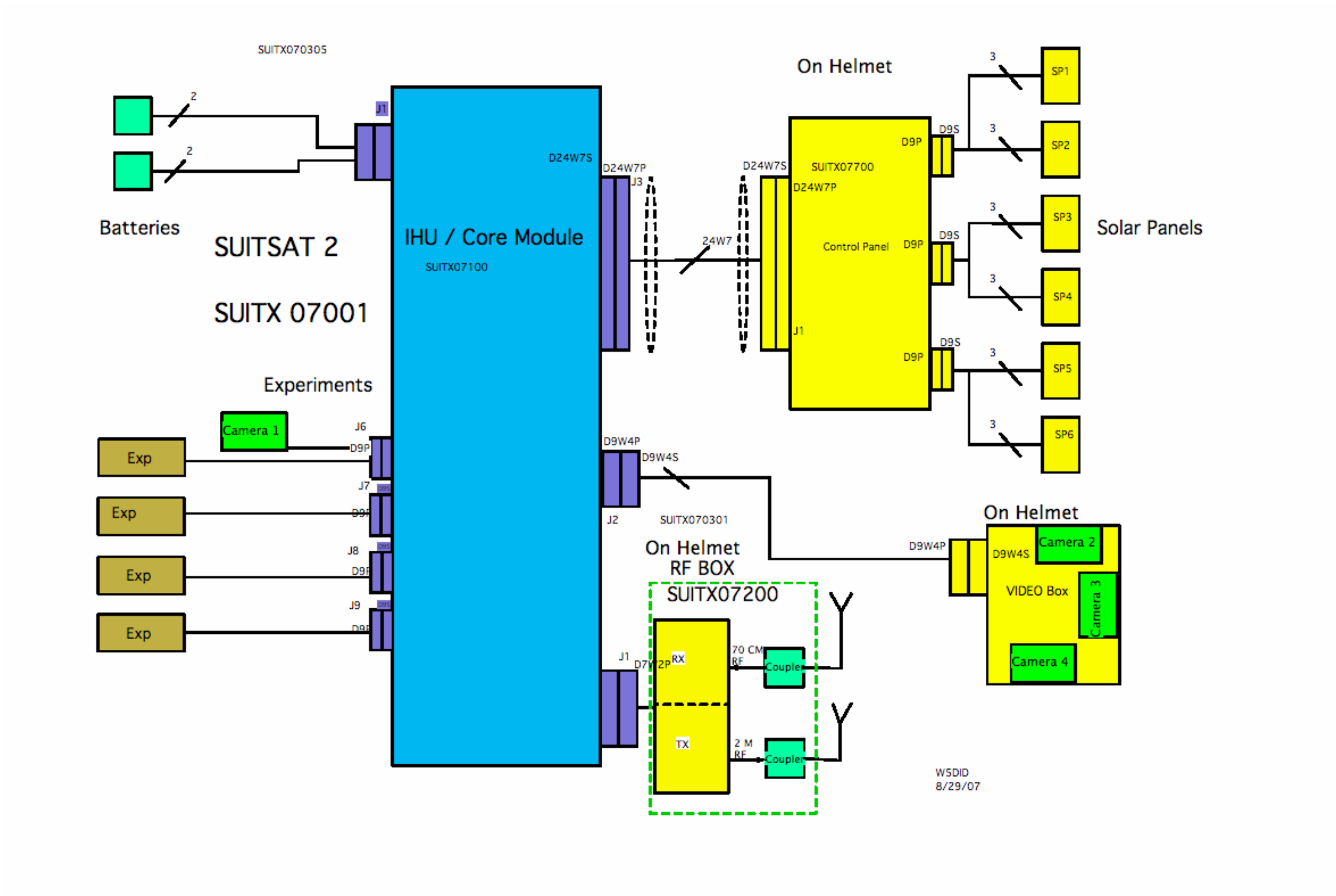
SuitSat-2/Radioskaf-2 has all new electronics. Included all the features of SuitSat-1/Radioskaf-1 and all the features that were planned but could not be included on SuitSat-1/Radioskaf-1 due to the launch time pressures. In addition to those features, SuitSat-2/Radioskaf-2 will have solar panels and a Digital Signal Processor (DSP) for enhanced radio capabilities. It will also have a power system and a transmitter and receiver that are prototypes of those planned for AMSAT's next satellite named Eagle.

Primary objective

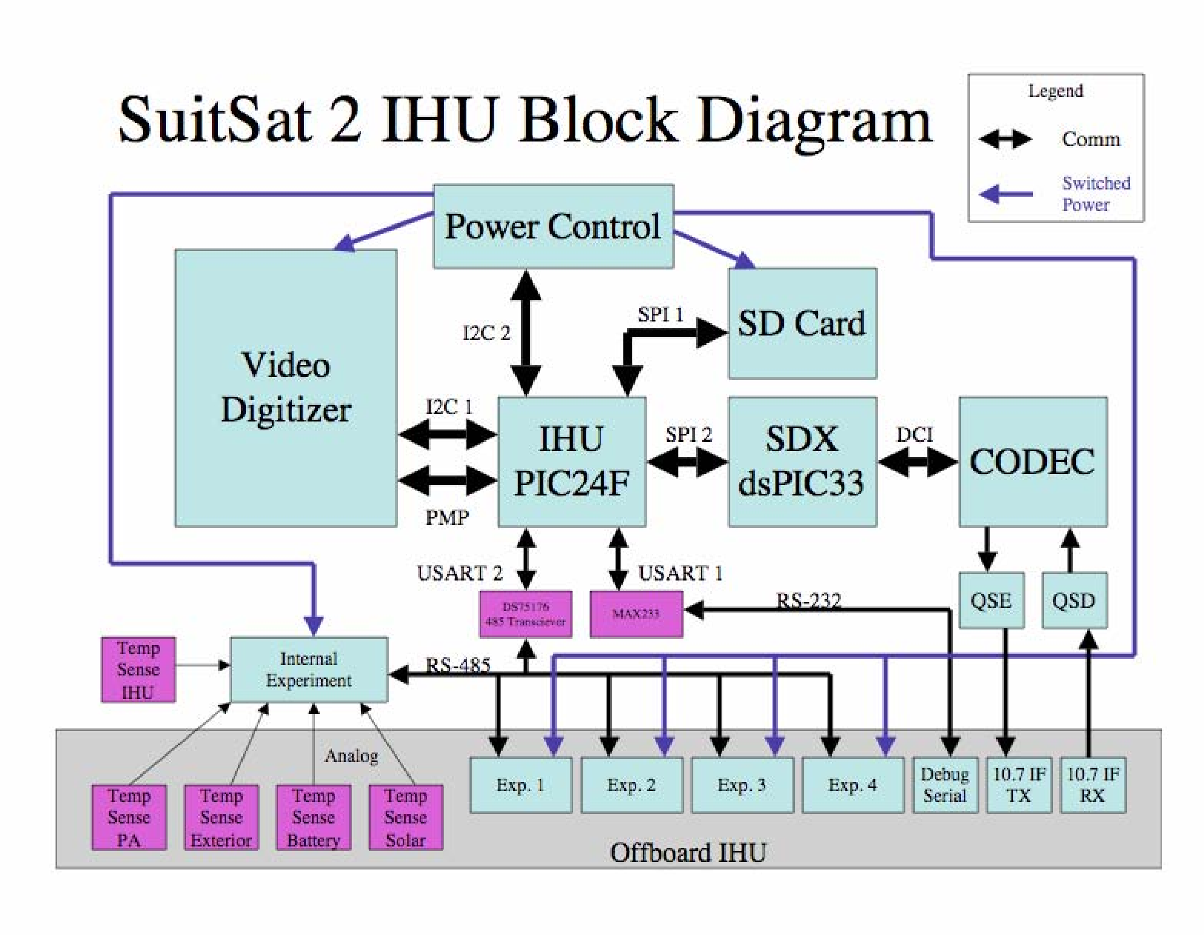
The primary objective of SuitSat-2/Radioskaf-2 will be to transmit commemorative and educational messages . The secondary but very important objective will be to use the suit to serve as a test vehicle to test new systems that are planned for future amateur radio satellites and future ISS deployed satellites. It will also carry materials such as photos and documents developed through an international outreach program as a part of its educational mission.

SuitSat-2/Radioskaf-2 will build upon the SuitSat-1/Radioskaf-1 design.

The safety interlock system designed and approved for SuitSa-1t/Radioskaf-1 will be incorporated into SuitSat-2/Radioskaf-2. There will be a new transmitter and receiver designed to incorporate a down converter that will convert the 70 cm signals down to a 10.7 Megahertz (MHz) intermediate frequency and then an up converter to convert the 10.7 MHz intermediate frequency up to the 2 meter transmit frequency. This RF system design will be reusable on future small satellite designs. This system is depicted in the block diagram in Fig.1. This is similar to the system used on larger satellites so it will be a stepping stone for the amateur satellite community that fits well with AMSAT's and the ARISS' teams desire to utilize this opportunity to test new designs for future satellites.



SuitSat-2/Radioskaf-2 will have a main computer which is called the Internal Housekeeping Unit (IHU). This computer provides the overall monitoring and control functions needed to keep everything working properly. A block diagram of the IHU is shown in figure 2.



The IHU will also include the same safety interlock circuit that was included in Suitsat/Radioskaf-1. This circuit performed flawlessly on SuitSat-1/Radioskaf-1 and has been through the NASA safety approval process. The IHU board will also include circuitry to implement the Video and Slow Scan TV (SSTV) system. There will be four cameras on SuitSat-2/Radioskaf-2. All will be miniature cameras that will be polled at intervals and the images examined to determine if there is a suitable image in the field of view. If there is a useable image, it will be sent down as a SSTV image. These cameras will be powered one at a time and at specific intervals.

Experiments

There will be four ports for experiments. The experiments will be supplied with 5V DC power. There will be a signal, at regular intervals, that tells the experiment that it can now download data to the IHU. Since this is a very low power satellite, the power supplied will be small. A document has been developed that specifies the interface requirements and limitations.

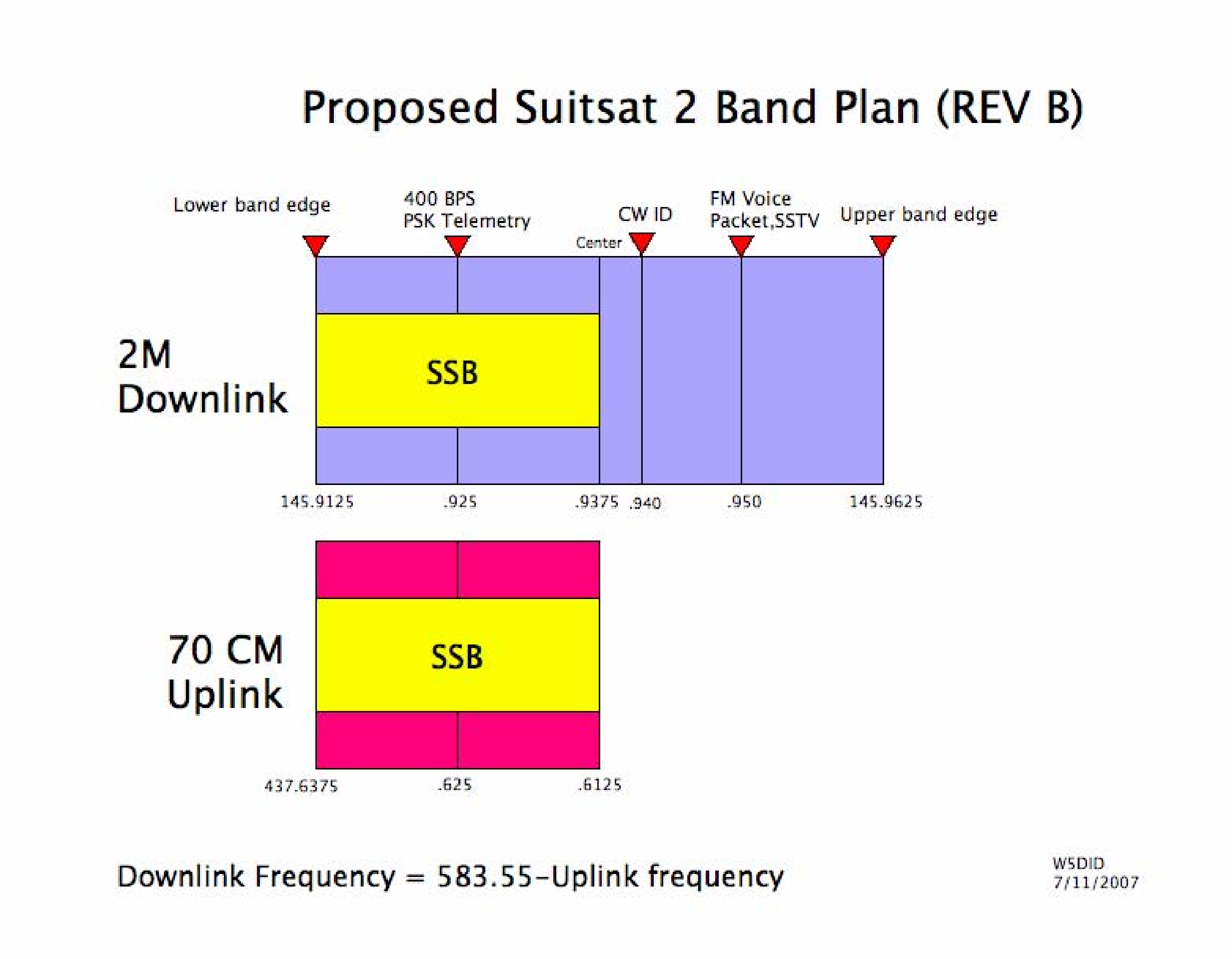
Radio

The SuitSat-2/Radioskaf-2 transmitter and receiver will be different from the SuitSat-1/Radioskaf-1 system. It will be based on a Software Defined Transponder (SDX) system. It will consist of two major components: the Radio Frequency (RF) Module and the Digital Signal Processor (DSP) module. The RF module will contain an up converter that receives a signal from the DSP module as a 10.7 MHz intermediate frequency zero dbm r.f. signal with a 50 KHz bandwidth and up converts it to 145 MHz signal of 50 KHz bandwidth centered on 145.9375 MHz. The system will be built, tested and delivered as a complete system including the antenna. This will reduce the possibility of problems such as was experienced on Suitsat1.

The receiver is a down converter with a 50 KHz bandwidth centered on 437.6125 MHz with an output at 10.7 MHz of zero dbm.

The combination of the Receiver and Transmitter modules constitute the essential building block necessary for a linear transponder. The addition of the Digital Signal Processor enables monitoring, manipulation and addition of signals within the passband.

The DSP processor receives the 10.7 MHz signal from the receiver down converter and processes it and outputs a 10.7 MHz signal to the transmitter upconverter. The DSP can also inject signals such as the cw ID, telemetry, audio and packet signals as determined by the software on the DSP. The proposed Suitsat/Radioskaf-2 band plan is shown in figure 3.

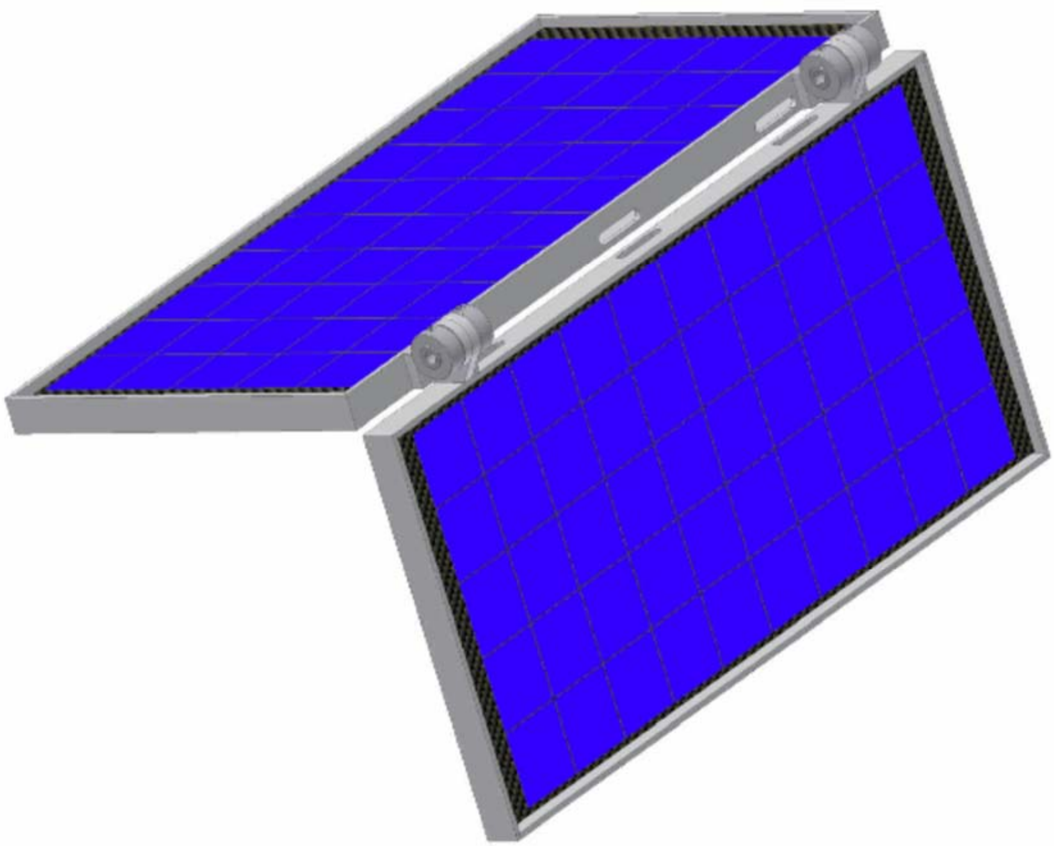


Solar Power System

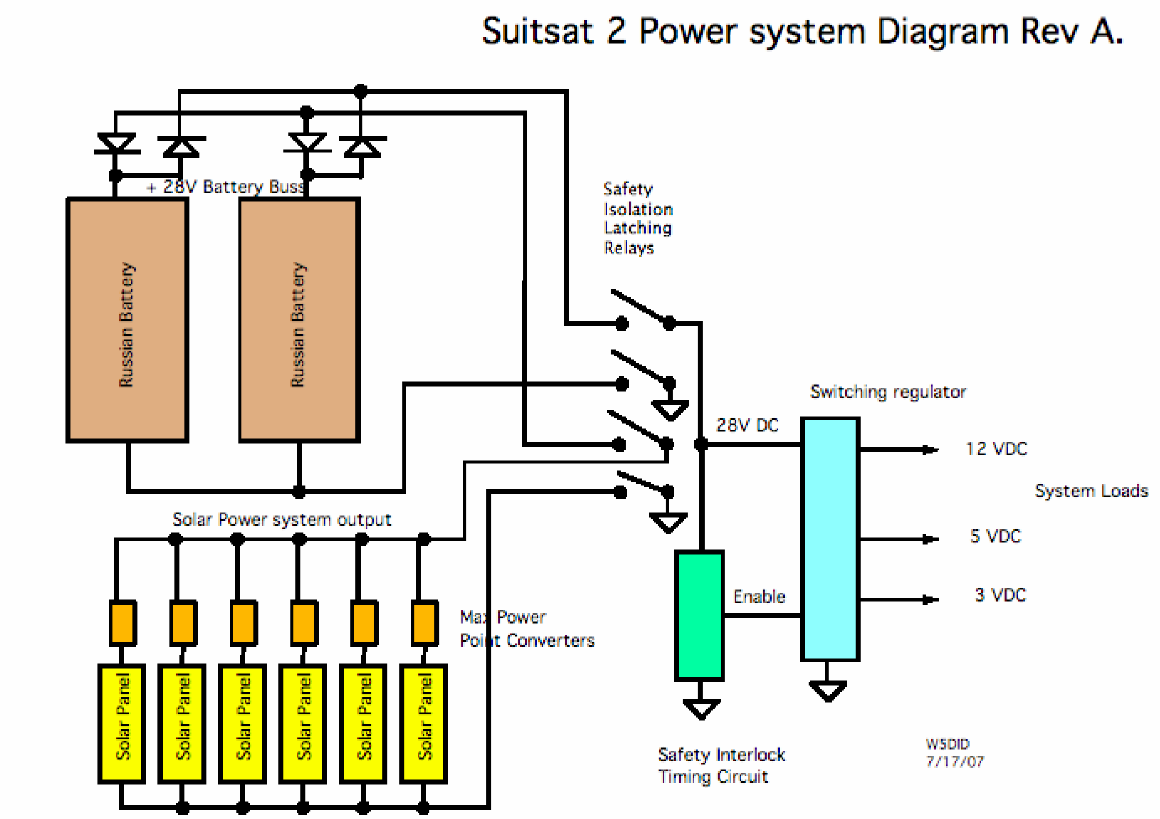
The Solar Power System consists of three major systems. The solar panels, the Maximum Power Point Converter and the batteries.

The solar panels are NASA developed panels that have flown on several NASA satellites. They were intended to be used as generic panels that were available to any new satellite being developed for the NASA Small Explorer (SMEX) program. When the program was in operation, these were state of the art panels. The SMEX program is no longer operational and these panels are surplus for NASA. They are in excellent shape and are being made available for SuitSat-2/Radioskaf-2. The panels will be mounted on the exterior of the Russian Orlan suit. There will be six panels mounted. Each needs to be facing a different direction so that power is received regardless of the orientation of the suit. . The idea is to fabricate a frame similar to a picture frame out of 3/4 inch angle aluminum.
The panels will be mounted inside the frame which is hinged to another frame. The two will fold together similar to a dual picture frame. The panels will face each other in the closed position. Three velcro double sided straps will be threaded through slots in the frame behind the panels. The two outer straps will

be threaded through the slots on only one panel. The third strap will be threaded through both panel's slots.
The panels will be held closed using all three straps until ready to be installed onboard ISS. Installation will be accomplished in three steps. First the two outer straps (the ones threaded through only one panel) will be loosened from being wrapped around the panels and attached to the leg or arm of the suit by wrapping the loose end of the velcro strap around the leg or arm and fastening it back to the other end of the same strap. The third strap will remain fastened holding the panel frames closed. The electrical cables will be connected and secured in place while still inside the cabin. After taking the suit outside, the third velcro strap will be disconnected from it's self and pulled around the leg and fastened to the opposite end thus opening the frame and exposing the panels. The cable will feed through the hole in the center of the hinges and through the side of the panel frame. One cable will have wires for both panels. This concept is illustrated in Figure 4.



A block diagram of the power system is shown figure 5.



These panels can provide 19 watts each when facing the sun. As configured they can provide about 5 watts average power over an entire orbit if operation during eclipse (nightime) is included.

Operating Modes

The SuitSat-2/Radioskaf-2 software will determine the operating mode based on available power from the batteries. There will be four basic modes which are:

Mode	% Power	CW	400BPS	FM Voice Msg.	Packet Data	SSTV Photos	SSB Transponder
4	25	X					
3	50	X	X				
2 (Default)	75	X	X	X	X	X	
1	100	X	X	X	X	X	X

Continuous Wave Identification (CW ID)

The CW ID will consist of the Suitsat 2 station ID, experiment data and a random Ham operators call. The list of random calls will be assembled by the ARISS representative from each of the ARISS participating partners. The list will consist of ham operators who have made a significant contribution to the Amateur Radio In Space programs including manned and unmanned satellites. The entire assembled list will be sent at random. There will also be a contest to see who can gather the most calls.

400BPS Telemetry

The 400 bps telemetry will be receivable by those who have an AO-13 or AO 40 telemetry decoding program or equivalent hardware decoder. It will be sent without the error correction bits in order to make the sequence shorter and to include legacy systems.

Slow Scan Television (SSTV)

The SSTV system will include 4 cameras on the suit pointing in different directions. The video system will examine the signal from each camera in sequence and capture a picture if there is anything in the field of view. This picture will be sent down on the FM voice channel in the Robot 36 format.

Commands

SuitSat-2/Radioskaf-2 is required to have some commands since it will be solar powered and has the potential need to be turned off. These will include shut down, reset, power levels and other commands yet to be determined.

Educational Outreach.

The SuitSat-2/Radioskaf-2 Team set up an educational group made up of Frank Bauer, KA3HDO; Rosalie White, K1STO; Rita Wright, KC9CDL and staff from Johnson Space Center Education Office, including Matt Keil, KE5ONH. Various members from the SuitSat-2 Team, along with Carol Jackson, KB3LKI, have assisted this group in many helpful ways.

SuitSat-2 will be an even greater force for educational outcomes than was SuitSat-1. Rita Wright, a former schoolteacher, has designed three levels of lesson plans (that were reviewed by her colleagues/teachers) about technology and space for children as young as 5 years old and up to 18 years old.

Voice messages from all over the world have been solicited from ARISS delegates in order for SuitSat-2 to include global greetings. Students' creative materials and classroom technical work are being solicited, and will travel into space with SuitSat-2.

Scouts have assisted with assembling the circuitry boxes for SuitSat-2.† College students have designed and tested many of the SuitSat-2 circuits.

Accomplishments Specific to Education

SuitSat-2's educational group discussed activities revolving around SuitSat-2 for youth of various ages and also some public outreach ideas. The group accomplished the following tasks:

A. Multiple lesson plans finished by Rita Wright for grades K-3, 4-6, 7-12. Rita found an artist to volunteer his time to create graphics for the lessons,

B. Got a promise from Bob Twiggs for material for college students to use,

C. JSC Ed Office and ARRL were given copies of the lessons,

D. Got tentative approval from ARRL to post the lessons on its web pages,

E. Designed parental release forms for publicizing photos of youth,

F. Contacted Steve Dimse and worked to get the www.suitsat.org site updated,

G. Composed one article about SuitSat-2 for Rick Lindquist to post; worked with him on updates for a story he wrote,

H. Kept Johnson Space Center Education Office (JSC Ed Office) informed as to the group's work on educational issues of the past six months including:
   a. Trenton college students' work on SuitSat-2
   b. Scouts' work on SuitSat-2,

I. Spoke with JSC Ed Office about them eventually distributing a news release to NASA Explorer Schools, Aerospace Education Specialists and the Science Engineering Mathematics Aerospace Academies,

J. Got advice from the JSC Ed Office on:
   a. what educational statistics to collect from teachers after they've used SuitSat-2 in their classes
   b. what educational outcomes should be our priority
   c. what is the best way to get teacher evaluations,

K. Spoke to Steve Dimse who may assist with collecting recorded voices of students for SuitSat-2 and

L. The SuitSat-2 Team is developing the potential for students to design experiments for use with SuitSat-2.

Accomplishments Specific to Public Outreach

Discussions on public outreach by the educational group included the following:

A. Ways to get Public Relations (PR):
   a. Amateur Radio media – ARRL, AMSAT, Westlink
   b. Science and teacher media – ARRL PR Manager might be able to distribute news releases; Rita can post information on the ARISS teacher reflector
   c. International media – each international ARISS delegate can share news details with their IARU and AMSAT societies, and ask for PR,

B. CW calls must be gathered, managed and coordinated w/ IHU developers,

C. CD-ROM images must be gathered, managed and coordinated with IHU developers,

D. Recorded voices (mostly students): all ARISS delegates will collect and manage,

E. Joe Julicher, of the SuitSat-2 Technical Team, found a journalism student to volunteer to write news releases. Joe's YL, a teacher, will supervise the student.

Plans will continue to be made for garnering publicity for SuitSat-2. Web sites will update readers on all aspects of SuitSat-2. The Web site for SuitSat-1 attracted nearly 10 million hits during its mission as reported by Rosalie White, K1STO, ARRL ARISS Program Manager and ARISS USA Delegate. If you have an interest in volunteering to work with schools or to handle publicity and general outreach, please contact one of the members of the team.

SuitSat-2/Radioskaf-2 development and project responsibilities

At a meeting at the NASA Goddard Space Flight Center, the joint Russian and American teams agreed to the following list of responsibilities:

The Russian team will supply a Russian Orlan spacesuit already on board the ISS, which has exceeded its useful lifetime, as a housing unit for the amateur radio system.

Six solar panels will be provided by U.S. team, obtained from The NASA SMEX program at GSFC.

The Russian partners will be responsible for designing the mounting, deployment, safety and associated crew training required for the solar panel system.

A Maximum Power Point converter will be provided by the U.S. partner.

The Russian team will supply one new 28VDC battery of the same type that is certified for use on the Russian Orlan suit for SuitSat-2/Rdaioskaf-2 and a second battery to the U.S. team to be used for testing and development.

The Russian team will provide the information necessary to design the battery charging system.

The U.S. team is responsible for defining all commands and telemetry.

The U.S. team is responsible for command and telemetry formats and protocols.

The U.S. team will provide 2 center feed V antennas and associated preamps and power amps.

The Russian partner is responsible for mounting the antenna, preamplifier and power amplifier.

The U.S. team will develop and certify for flight the Internal Housekeeping Unit (IHU) with interfaces.

The U.S. team will provide and certify 4 cameras for flight.

The U.S. team will develop and provide procedures and diagrams for assembling/connecting the U.S. delivered components to our Russian partner.

The Russian team will develop the procedures for the full assembly of SuitSat-2/Radioskaf-2 on board the International Space Station (ISS).

Schedule

U.S. team will deliver hardware to Energia in Spring 2008.

High Efficiency VHF Power Amplifier with a Silicon Carbide Transistor for Space Applications

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1 - Introduction

Achieving high power efficiency from an RF power amplifier is always a desirable feature. This is particularly important in certain applications, like in space or portable hardware, where the available dc power is limited.

This paper describes a high efficiency amplifier with a Silicon Carbide (SiC) transistor, operating at 145 MHz. It was specifically designed for AMSAT Eagle's VHF downlink. SiC is a relatively new compound semiconductor technology, which provides high voltage operation, high gain, and outstanding operating temperature.

2 - Space Hardware Design Requirements

Designing electronic hardware for a satellite involves many specific requirements. As a result, a space-qualified part is many, many orders of magnitude more expensive than the same part for industrial use.

The ultimate goal for space hardware is no failure during the mission. To achieve this high level of reliability, many issues must be taken into account. A spacecraft must be able to operate in a very harsh environment, with high levels of radiation, extreme temperatures, lack of air, and severe vibration and shock during the launch.

2.1 - Vibration and Shock

Traveling to space in a rocket is not an easy ride. At liftoff and during the following seconds, the rocket engines generate elevated noise levels. This high acoustic pressure results in very intense vibrations in the spacecraft. Also, the different stages of the flight, vehicle separation and rocket firing, are normally produced by pyrotechnics, generating severe shock. Another type of shock is when the rocket breaks the sound barrier.

Most vibration occurs in the audio frequency range. Space hardware is tested on vibration tables that simulate the launch. Acoustic testing is performed on space hardware to simulate the conditions the spacecraft will encounter during its journey into space. The testing is normally done with frequencies that range from 10 Hz to 10 KHz.

Space hardware is specially designed in order to be able to withstand high levels of vibration and shock. It is common practice to use special glue-like compounds to tack down large components (toroidal cores, connectors, etc.). RF power transistors are also soldered to the heatsink, instead of attaching them with screws.

2.2 - Operation in vacuum

Due to the lack of air in space, the electronics (also called the "payload") built into the satellite must be able to operate satisfactorily in the vacuum. Since the time the rocket travels through the atmosphere is relatively short, a fast decompression will take place. It is customary to provide tiny holes in the payload enclosures in order to permit the air to escape.

Another important issue associated with the lack of air is the fact that heat cannot be dissipated by convection, like it is normally done in equipment designed to operate on the earth's surface. A heatsink in space is only good to transmit the heat from one place to another, and eventually radiate some of it to space.

The lack of convection also affects other components like resistors. Their power dissipation capability in vacuum is much lower than at normal atmospheric pressure. Surface mounted resistors and certain integrated circuits also rely on the printed circuit board copper traces to dissipate heat. Since heat is mostly conducted by the printed circuit instead of being dissipated, the via holes that connect the top copper traces to the bottom ground plane are used to conduct the heat to the heatsink, improving in this manner the heat dissipation of the electronic components.

2.3 - Radiation

The effect of radiation on electronic components is a subject of great concern in space hardware design. This is particularly important for amateur radio satellites in an elliptical orbit (also called HEO, or high earth orbit satellites, like Oscar 40), since the satellite will cross the Van Allen radiation belts that circumvolve the earth about twice a day.

Certain electronic components, like metal-oxide-semiconductor (MOS) devices, can suffer from degraded performance due to the effects of radiation to their oxide layer. This results in a drift in the device's parameters.

Other types of failures are called "single event", and are caused by cosmic rays and high energy protons. They manifest as high current transients, logic circuits momentary failure, etc.

Apart from electronic problems, certain materials, like Teflon, can become brittle if exposed to radiation, which can lead to component failure after a few years.

2.4 - Temperature

Due to the lack of air, the parts of the satellite that face the sun can get very hot, and the shadow areas extremely cold. It would be an extremely difficult task, or maybe even impossible, to design electronic equipment that could operate under those conditions.

To overcome this problem, most satellites have what is called “heat pipes”. These devices consist of hermetically sealed metal tubes that contain a fluid. The continuous evaporation and condensation of the fluid allows the transfer of heat from a warm part to a cooler area of the satellite. As a result, an averaging of the temperature is achieved, avoiding extreme cold or hot areas.

Since the satellite operates in vacuum, all the heat generated by the satellite must eventually be radiated to space.

Thermal stress is another issue that must be considered. Since the satellite components might be subjected to sudden changes in temperature, the expansion and compression of dissimilar materials can lead to cracks and mechanical failure. Typical examples are the tabs of RF power transistors, which must be bent in such a way that they resemble an inverted “u” spring. In this manner, the different expansion coefficients of the transistor materials, the printed circuit board and the metal fixture where the transistor is mounted are compensated by expanding or compressing the tabs of the transistor.

2.4 - Multipacting

Multipacting is a phenomenon of resonant electron multiplication in vacuum. It occurs when RF voltage is applied between two metal plates that are in close proximity. This effect is a function of the RF voltage, the frequency, and the distance between the metal plates. Multipacting can produce a breakdown effect, leading to the malfunction of an electronic device.

Satellite designers analyze the spacecraft design in order to identify potential areas where multipacting can occur. Typically, directional couplers, filters, or even small gaps between a printed circuit board and a connector mounted on the wall of an enclosure can present a problem.

The most common cure to multipacting is to fill the gap (vacuum) with a specially designed compound. However, the dielectric properties of the filler might be a problem, so multipacting must be avoided by proper design whenever possible.

2.5 - Outgassing

Some of the elements that constitute a satellite may slowly release a very small mass of various gases after the spacecraft is placed in orbit. Unfortunately, since the satellite operates in vacuum, even a tiny amount of gas can cause damage to sensitive parts of the satellite, like optics (video cameras and telescopes), heat radiators and solar cells. Outgassing can also be enhanced by radiation effects.

Certain plastics, paints, or printed circuit board substrates are typical elements that can cause outgassing problems.

2.6 - Electronic components derating

The ultimate goal of a satellite payload is to operate correctly during the entire mission. In order to achieve this high reliability, the electronic components used to manufacture space hardware not only must be carefully selected and controlled, but they must be also operated below their maximum temperature, voltage, current and power ratings. This technique is called derating.

Component derating is usually indicated as a percentage of the nominal component specification.

2.7 - Tin, cadmium and zinc whiskers

When pure tin, cadmium and zinc are used in space, it is possible that a conductive, single crystal structure called "whisker" can grow, producing catastrophic short circuits that can jeopardize a mission. These whiskers are just a few microns in diameter, but can grow up to half an inch in length.

Sometimes, the circuit has enough current capability to fuse the whisker (between 10 and 50 mA), so the failure could be momentary. However, if it is the case of a high impedance, low voltage circuit, the damage can be permanent.

2.8 - Component traceability during manufacture

Regular components for industrial or commercial applications are manufactured under various processes. Sometimes, a manufacturer will introduce changes to some of those processes, without affecting the performance of the component. However, this may lead to trouble in space applications due to the radiation levels, sudden temperature changes and high vacuum.

3 - High Efficiency VHF Class-E Amplifier

The following text is based on “Class-E Silicon Carbide VHF Power Amplifier”, by Marc Franco and Allen Katz, presented at the IEEE International Microwave Symposium 2007 in Honolulu, Hawaii [1]. The original publication is copyright of the IEEE, who granted permission to use portions of the original work in this paper. Cree, the manufacturer of the SiC device used in the amplifier, made the IEEE paper available on their corporate website [2].

3.1 - Class-E amplification

Not all the dc power delivered by the power supply will be converted into RF power by the amplifier. Unfortunately, part of the dc power will be turned into heat. For space applications, where every watt of dc power is very expensive and heat dissipation is of great concern due to the lack of air, it is very important to maximize the RF power amplifier efficiency.

Most of the energy lost in heat is due to the fact that linear amplifiers operate the active devices in such a way that there is a voltage drop and significant current flowing through them simultaneously. The product of that voltage and current is the energy that turns into heat. If we could avoid that situation, that is, having no current when the voltage is maximal, and vice versa, then the power dissipated by the active device would be minimized.

One way to achieve the above conditions is to operate the active device as a switch. In this way, when the switch is closed, the voltage is zero and the current is maximal, and when the switch is open, the voltage is maximal and the current is zero.

Class-E amplification was developed by Nathan Sokal, WA1HQC, and Alan Sokal WA1HQB [3] [4]. As shown in Fig. 1, a class-E amplifier operates the active device as a switch. However, since a transistor has certain amount of shunt capacitance at the output, it does not look like an ideal switch. A class-E amplifier has an ad-hoc wave-shaping LC network at its output that absorbs the transistor output capacitance, and as a result, it achieves almost perfect switch performance and very high efficiency.

Unfortunately, class-E amplifiers are nonlinear, that is, their output signal is not exactly a larger replica of the input signal. This means that SSB or any other envelope-varying signal cannot be amplified with low distortion.

Class-E amplifiers can achieve efficiencies in the high nineties. The limiting factors are usually the series resistance of the active device, and losses in the output matching and wave-shaping networks.

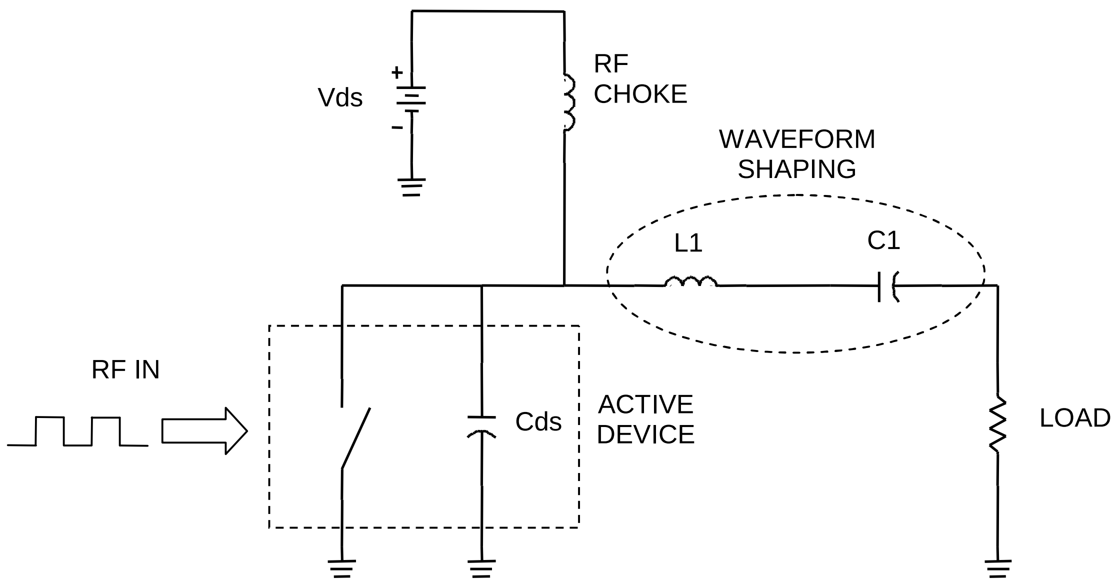

Fig. 1 – Class-E RF power amplifier concept

3.2 - Class-E Silicon Carbide 145 MHz amplifier design

The amplifier's design goal was an output power of 20 W at a frequency of 145 MHz, with no tunable parts, 100 KHz bandwidth, and harmonics and spurs at least 60 dB below the carrier. Cree's CRF24060 SiC MESFET was chosen as the active device for its high break down voltage, lack of internal matching, and availability of a nonlinear model. The amplifier's schematic diagram is shown in Fig. 2.

The output waveform shaping network was designed according to the equations provided in [4] for a Q of 2.27. A maximum drain voltage of 30 V was used in order to avoid exceeding the device's maximum drain voltage.

The output load impedance of approximately 18 ohms was matched to 50 ohms with an L network that shares the inductor with the waveform shaping network. Finally, a low pass filter section for improved spectral purity was utilized.

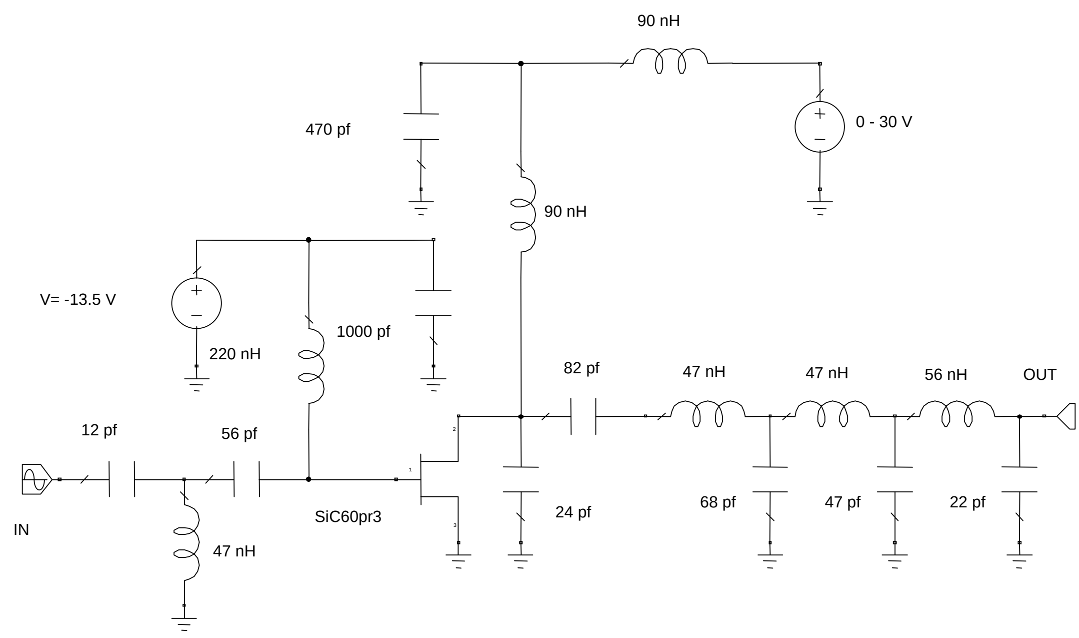

Fig. 2 – Schematic diagram of the SiC VHF power amplifier

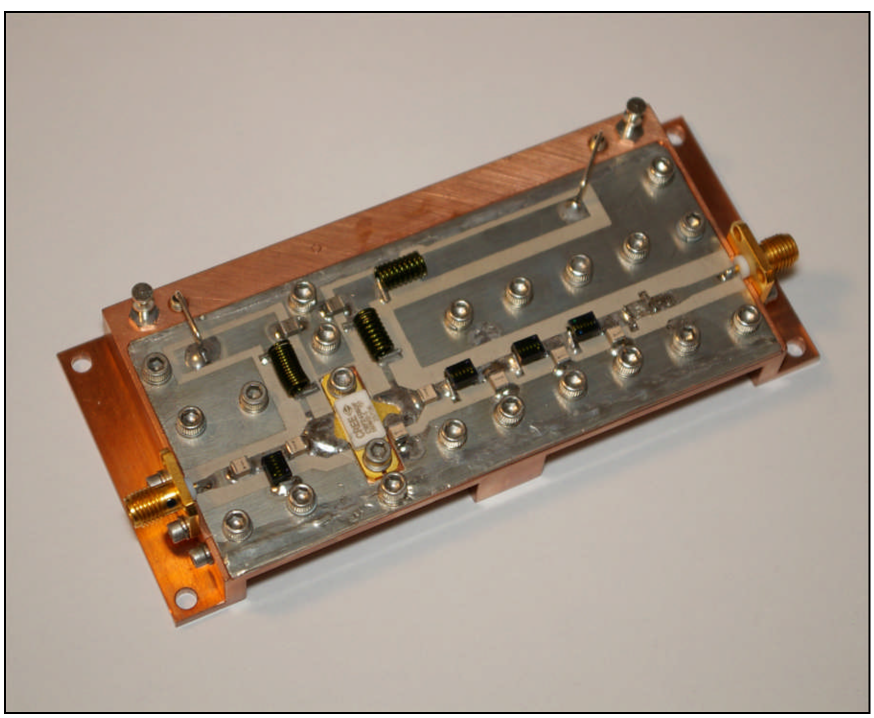

Fig. 3 – High efficiency SiC MESFET class-E VHF amplifier

The input of the active device was matched to 50 ohms by means of a high pass filter network, in order to prevent the attenuation of the high frequency components of the drive signal.

Since it was desired to provide linear amplification by restoring the input signal's envelope with drain amplitude modulation [5] [6] [7], the drain bias network was built with a low pass filter that allows drain amplitude modulation frequencies of up to a few MHz to pass through it with minimum attenuation, while at the same time providing acceptable isolation at the carrier frequency and its harmonics.

The amplifier component values were optimized with AWR's Microwave Office nonlinear simulator. Every effort was made to utilize standard value components, and to avoid the use of trimmer capacitors or adjustable inductors.

The amplifier prototype, shown in Fig. 3, was implemented on a Rogers 6002 30 mil substrate for its excellent outgassing and thermal characteristics, which makes it suitable for space applications. ATC 700B standard value ceramic capacitors were used for the matching and biasing networks. Coilcraft air spring inductors with 2% tolerance were utilized throughout the design; however, the flight unit will employ inductors with no plastic coating.

3.3 - Performance as a function of drain voltage

Fig. 4 shows the amplifier RF output power as a function of drain voltage. This test was carried out with a constant input power level of 27 dBm, achieving the desired output power of 20 W and a power gain of 16 dB. Only the fundamental component of the output was considered in this measurement since the amplifier has a built-in low pass filter and all harmonics and spurs were at least 60 dB below the fundamental.

The drain efficiency as a function of drain voltage is shown in Figure 5. This efficiency was again measured at a constant input power level of 27 dBm. The efficiency was approximately constant and around 86% from a drain voltage of 2 V up to the maximum drain voltage of 30 V.

Figure 6 shows the power added efficiency (PAE) of the amplifier for a constant drive level of 27 dBm.

The RF peak output voltage as a function of drain voltage is shown in Fig. 7, and illustrates the amplifier's excellent drain voltage to RF voltage linearity.

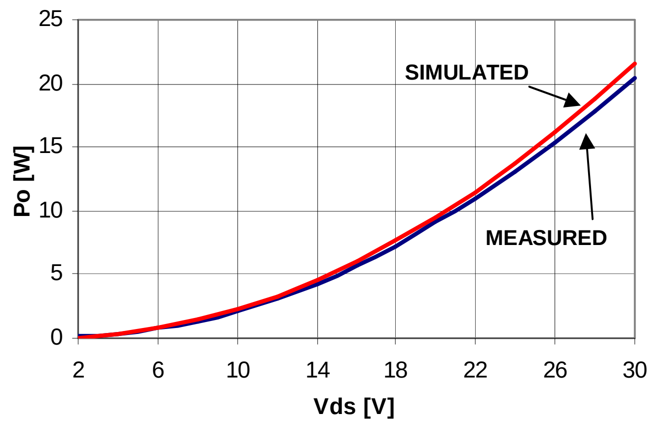

Fig. 4 - RF output power as a function of drain voltage.

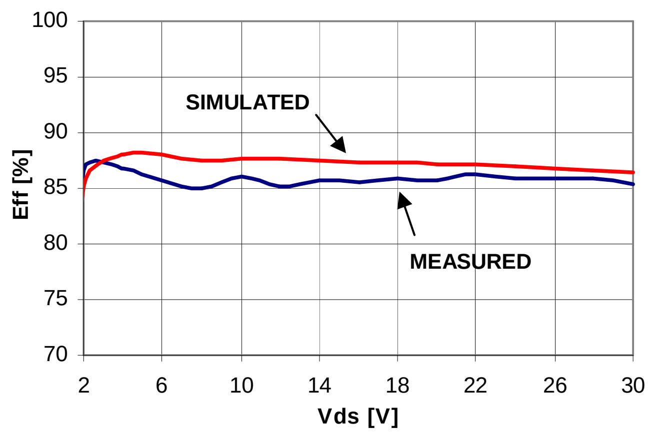

Fig. 5 - Drain efficiency as a function of drain voltage.

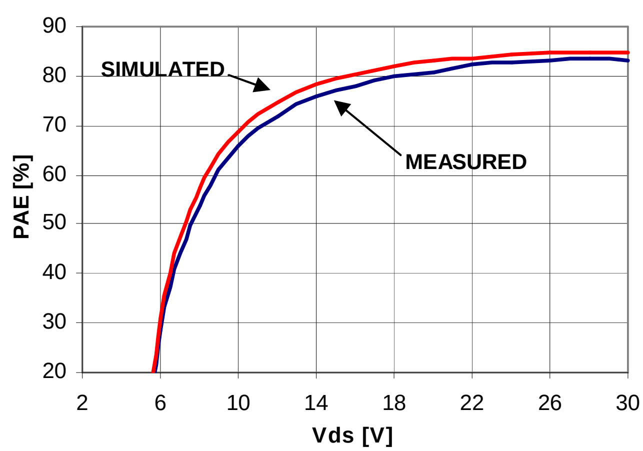

Fig. 6 - Power added efficiency as a function of drain voltage.

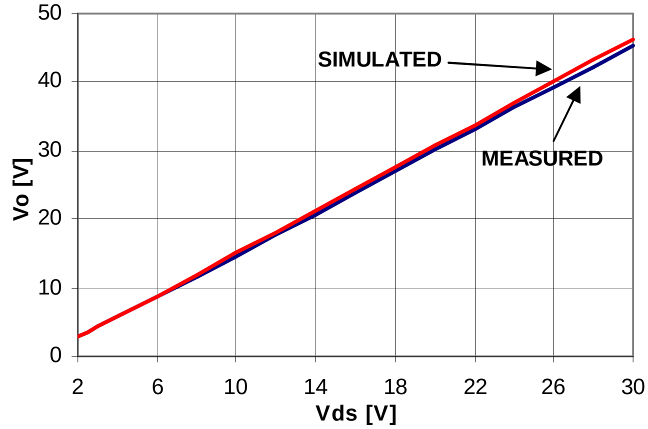

Fig. 7 - RF peak output voltage as a function of drain voltage.

3.4 - Spectral purity

Fig. 8 shows the measured output spectrum of the amplifier. The simulation predictions and measured level for the second harmonic were identical at 58 dB below the fundamental. However, the measured third harmonic was approximately 20 dB higher due to coupling effects not taken into account during the simulation.

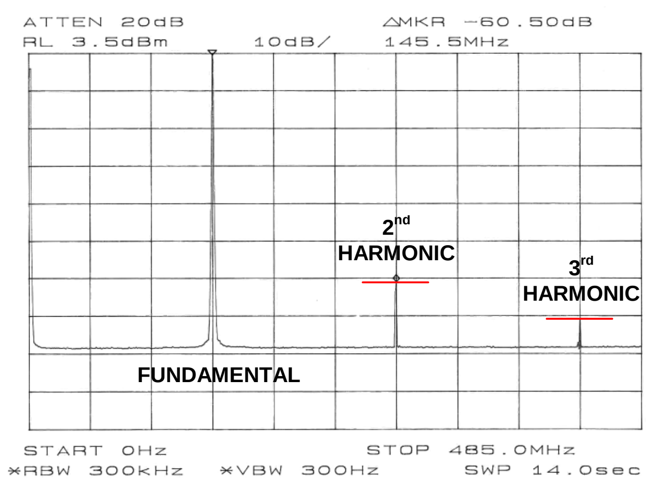

Fig. 8 - Measured output spectrum.

4 - Conclusion

A high-efficiency class-E amplifier was designed, simulated and demonstrated practically. The simulation and the experimental results agreed so closely, that no component values changes were necessary.

A silicon carbide MESFET was used as the active device. This semiconductor technology has not been previously reported to be successful in producing very high efficiency VHF amplifiers. Since SiC devices operate from higher voltages than GaAs devices, they can be advantageously used in class-E designs. Given the possibility of SiC devices becoming space qualified, they could constitute the semiconductor of choice for these applications.

The most significant simulation and experimental results are summarized in Table I. A maximum drain dc to RF efficiency of 86.8 % was achieved. All measurements were done at a constant input power level of 27 dBm. The maximum power added efficiency for this drive level was measured at 83.5 %. A 20.5 W output power level was reached at a 30 V drain voltage.

Table I
SiC VHF Power Amplifier – Simulated and experimental results

Parameter	Simulated	Measured
Maximum Output Power	21.5 W	20.5 W
Nominal Input Power	27 dBm	27 dBm
Maximum Drain Efficiency	88 %	86.8 %
Maximum Power Added Efficiency	84.8 %	83.5 %
Maximum spurs and harmonics	-58 dBc	-58 dBc

5 - References

[1] M. Franco, A. Katz, "Class-E Silicon Carbide VHF Power Amplifier", *IEEE-MTT-S International Microwave Symposium Digest*, Honolulu, Hawaii, June 2007.

[2] http://www.cree.com/products/wireless_docs.htm

[3] N. Sokal and A. Sokal, "Class E – A New Class of High-Efficiency Tuned Single-Ended Switching Power Amplifiers," *IEEE Journal of Solid-State Circuits,* June 1975

[4] N. Sokal WA1HQC, "Class-E RF Power Amplifiers", *QEX*, January 2001.

[5] L. R. Kahn, "Single Sideband transmission by Envelope Elimination and Restoration," *Proc. IRE*, vol. 40, no. 7, pp. 803-806, July 1952.

[6] http://www.amsat-dl.org/dl/HELAPS_en.pdf

[7] http://www.amsat-dl.org/dl/HelapsTechnologyTransferSeminar.pdf

AstroSat - SkyWave

Supporting Radio and Astronomy Amateurs

Giorgio Perrotta + Florio Dalla Vedova, LX2DV ex IW2NMB
AMSAT-Italia with UAI

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Abstract

AMSAT-Italia described at the AMSAT-NA 2006 Symposium its **SkyWave**, Ionosfera and RATS programmes. Initiated since the end of the year 2000, these programmes aim at contributing to the international research effort on Space Weather and ionosphere, and this mainly for Radio-amateurs interests.

On 23rd of September 2007, AMSAT-Italia and UAI (Unione Astrofili Italiani, see www.uai.it) engaged officially into a collaboration for the merging of their two satellite missions: AstroSat and SkyWave.

The present paper informs the AMSAT Community about the new **AstroSat-SkyWave** programme, describing its scope and main elements. The AMSAT Societies are herewith invited to comment, suggest any improvement and contact AMSAT-Italia for possible collaborations on this programme.

1 Introduction

AstroSat-SkyWave is the new joint satellite project by UAI (Unione Astrofili Italiani, which represents more than 50.000 members) and AMSAT-Italia, the Italian branch of the AMSAT organization.

The system will consist of two microsatellites, nominally around 50 kg each, launched in a nominal polar orbit at 800 km altitude. The first satellite will carry a primary optical payload for astronomical observations, but might carry auxiliary payloads as well.

The second satellite, which would be launched two years after the first - and not necessarily in the same orbital plane - will carry two primary payloads : a multiband receiver to establish - in cooperation with existing ground stations - a Space Based Very Long Baseline Interferometric (SB-VLBI) system aiming at characterizing the faint emissions of radiostars ; and the AMSAT-Italia **RATS** topside sounder, basically a pulsed radar operating in the 0.1 to 20 MHz, for probing the Earth's ionosphere and assessing the HF propagation effects of its ion/electron content. Secondary payload can be accommodated as well.

The **AstroSat-SkyWave** project represents a world "first" in that, although amateur satellites have been developed, launched and operated by radio-amateurs and astronomy missions have been realized, on a small scale, by University students, a complex and high performance multipurpose multisatellite system has not yet been conceived by joint amateur groups having adjacent and partly common interests.

2 Who will benefit

The project has, obviously, a strong scientific content besides aiming at providing the amateur communities with a facilitated access to a versatile space asset. Indeed, since most Amateurs participating to the project definition, are also professionals working in the Space sector or in major Research Centers or Academic Institutions, they will assure the coherence between the specific project mission goals and the medium-long term objectives of the amateur, scientific and technical communities they come from.

The educational value of the project is also outstanding, thanks to the mix of experiments being conceived that, besides targeting important research themes in astronomy, radio-astronomy and radio-communications, leaves room to accommodate additional small experiments of scientific or technological nature by interested third countries or parties. The "educational" contribution of the project will be implemented in several ways :

- establishing cooperation agreements with selected University's Departments for advanced, applied, research themes in which they have specific skills: the cooperation may imply assigning thesis, or co-funding doctoral candidates;
- accepting young graduates as part-time or full-time volunteers in project working-groups: the project management team will provide guidance and direction helpful in their transition from University to the real world;
- for technical schools a training programme will be defined aiming to involve the Students in data reception and processing, in particular where the project' Ground Segment assets will be located;

The didactic effort will be directed along the following lines:

- creating a project- specific website
- taking the opportunity of this website to add a section providing information about Space systems, technologies and applications, paying attention not to duplicate things that already exist on Internet, however.
- establishing ways to interact directly with the Users' communities, in continuation of the didactic activities already organized by AMSAT-Italia (e.g. by integrating AMSAT-Italia's **Ionosfera** website [2]), UAI and other amateur associations;
- finding opportunities to use the media for informing the general public about the contribution of the project – and of the Amateurs Communities- to the scientific knowledge and progress;

Besides the direct contribution by the Amateurs, the realization of the project may rely on the support - in technology, tools and know how - by SMEs (Small Medium Enterprises) with experience in aerospace programmes, most of which achieved through prior participation to national and international space projects either as Prime or Subcontractors.

*The possible and highly desirable participation to the project of other Amateur groups worldwide will of course undoubtedly widen the **AstroSat-SkyWave** purpose and utilization.*

3 The first satellite

The first satellite, proposed for launch in 2010, will carry a small communication transceiver for the radioamateur (AMSAT) Community, together with two main “scientific” payloads :

A 250mm diameter “fast” (F# 3.6) telescope will be designed and realized by amateur-astronomers. The telescope will serve for three main missions: photometry, imaging and spectrometry. To this end a mobile plate is provided at the focal plane level, supporting two CCDs of 2000 x 2000 pixels each and an hole for letting pass the collimated beam towards a spectrometer underneath the focal plane.

- The photometry mission aims at the discovery of planets outside the Solar system, through the observation of the starlight intensity variations vs time. The target observation area extends through ±40 deg. with respect to the ecliptic plane.
- The imaging mission provides a space access to amateurs for planning and taking images of the sky exploiting the absence of the atmosphere and the long observation times feasible with inertial pointed satellites.
- The spectrometry mission aims at gathering spectral information about the light emissions of stars preselected through previous observations either performed with this telescope or other optical means. The spectrometer will cover the visible and near infrared bands and will have a resolution around 5 micron.

A second priority payload could consist of a receiver operating in the 10 to 40 MHz bands for listening to the solar and jovian radioemissions. In this band there will be a lot of human-related interferences that will have to be filtered to reveal the faint but wanted radioemissions. However the acquired unwanted data can also be seen as a precious source of information when suitably processed.

Besides these other small “opportunity payloads” might also be accommodated within the microsatellite mass and DC power margins.

4 The second satellite

The second satellite, proposed for launch in 2012, will also carry a small communication transceiver for the radioamateur (AMSAT) Community, together with two main “scientific” payloads :

One will be a receiver operating in selected frequency slots from 1.4 to 24 GHz connected to a 3m diameter, meshed, parabolic antenna in-orbit deployable. This payload will operate essentially in two modes:

- in a stand-alone mode it will perform radiometric measurements of the emissions by radiostars, providing information about the average signal power, its spectral features enabling to compute the star relative speed from the signal Doppler and spacecraft datum
- in the interferometric mode the satellite receiver will operate in synchronism with one or more ground stations all looking at the same radio star hence receiving the same signal.. The very long interferometer baseline between the satellite and the ground terminals, which could go up to 9000 km, allows achieving a very high spatial resolution while the low sensitivity feasible with terminals equipped with antennas of about 3m diameter is compensated by the long observation times feasible with a spaceborne receiver.

The second payload will be the AMSAT-Italia's **RATS** topside sounder, which is basically a pulsed radar operating in the 0.1 to 20 MHz band. The EM pulses, downward directed, will interact with the electrically charged atmospheric layers which will reflect a fraction of the incident energy depending on the ion content. The echoes received and processed, will give a real time picture of the spatial and temporal variations of the ionosphere which has a deep impact on the HF (DX) radiowaves propagation. Besides directly contributing to better the forecast of the propagation conditions more conducive to satisfactory long range ionospheric communications, the experiment will provide an important contribution to the widespread research effort on the "Space Weather".

Here also, besides these main payloads, other small "opportunity payloads" might also be accommodated within the microsatellite mass and DC power margins.

5 The ground segment

The Ground Segment of the project is where much of the education, learning and *...yes...* entertainment -at least for the amateurs- will come from. Indeed, besides the TT&C and the Master Control Station, that will have to be at least duplicated for reliability and availability reasons, the system will be potentially open to :

- the (AMSAT) radioamateurs with at least two new LEO-orbiting transceivers for communications;
- the radioamateurs wanting to receive and elaborate the satellite telemetry data, transmitted in the UHF amateur band;
- amateurs participating to the "Space Weather" groups, in charge of receiving and elaborating the data acquired by selected spaceborne instruments such as the **RATS** topside sounder;
- the radioastronomers equipped with terminals enabling the reception of the interferometric data transmitted, at S:band by the second satellite. Special receiver kits- compatible with the satellite functionalities- are being considered to facilitate the integration of medium size antenna terminals in the **AstroSat-SkyWave** network for exchanging data with a primary Data receiving and processing center;
- educational or didactic bodies wanting to interactively access, via Internet, to a repository of information, data and programmes enabling students to carry out guided paths toward the acquisition of certain skills.

6 Future plans

AMSAT-Italia and UAI have now set up an integrated Working Group (WG) for the development of the **AstroSat-SkyWave** mission(s).

First action of the WG is to interest the Italian Space Agency (ASI) in order to have initial support for a (Phase-A) Feasibility Study. Between other, this study will also aim at defining the various elements composing the AstroSat-SkyWave system(s) in order to allow the subsequent distribution tasks (i.e. developments) between interested organizations (and we hope many of the AMSATs !).

In the mean time, both AMSAT-Italia and UAI will continue to pre-inform the worldwide potential Users and Actors about the AstroSat-SkyWave programme. So …

… if this programme and approach interests you, please contact AMSAT-Italia. You are welcome !

References

[1] Florio Dalla Vedova, IW2NMB ; Fabio Azzarello, IW8QKU ; Paolo Pitacco, IW3QBN ; AMSAT-Italia : "SkyWave, Ionosfera and RATS : Radio Amateurs Efforts in Ionospheric Studies" ; Proceedings of the AMSAT-NA 2006 Symposium

[2] Ionosfera website : http://esa-spaceweather.net/sda/ionosfera/index2.htm

[3] F. Dalla Vedova : "Appello per una missione AMSAT sulla Radio-propagazione Ionosferica (Issue 0.0)", AMSAT-I News Vol. 8, Num. 5 (2000)

An *Improved* Parasitic Lindenblad Antenna for 70cm

By Anthony Monteiro, AA2TX

Abstract

A traditional Lindenblad antenna employs four, dipole, driven-elements to create a circularly-polarized, omni-directional radiation pattern. With most of its gain at low elevation angles, the Lindenblad is well suited for accessing Low Earth Orbit (LEO) satellites and can often be used instead of a beam antenna eliminating the need for complex azimuth/elevation rotator systems. This makes the Lindenblad especially useful for portable and temporary satellite operation.

Unfortunately, constructing these antennas can be difficult because of the need to feed the four, driven dipoles. Previously published designs have used folded-dipoles, balanced lines, BALUN transformers and special impedance matching sections in order to provide a good match to 50-ohms. On the 70cm band, tight tolerances are needed and this can make the construction especially challenging.

This paper presents a considerably simpler way to construct a Lindenblad antenna. It uses just a single, dipole driven-element. The linear polarization of the dipole is converted to circular polarization via a passive, parasitic polarizer. This antenna design is an improvement over an earlier design[1] and employs a sleeve dipole which eliminates the need for an external BALUN resulting in lower losses as well as simpler construction.

Introduction

A Lindenblad antenna provides circular polarization and an omni directional radiation pattern that has most of its gain below 30 degrees of elevation. This pattern is ideal for accessing Low Earth Orbit (LEO) satellites. The omni-directional pattern eliminates the complexity of azimuth/elevation rotors and their associated control systems yet the Lindenblad antenna can still provide a solid uplink or downlink signal to access most amateur LEO satellites. This makes it ideal for portable and temporary satellite operation as well as providing a good option for many permanent stations as well.

This antenna was invented by Nils Lindenblad of the Radio Corporation of America (RCA) around 1940.[2] The antenna uses four, dipole, driven elements that are fed in-phase. The dipoles are canted at 30 degrees from horizontal and positioned equally around a circle of about 1/3 wavelength diameter. At the time, Lindenblad was working on antennas for the then nascent television industry but the start of World War II delayed his TV broadcasting work.[3]

After the war, Brown and Woodward, also of RCA, began investigating ways to reduce fading on airplane-to-airport radio links.[4] Airplanes use linearly polarized antennas so using circular polarization on the airport antenna could reduce or eliminate the cross-polarization induced fading that results from the maneuverings of the airplanes. Brown and Woodward decided to try Lindenblad's earlier TV antenna idea and constructed VHF and UHF prototypes. An original Brown and Woodward prototype is shown in the photograph of Figure 1.

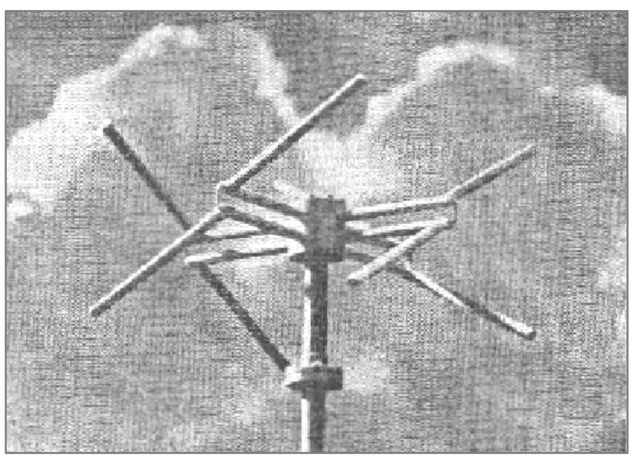

Figure 1. Original Lindenblad Antenna Prototype[5]

The Brown and Woodward design uses tubing for the dipole elements and a 100-ohm open-wire BALUN for each dipole. The actual dipole feed is a coaxial cable that runs through the center of one side of the open-wire line. The four coaxial cables meet at the center hub section of the antenna where they are combined in parallel and fed to another coaxial cable as an impedance matching section to get a good match to 50-ohms. While this design is very clever and in fact worked very well, it would also be quite difficult for the average ham (or this author!) to duplicate.

The main cause of the difficulty in designing and constructing these antennas is the need to feed the four driven dipoles. Each dipole presents a 75-ohm balanced load and they generally need to be fed from a single 50-ohm unbalanced coaxial cable. Most previous Lindenblad antenna designs have used folded-dipoles, balanced lines, BALUN transformers and special impedance matching cables in order to provide a good match to 50-ohms. These in turn, impact the complexity of the mechanical design.

The goal of this project was to develop an antenna for the 70cm band that would have the same radiation pattern as a right-hand circularly polarized (RHCP) Lindenblad but would be much easier to construct.

A *Parasitic* Lindenblad Antenna

The idea of a *parasitic* Lindenblad is to use only a single driven element along with parasitic elements to create the radiation pattern. A driven element in an antenna is so called because it gets its power from an attached feed line (or delivers power to the feed line if it is used for receiving.) A parasitic element on the other hand, gets its power from a surrounding electro-magnetic field; it does not have an attached feed line.

The use of parasitic elements in antennas was pioneered by Professor Shintaro Uda of Tohuku University in Japan, in the mid 1920s.[6] He wrote the first published article on this concept in 1926. Professor Hidetsugu Yagi, a colleague at the University, collaborated with Professor Uda and wrote an article in English which was published in 1928. This article was so widely read that the design became commonly known as a Yagi antenna. The Radio Corporation of America quickly bought the patent for this antenna and soon after Yagi antennas were being sold for television reception. Of course, Yagi-Uda beam antennas have been widely used by amateur radio operators since the 1940s so the idea of an antenna with parasitic elements should be a familiar concept.

Parasitic elements in Yagi-Uda antennas are always in the same plane as the driven element because their purpose is to improve the gain or front-to-back ratio of the antenna. In contrast, the Parasitic Lindenblad has all of the antenna elements in different planes as the purpose of the parasitic elements is to convert linear polarization to circular polarization.

The Parasitic Lindenblad antenna uses a central vertical dipole as a driven element and an array of parasitic elements that make up the passive circular polarizer. The parasitic elements are arranged very much like those in a traditional Lindenblad antenna. The parasitic elements are canted at 30 degrees from horizontal and positioned equally around the center driven dipole on a circle of approximately 1/3 wavelength diameter.

The parasitic elements absorb power from the electro-magnetic field of the driven element and this causes a current to flow in them. The induced current flow in the parasitic elements causes an electro-magnetic field to be generated just as if they had been driven from a feed line. However, the current flow in each parasitic element travels along the path of the conductor, which is at 30 degrees from horizontal, rather than vertically like the driven element. This current flow distribution is exactly like the dipole currents in a traditional Lindenblad and the resulting electro-magnetic field generated from the parasitic elements is circularly polarized just like that of a Lindenblad. The circularly polarized field has both horizontal and vertical components and they are in phase-quadrature.

The overall effect is the sum of the radiation patterns of a traditional Lindenblad and a co-located vertical dipole with the same power applied to both. Since the power in the parasitic elements goes equally into vertical and horizontal components, the vertical field component from the parasitic elements is only one-half the magnitude of the field from the driven dipole.

The key to making this work is that the parasitic element lengths are tuned so that the current induced in them is 180-degrees out of phase with the driven dipole. This makes vertical field component from the parasitic elements cancel half the field from the driven element leaving a resulting vertical field component that is the same magnitude as if it was from a Lindenblad but of opposite polarity. The field cancellation is not perfect because the radiation pattern of the dipole is not exactly the same as the vertical pattern from the parasitic elements but, it is very close over a significant range of elevation angles.

The horizontal field from the parasitic elements is unaffected by the driven dipole because it produces no horizontal component. So, the combined horizontal and vertical fields from the driven and parasitic elements are virtually the same as those from a real Lindenblad except that the polarization sense is reversed. This means that we have to make the parasitic elements canted like a left-hand polarized Lindenblad to produce an antenna with right-hand circular polarization.

Impedance Matching

At resonance, an ordinary dipole would provide a load impedance of about 75 ohms. Due to the mutual coupling in the Parasitic Lindenblad, the parasitic elements draw power from the driven element and load it down reducing its radiation resistance. The impedance of the driven dipole would be about 32-ohms at resonance. This 32-ohm load would not provide a very good match to 50-ohm coaxial cable.

To keep construction simple, it is desirable to provide a good match without requiring any additional components or using folded elements. A convenient way to provide this match is to use an off-center-feed for the driven element. The Parasitic Lindenblad driven element is fed slightly above its center where the impedance is close to 50 ohms.

The vertical dipole driven element also requires a balanced feed for proper operation. If the coaxial cable was just connected to the dipole, a significant antenna current would flow over the outside of the coax shield which would negatively affect the radiation pattern and cause an impedance mismatch.

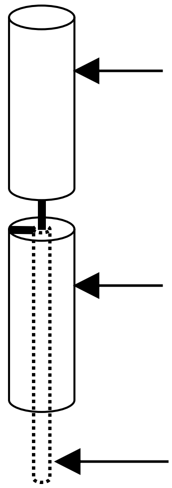

Figure 2. Sleeve Dipole

To prevent these antenna currents from flowing on the coax shield, a sleeve dipole is used for the driven element. Please see Figure 2. The coaxial cable runs through the center of the lower dipole element tube. The coax center conductor is connected to the upper dipole element and the coax shield is connected to the lower dipole element.

The inner wall of the lower dipole element and the outer shield of the coaxial cable form a coaxial resonator. By making this resonator an electrical ¼-wavelength at the operating frequency, we can create a very high impedance condition for the outer shield current at the open (bottom) end of the lower dipole element. This high impedance effectively decouples the coax feed from the antenna without requiring a BALUN. This is an improvement over a previous design[7] and has lower losses which results in the antenna having higher effective gain and higher power handling capability.

Antenna Construction

This antenna was designed to be easy to construct using only hand tools. All of the components except the coaxial cable assembly and N-adapter can be commonly found in any of the larger hardware stores. The complete parts list is shown in Table 1.

The coaxial cable assembly uses RG-188A/U which is very thin and has a Teflon jacket. This type of cable is required for proper operation of the coaxial sleeve resonator. Its thin size and low-dielectric-constant jacket allow the resonator to operate with a wide bandwidth centered on the satellite portion of the band. Any other type of cable may cause mistuning which may result in a degraded radiation pattern and a high SWR. The exact length of the cable is not critical but, to limit losses, should only be long enough to reach the antenna preamp.

Quantity	Description
1	2-foot length of ¾" OD, 17-gauge, aluminum tubing Note: Available from Texas Towers www.texastowers.com
4	1-foot length of 1/8" aluminum tubing or use #8-AWG aluminum ground wire
3	#8 x 3/8" aluminum sheet metal screw
3	1/8" aluminum pop rivet or use #8 x 3/8" aluminum sheet metal screw
1	½" gray PVC insert coupling, LASCO Fittings #1429-005
2	½" gray PVC adapter, female insert x FIPT, LASCO Fittings #1435-005
1	½" x 12" threaded gray PVC riser
4	½" x 5" gray PVC ferrule for rain gutter nails
1	1" x ¾" PVC electrical conduit reducer bushing, CARLON E950FE
1	¾" x ½" PVC electrical conduit reducer bushing, CARLON E950ED
1	¾" black plastic end cap
4	½" black plastic end cap
1	5-foot RG-188A/U SMA Male/Male cable assembly, L-com CCS188A-5 Note: Available from www.l-com.com
1	SMA Female to N-Male adapter, L-com BA34 or equivalent Note: Available from www.l-com.com
Misc.	1/8" and ¾" heat shrink tubing, regular bodied gray PVC solvent cement for Carlon™ conduit,, *Marine Goop™* outdoor waterproof contact adhesive, *Ox-Gard™ OX-100* grease for aluminum electrical connections

Table 1. Parts List

The aluminum tubing is supplied in standard lengths and must be cut to size as shown in Table 2. Cut all the tubing before starting assembly of the antenna. The length of the antenna mount tube is not critical but should be between 8 and 18 inches.

Quantity	Material	Length	Use
1	¾" tubing	4-15/16"	upper driven element
1	¾" tubing	5-7/8"	lower driven element
1	¾" tubing	~13" (left over)	antenna mount
4	1/8" tubing	11-5/8"	parasitic elements

Table 2. Aluminum Tubing Cut Dimensions

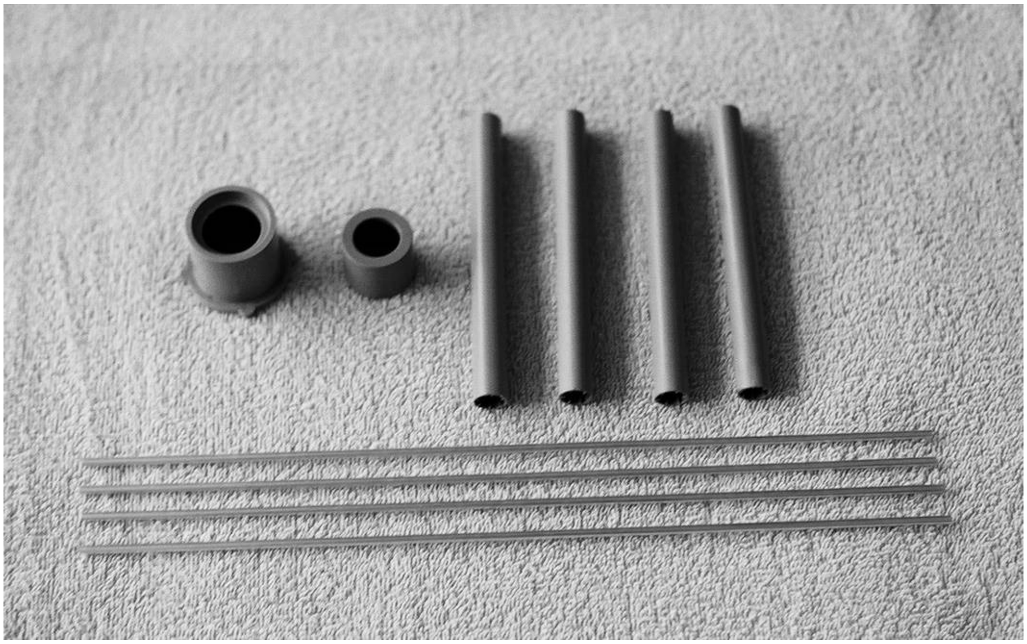

Figure 3. Polarizer Components

The components to make the polarizer are shown in Figure 3. The parasitic elements are made from the 1/8" aluminum tubing lengths. The polarizer structure is made from UV-resistant (gray) PVC components and consists of four, rain-gutter ferrules, a 1" x ¾" conduit adapter, and a ¾" x ½" conduit adapter.

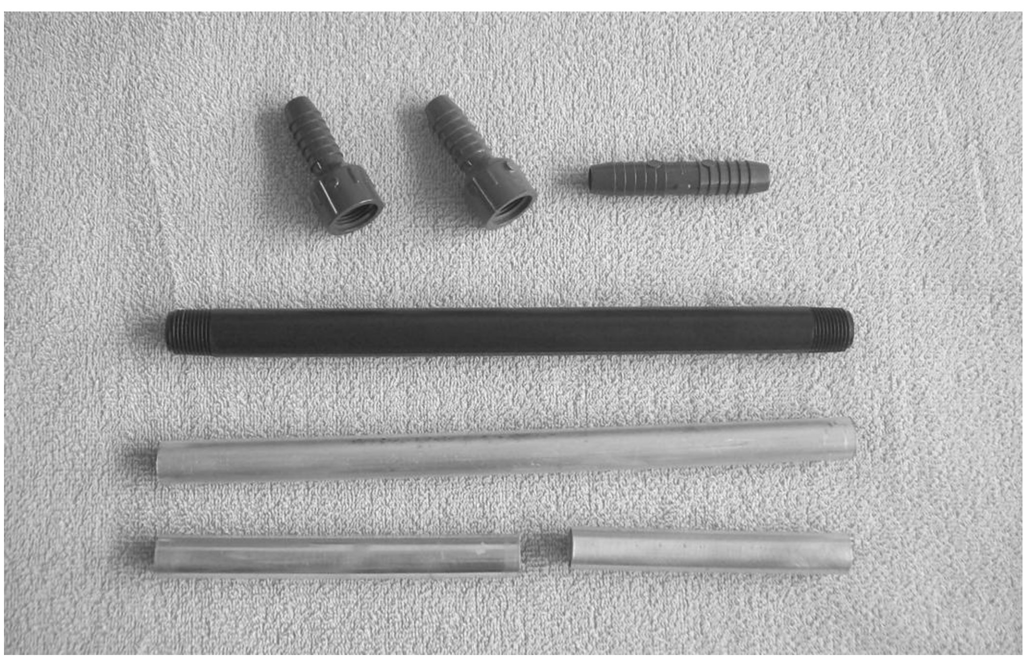

Figure 4. Driven Element and Support Components

The components to make the dipole driven element and the associated support structure are shown in Figure 4. The dipole driven element is made from two pieces of ¾" OD aluminum tubing that are connected with a PVC insert coupling. The dipole is mounted to a threaded 12" x 1/2" PVC riser using an insert-to-threaded adapter. At the other end of the riser, a second insert-to-threaded adapter is used to attach the antenna to a section of aluminum tubing used to mount the antenna to a mast.

Assembly

Start by making the parasitic element assemblies, see Figure 5. Cut the plastic ferrules to 3-3/4" length. Drill a 1/8" hole through each ferrule 3/16" from the end. The hole should go through both ferrule walls and be centered as much as possible. Push a parasitic element through the hole in the ferrule and center it so that it sticks out the same amount on both sides of the ferrule. Apply the Marine Goop™ liberally through the end of the ferrule to coat the wire and the inside of the ferrule wall. Set these aside for several hours until dry.

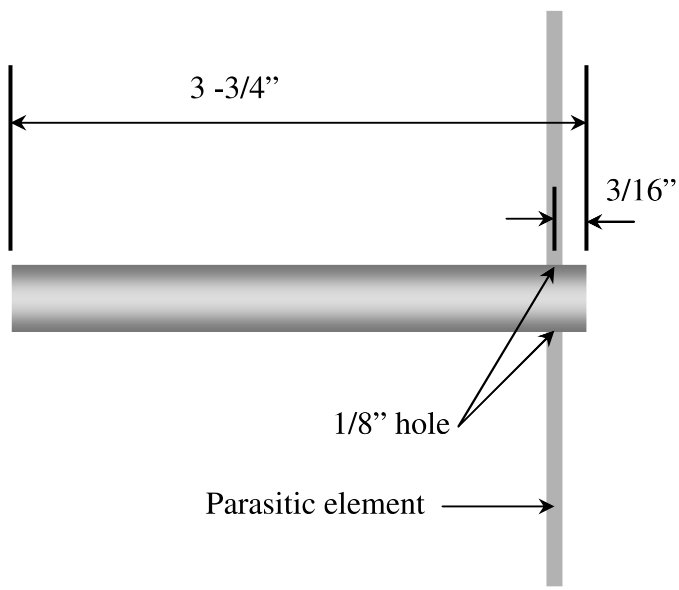

Figure 5. Parasitic Element Assembly

Next make the driven dipole assembly. Modify the PVC insert coupling for use as the dipole center insulator. Drill a ¼" hole in the center of the coupling and cut off 1" of one of the sides. The photograph in Figure 6 shows a close-up of a standard coupling on top and the modified coupling on the bottom.

The long end of the coupling goes into the upper (shorter) dipole rod and the short end of the coupling goes into the lower (longer) dipole rod. Gently tap the dipole rods onto the center insulator using a hammer until the ends of the rods are spaced ¼" apart and centered on the hole. Drill a hole in each dipole rod about 3/16" from the end for a #8 machine screw (#29 drill bit.) The holes should be directly across from each other on each end of the hole in the coupling and should go through the coupling.

Figure 6. Standard and Modified Insert Coupling

Next, modify the coaxial cable assembly by cutting off one of the SMA connectors at the end. Put a piece of heat-shrink tubing over the remaining connector where it attaches to the cable and apply heat. This will keep moisture out of the back end of the connector.

Next, assemble the antenna mount by screwing the PVC insert-to-threaded adapters to each end of the PVC riser. Push the bottom (longer) dipole rod onto one of the insert ends as far as it will go. Push the remaining aluminum mounting tube onto the other end as far as it will go. Tap the 1" piece that was cut from the PVC insert coupling into the end of the antenna mounting tube. This will prevent any sharp edge on the tube from cutting the coaxial cable. Drill a 1/8" hole near each end of the mounting tube and at the end of the lower dipole rod. The holes should go through the PVC inserts and will be used to fasten the parts together with 1/8" rivets (or drill holes for #8 screws.) After drilling the holes, temporarily remove the mounting tube and disassemble the dipole. Clean the screw holes around the dipole with steel wool.

Pass the coaxial cable up through the mounting tube, through the PVC adapters and riser and through the bottom of the lower dipole tube. Then, push the coax through the ¼" hole in the center coupling. Push the dipole rods back onto the center coupling and align the holes in the tubing with the holes in the PVC coupling.

Strip 1" of the jacket off of the coax cable and carefully separate the braid to make a wire lead. Strip the center insulator off leaving about ¼" from the braid. Now attach the braid to the lower dipole rod with a #8 screw. Use a liberal amount of *Ox-Gard*™ grease on the dipole tube. **THIS IS REALLY IMPORTANT -> Make the connection from the coax cable to the lower dipole tube as short as possible.** The coax cable should actually touch the end of the dipole tube. Run the center conductor of the coax over to the upper dipole tube and attach with a #8 screw again using liberal amounts of *Ox-Gard*™ grease on the tubing. The completed electrical connections should look as shown in Figure 7.

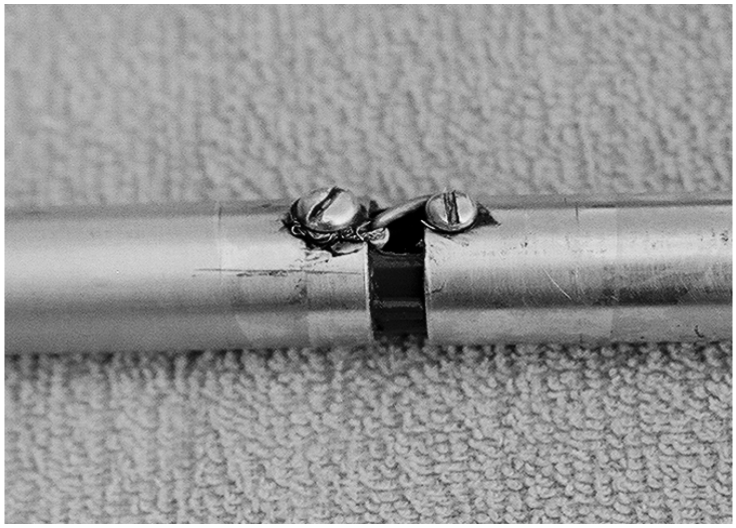

Figure 7. Dipole Electrical Connections (shield braid on left)

Cover the dipole connections with a piece of heat-shrink tubing and heat. If the heat-shrink tubing extends more than 1” above the screw on the upper dipole, cut the extra off with a sharp knife. Now, put the dipole and antenna mounting assembly back together and fasten all the parts with the pop-rivets.

To make the parasitic element hub, drill four, ½” holes in the 1” x ¾” conduit reducing bushing, spaced equally around the bushing with the holes flush with the top of the flange. The four parasitic element assemblies will fit into these holes but do not attach them yet. The ¾” x ½” conduit reducing bushing will have a smaller hole in one end that will be just a little too small to fit over the ¾” aluminum tubing. Drill or file this hole out until it provides a snug fit to the tubing. Cement the ¾” x ½” bushing to the 1” x ¾” bushing with the holes for the parasitic assemblies at the bottom and the snug ¾” hole at the top.

Clamp the hub to a convenient support and set it so the flange end with the holes is perfectly horizontal. For each parasitic assembly, apply the gray PVC solvent cement around the outside of the ferrule on the end away from the parasitic element tube. Carefully insert the ferrule into the ½” hole in the hub about 1/8” and quickly set the angle of the element to 30-degrees from horizontal by rotating the ferrule. Looking towards the hub, the left hand side of the parasitic element should be up. The parasitic elements should be 4-1/16” from the exact center of the hub. Allow the PVC cement to dry on all of the parasitic assemblies. When dry, glue the black plastic end-caps onto the open ends of the ferrules. The completed polarizer is shown in Figure 8.

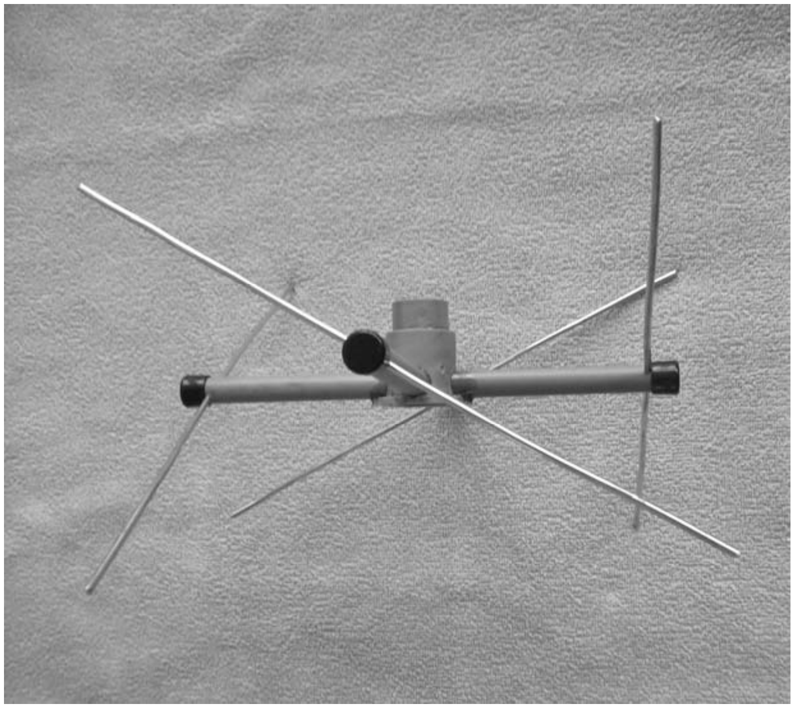

Figure 8. Completed Polarizer Assembly

Slide the polarizer assembly over the upper dipole tube with the flange side down until it is as far as it will go. The inner rib of the 1” x ¾” bushing will stop on the #8 screw in the upper dipole tube. The bottom flange of the polarizer should be about 5-7/8” from the top of the upper dipole tube. Drill a hole for a #8 screw through the upper bushing of the polarizer and through the upper dipole tube. Fasten the polarizer in place with the #8 screw. Push the ¾” black plastic end cap onto the upper dipole tube. This completes the construction of the antenna. The completed antenna is shown in Figure 9.

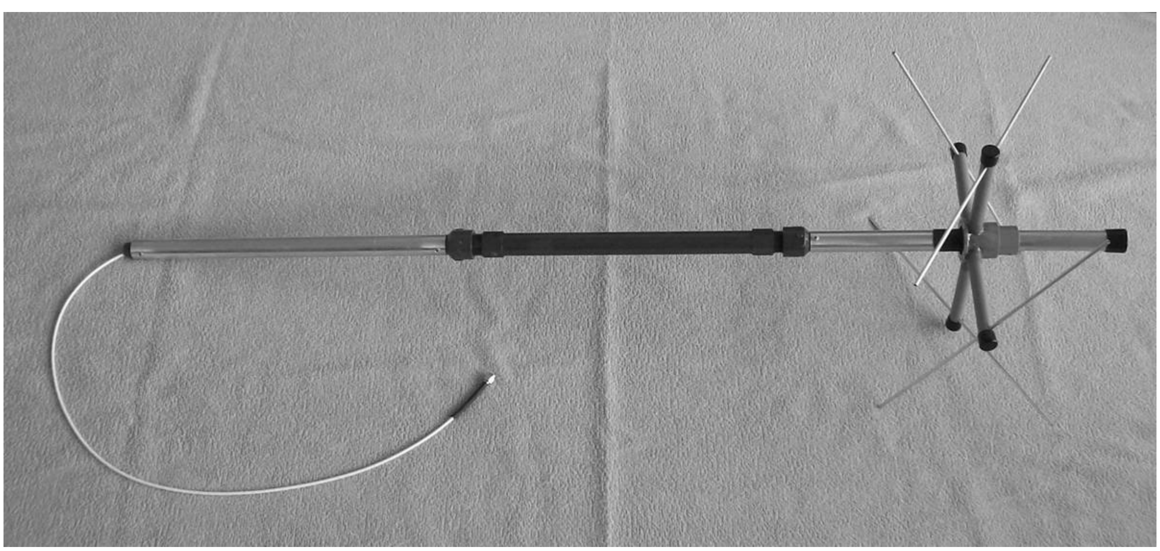

Figure 9. Completed Parasitic Lindenblad Antenna

Radiation Pattern

The antenna elevation pattern predicted by an *EZNEC* model is shown in Figure 10. This is the right-hand circularly polarized gain at 436 MHz with the antenna is mounted at 10-feet above real ground. The primary plot in gray is the pattern of the Parasitic Lindenblad antenna. The plot in black is the pattern of a traditional Lindenblad at the same height. As can be seen on the plot, the Parasitic Lindenblad pattern is virtually identical to a real Lindenblad up to about 45 degrees of elevation. Even above that, there is very little difference in the patterns.

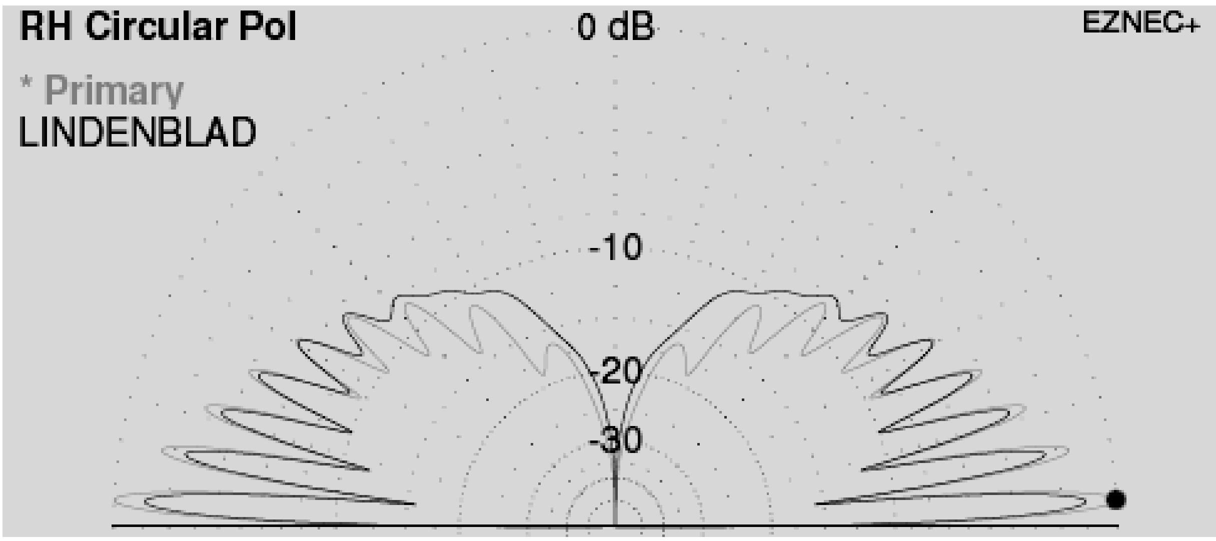

Figure 10. Radiation Pattern

The maximum gain predicted by the model is 7.4 dBic at an angle of 3.1 degrees elevation as shown by the black dot on the plot. Note that the radiation pattern will have more and finer lobes if the antenna is mounted higher above ground and the maximum gain will vary with height and ground quality like any antenna. The predicted azimuth pattern, not shown, is almost perfectly circular with less than 0.1 dB variation.

Impedance Match

The impedance match to 50-ohms was checked using an MFJ-229 SWR Analyzer. This device has a digital readout of the frequency and SWR. The antenna was mounted at 10-feet and connected to the analyzer on the ground through a 6-foot jumper cable of 9913F coaxial cable. The SWR was measured across the 70cm band and the results are shown in the chart of Figure 11. As can be seen from the chart, the antenna provides an excellent match in the satellite sub-band and is low enough to be usable over the entire 70cm band.

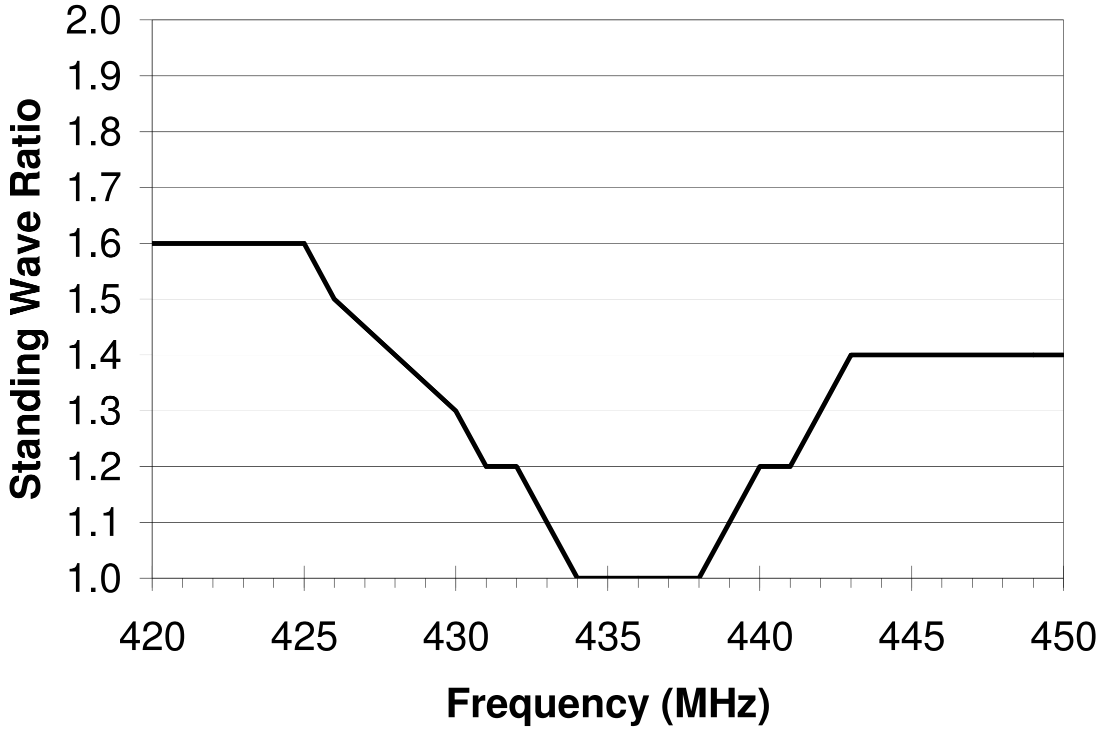

Figure 11. Impedance Match to 50-Ohms

Power Handling

This antenna was designed to handle at least 100 watts and this was tested, using a high-power amplifier, by running CW key-down for 10 minutes. The lower dipole sleeve was slightly warm after this test but there were no observed ill effects to the antenna.

Circularity

The antenna axial ratio was checked by measuring its response to a horizontally polarized test signal and then rotating the antenna from its normal vertical position through 90 degrees to a horizontal position. This resulted in a change in response of less than 1 dB which is very good for an omni-directional antenna. A similar test with a horizontally polarized reference antenna produced a difference of over 15 dB.

Summary

This paper has presented a design for a Parasitic Lindenblad antenna. This antenna is much easier to construct than a traditional Lindenblad because it uses just a single, dipole, driven-element and a passive circular polarizer. Yet, the antenna radiation pattern is nearly identical to a traditional Lindenblad.

The Parasitic Lindenblad has been used to make SSB and FM contacts via the AO-07, FO-29, SO-50, AO-51 and VO-52 satellites. It is omni-directional and does not require rotator system making it an ideal alternative to a beam for portable and fixed station operation on LEO satellites.

[1, 7] *A Parasitic Lindenblad Antenna for 70cm*, by Anthony Monteiro AA2TX, Proceedings of the AMSAT – North America 2006 Space Symposium, pp. 53-67.

[2] N. E. Lindenblad, U. S. Patent 2,217,911

[3] It is interesting to note that in 1984 RCA was recognized with an *Emmy Award* for pioneering work in the development of circular polarization technology in television broadcasting, some 44 years later!

[4] *Circularly Polarized Omnidirectional Antenna,* by George H. Brown and O. M. Woodward Jr., RCA Review vol. 8, no. 2, June 1947, pp. 259-269.

[5] *Ibid*. pg 267.

[6] *Directive Short Wave Antenna*, 1924, IEEE History Center, Rutgers University, New Brunswick, NJ, USA available at: www.ieee.org

A High Efficiency, Broadband GaN Amplifier for Amateur Radio

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Abstract

The design and application of highly efficient, broadband amplifier is presented. The amplifier produces more than 20W over nearly a decade of bandwidth. Simple design techniques as well as freeware software is referenced to keep this amplifier well within the capabilities of the radio amateur.

Index Terms
GaN HEMT, HPA, High Efficiency Amplification, AO51, Amateur Radio

I. Background

In the design of High Power Amplifiers, HPAs, we are constantly evaluating new RF devices. Many of these devices produce between 50 and 100W per transistor with gains that vary from 10 to 20dB. Because common RF laboratory test equipment signal sources have output power capability that is usually limited to 100 to 200mW, there is always a need to have a dependable driver amplifier to be able to characterize the output power of the device under test. When evaluating a variety of devices covering a wide frequency range from 50MHz to 500MHz this typically required the use of several different driver amplifiers, each tuned for the specific band of interest. Thus it is desired to have a broad band amplifier capable of covering this entire range. This allows us to test higher power amplifiers that cover the Amateur Radio 6m, 2m, 1.25m, and 70cm bands without changing the test setup of the driver amplifier. Thus the original goal of this work was to design an amplifier that could produce 20W with >15dB gain and cover the 50MHz to 500MHz frequency range.

II. GaN Technology

A new RF device technology that is emerging is Gallium Nitride, GaN. Presently there are a few companies producing high electron mobility transistors, HEMTs, using Gallium Nitride technology. These include: Eudyna, RFHIC, and Cree. Gallium Nitride technology is of particular interest to the amplifier design community because of the following properties:

- high power density
- high breakdown voltage
- high operating temperature
- high input impedance
- high efficiency

These characteristics make GaN HEMTs a natural for the requirements of the broad band driver amplifier. The device chosen for this amplifier is the EGN045MK by Eudyna.

III. Amateur Radio Applications

An amplifier covering an instantaneous bandwidth from 50MHz to 500MHz is of obvious interest in amateur radio applications. A highly efficient amplifier is of particular interest because many radio applications are battery operated. One such application is the operation of FM low earth orbiting satellites such as AO51 and AO27.

Operating AO51 and AO27 with 5W handheld transceivers can be a challenge in the mountains of southwestern Pennsylvania where there is persistent foliage attenuation of VHF and UHF radio waves. Having 3dB to 6dB higher output power can make a significant improvement when uplinking to these satellites. The remainder of this paper will describe the design, test results, and LEO operation of the amplifier. A design goal of 20W with an efficiency >50% over the entire 50MHz to 500MHz bandwidth has been established.

IV. High Efficiency Amplification

In recent years there has been much written on the subject of high efficiency amplification. Much of this work is grounded in low conduction amplification modes such as class D, E, and F. In these modes the transistor is biased at or near cutoff so that the conduction angle is minimized. These are all variations of switch mode amplifiers that require precisely tuned circuits or harmonic terminations for proper operation. As a result they do not lend themselves readily to broad band operation. An often-overlooked high efficiency amplification mode is the overdriven class A amplifier [1]. The class A amplifier is better suited for broad band operation due to the longer conduction angle and resulting load impedance. Class A bias is also more useful for using the amplifier as a driver amplifier for higher power device testing. When the class A amplifier is driven into saturation, the output waveform is clipped thus decreasing the conduction angle which results in higher efficiency. Due to the high breakdown voltage and robust nature of the GaN HEMT, saturated class A operation is possible.

V. Amplifier Design Tools

The amplifier design is divided into two parts: RF Design and Bias Circuit design. To encourage participation of radio amateurs and in keeping with the educational theme of the 2007 AMSAT symposium, two freeware software programs are used to complete the design of the amplifier. The student version of Ansoft Corporation's 'RF Designer SV' software was used to simulate the RF design portion of the amplifier. This software can be downloaded from Ansoft's website: www.ansoft.com . The bias circuitry was designed using Spice. An excellent freeware version of Spice is LTspice/SwitcherCAD III available from Linear Technology Corp. It is available for download from their web site: www.linear.com . These two programs were particularly helpful in that they were able to show the effect of substituting one part for another before actually making the substitution. In addition to these two programs, the 2007 student version of Matlab was used in preparing the plots of output power and efficiency.

VI. Bias Circuit Design

The amplifier is intended to operate from a single 28 VDC power supply. A highly efficient amplifier can mean that a common 28 VDC wal-wart style power supply can be used to power the amplifier. Thus the drain of the HEMT will be connected to the 28 VDC source. The gate of the HEMT must be biased negative with respect to the source. The source of most RF power HEMTs are flanged and therefore connected to DC ground. Therefore a negative voltage must be generated to operate the device. The Linear Technology LT1611 was chosen as the DC/DC converter to generate the negative gate voltage. This device generates a regulated negative voltage and up to 150mA with minimal external components. The GaN HEMT will draw negligible current from the negative supply under small signal (< 50mW) drive conditions. However when the amplifier is saturated the HEMT can draw over 10mA of gate current. Therefore a voltage divider will set the gate voltage close to -1V and allow a bleed current of 10mA. An MC7808 8V regulator is used to step the +28 VDC input supply down to a usable input voltage to the LT1611.

As with any GaAs or GaN device, it is important to set the negative voltage to the gate before applying the +28 V to the drain. It is very important to properly sequence the gate and drain voltages to avoid damaging the device. A P-channel MOSFET is used as a switch for the +28 V to the drain. The output from the LT1611 is used to turn the MOSFET switch on and off. This is where a good Spice model is required to ensure proper sequencing of the gate and drain supply voltages. Figure 1 shows the Bias Circuit schematic.

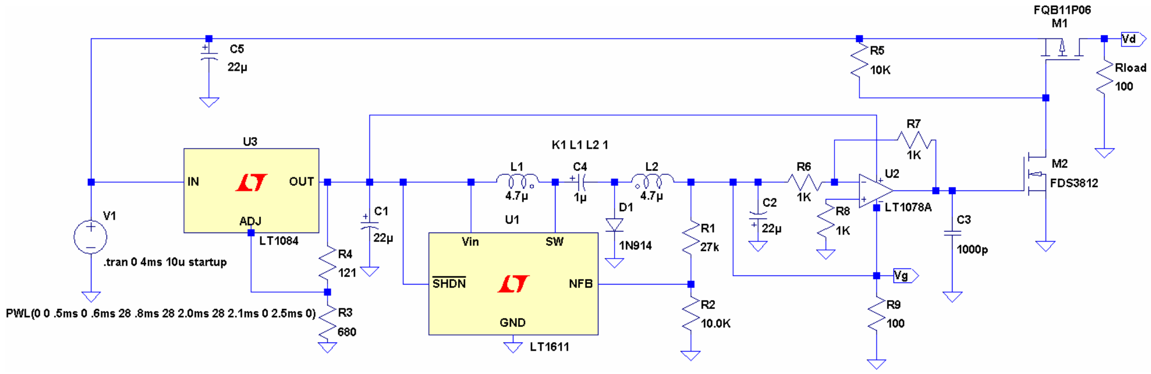

Figure 1. Spice Model of Bias Circuit in LTspice/SwitcherCAD III

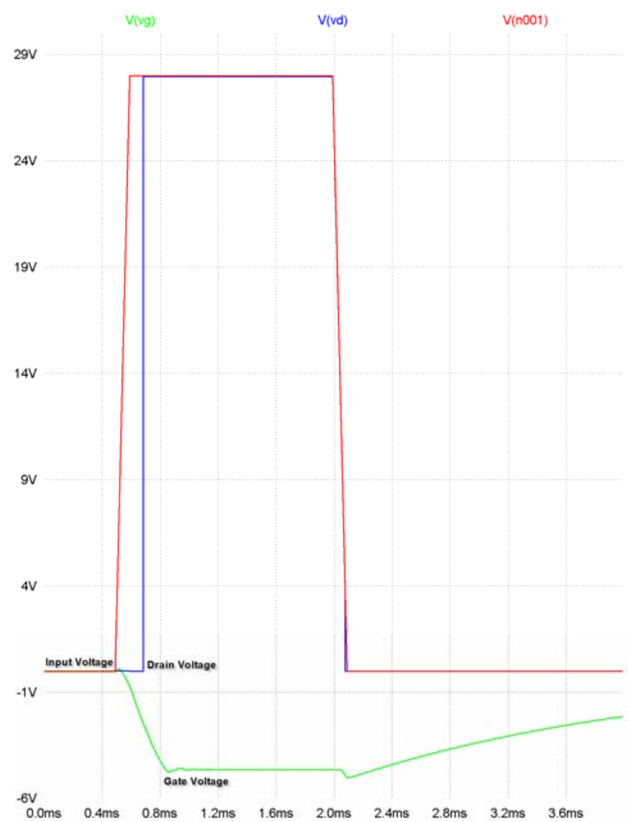

Figure 2. Timing diagram for bias sequencing circuit showing relationship among the 28VDC input voltage, output voltage, and negative gate voltage.

Figure 2 shows the gate and drain voltages from startup of the +28 V supply. As shown the gate voltage is stable before the +28 V drain voltage ramps up. When the input voltage is turned off, the gate voltage slowly decays over 1.5 msec. The bias circuit board is built on FR4 circuit board material and will be mounted adjacent to the RF amplifier board.

VII. RF Circuit Design

Because this amplifier is intended for small signal as well as large signal operation, the device is biased in the class AB region. This allows us to use small signal S-Parameters as a starting point for the RF circuit design. First the S-Parameters are analyzed for stability. To stabilize the device for operation in the VHF-UHF frequency range, a 5 ohm resistor is added in series with the device input. Also an RC feedback circuit has been added to guarantee that the stability factors K and B1 are satisfied [2]. A 4 section low pass network is used to match the input and output of the device for maximum gain and good return loss over the 50 MHz to 500 MHz bandwidth. Figure 3 shows the initial schematic in Ansoft Designer SV. The block labeled ‘EGN045MK’ is a data file that contains the S-Parameters for the GaN HEMT device. The input and output matching elements can be tuned to observe their effect on the gain and VSWR before the circuit is built. The amplifier circuit is designed on Rogers RO4003 substrate material. This substrate was chosen for its good RF characteristics and ease of processing. To simplify the assembly, all of the series inductors were replaced with high impedance (70 ohm) transmission lines to effectively distribute their inductance over a length of high impedance transmission line. The capacitors used are made by Dielectric Laboratories (C17CF series). The complete schematic of the amplifier is shown in Figure 4. Note the use of the VK200 ferrite core to feed the gate and drain bias voltages to the device. The VK200 presents a resonance free, broadband choke to the device for stable operation. A series of decoupling capacitors are also provided on each bias feed that provide a proper broadband shunt. A 100 ohm potentiometer is used on the gate circuit so that the gate bias can be tweaked for a particular quiescent point. This allows experimentation with the conduction angle and operation mode of the amplifier.

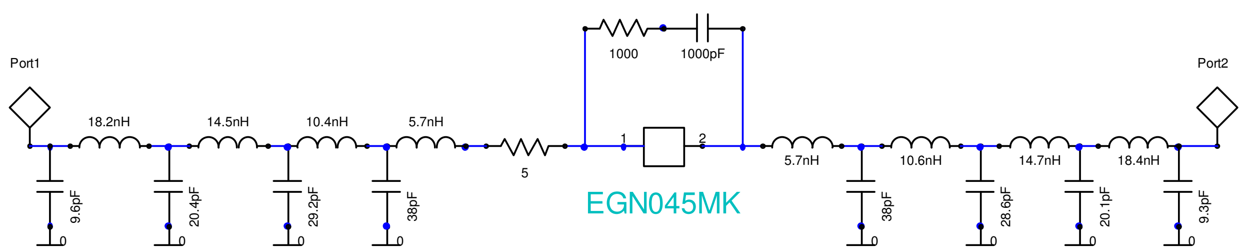

Figure 3. Schematic prepared for Linear Simulation in Ansoft Designer SV

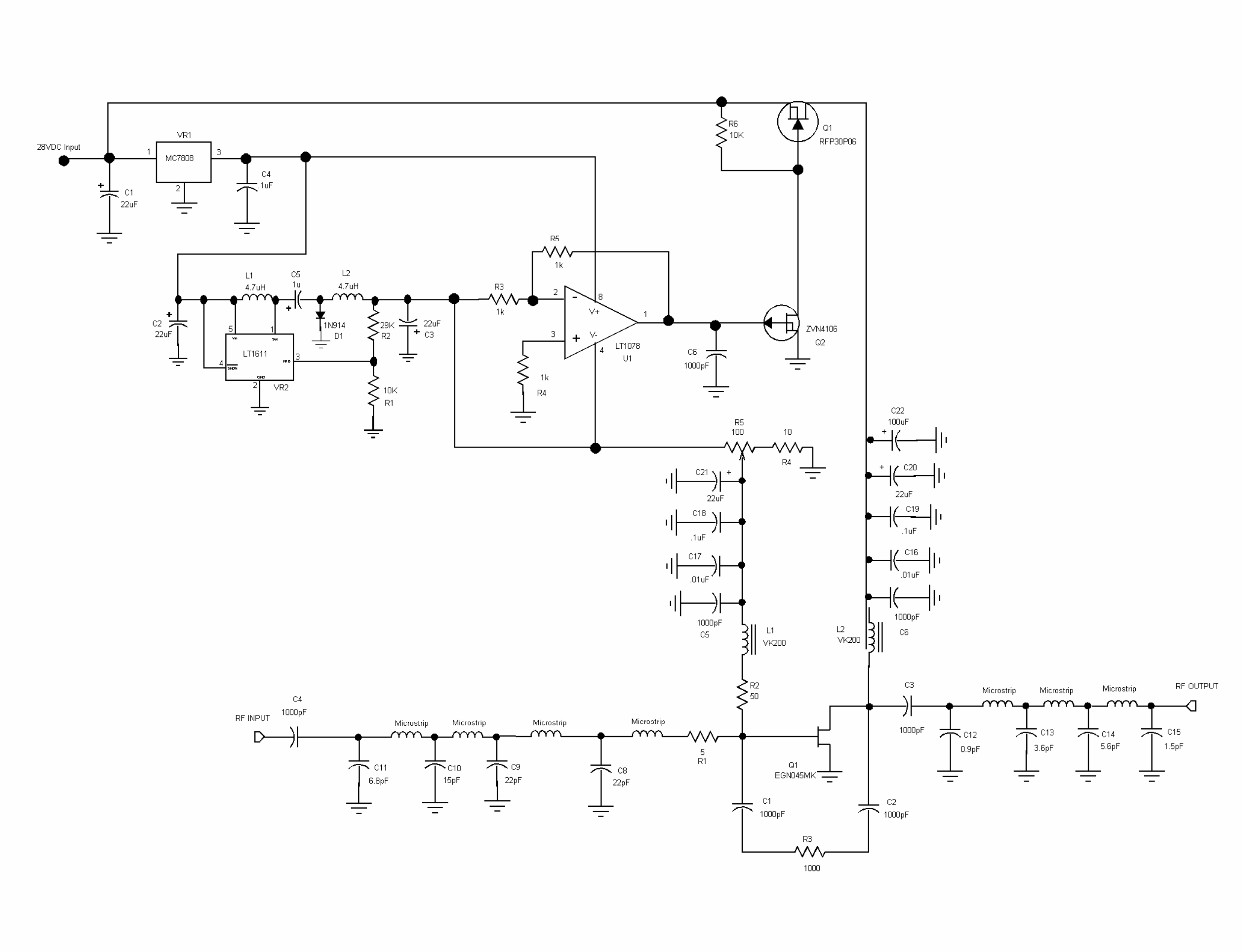

Figure 4. Complete Broadband Amplifier Schematic

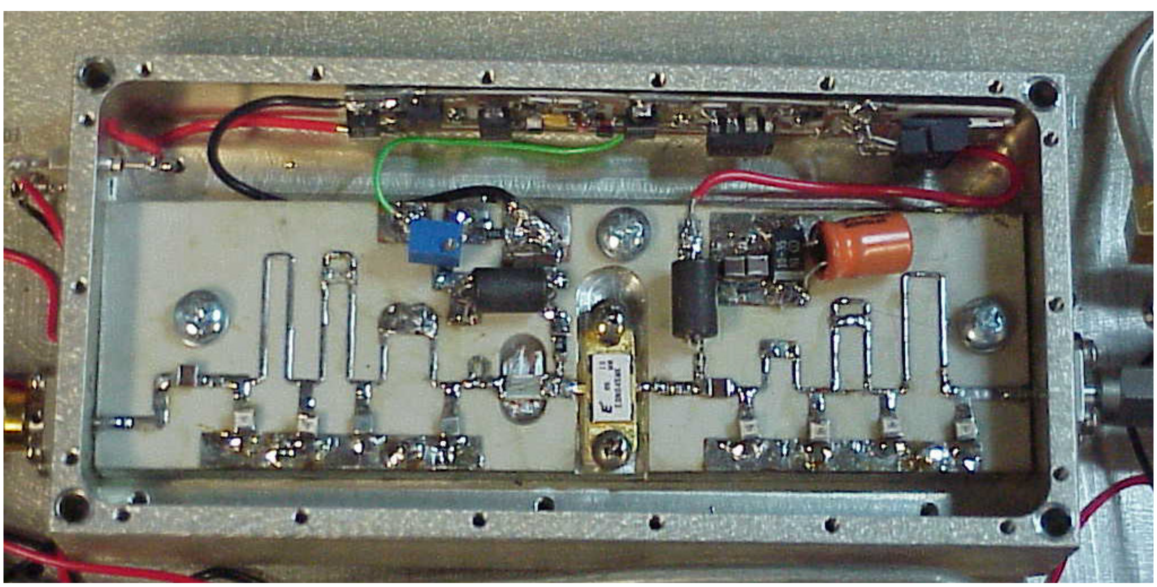

Figure 5. Assembled Broadband Amplifier with Bias Board mounted on side wall.

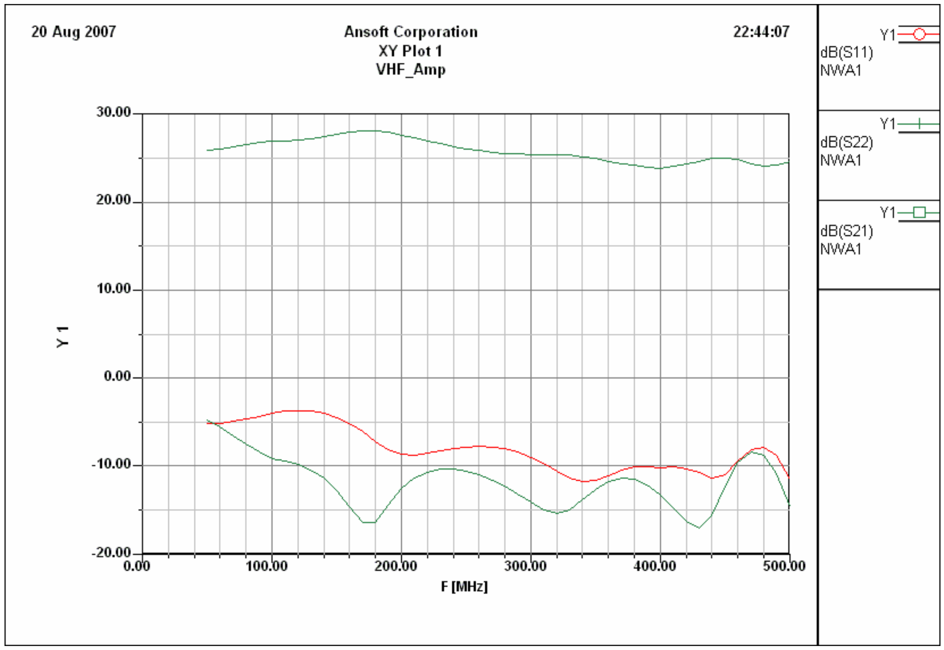

Figure 6. Simulated Gain(S21), Input Return Loss(S11), and Output Return Loss(S22).

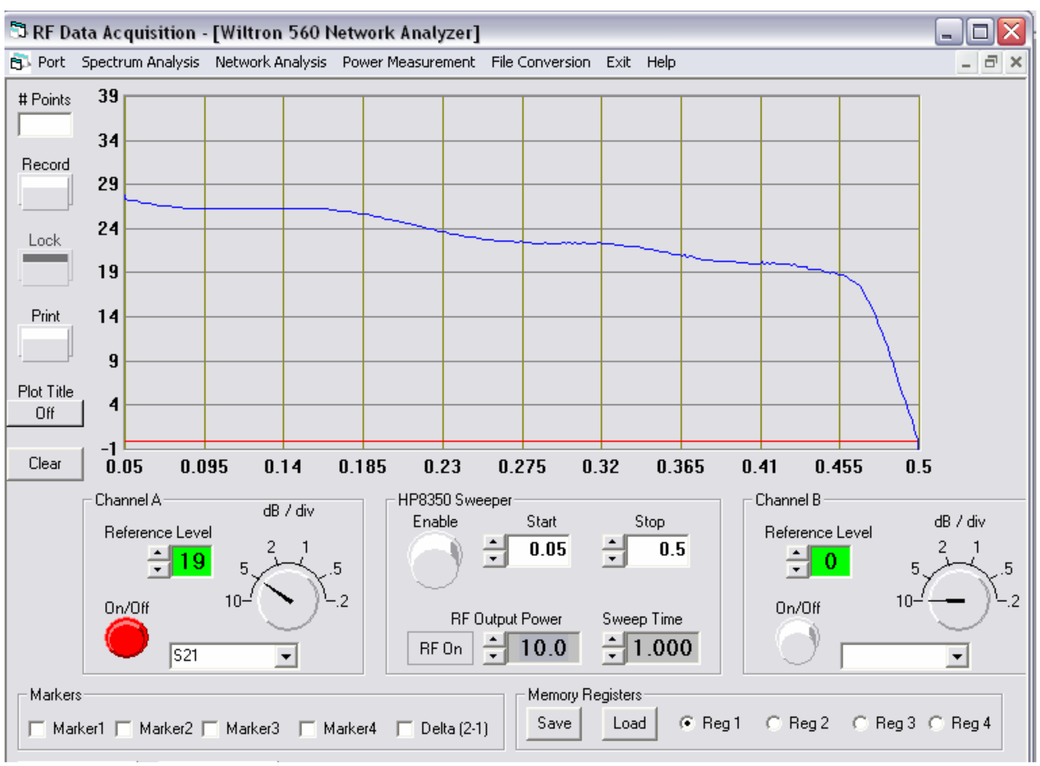

Figure 7. Measured Small Signal Gain vs Frequency in GHz.

VIII. Measured Performance

The gate voltage was adjusted to approximately -1.1 V which resulted in a drain current of 600mA. This puts the device well within the class AB bias range. The small signal gain vs frequency was evaluated on a scalar network analyzer. As Figure 5 shows, only minor tuning was performed on a couple of the inductive transmission line sections to improve the gain above 400 MHz. The final measured gain is shown in Figure 6. As the figure shows, the measured response is very close to the simulated circuit. The output power and drain current were then measured to evaluate the overall efficiency of this amplifier. The amplifier was evaluated in each of the four amateur bands: 50 MHz, 146 MHz, 222 MHz, and 440 MHz. The output power and efficiency is summarized in Table 1.

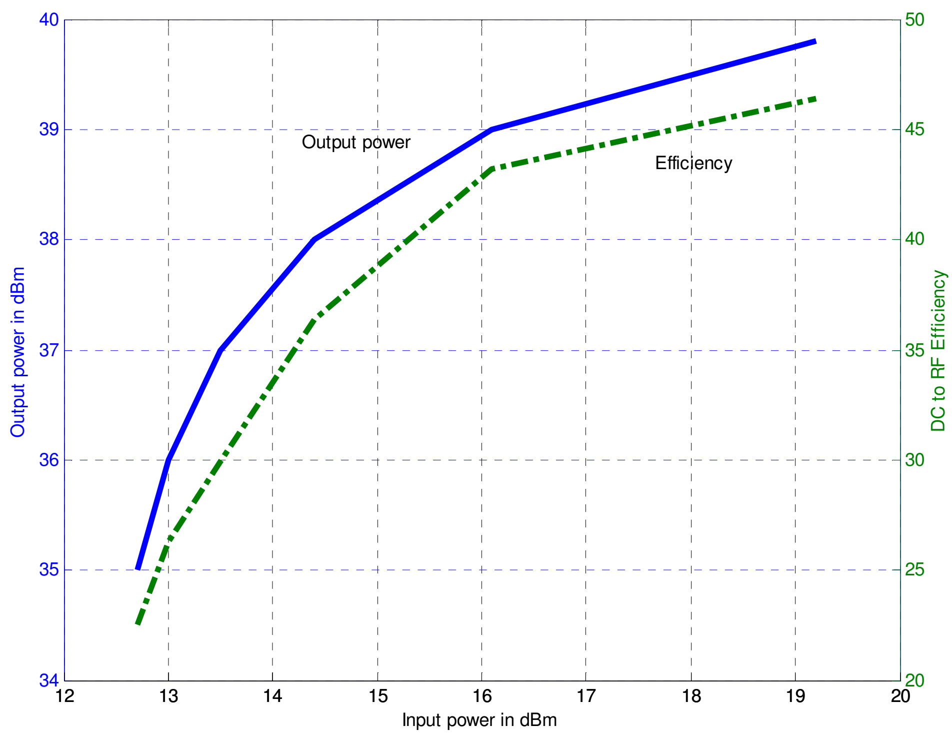

Figure 8. Output Power and Efficiency at 50 MHz

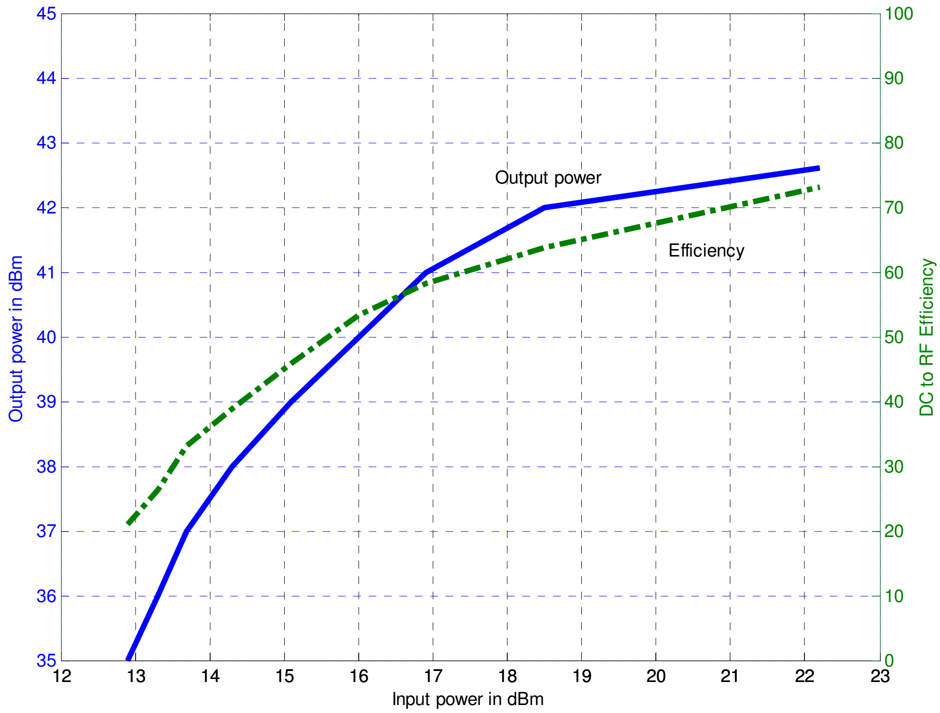

Figure 9. Output Power and Efficiency at 146 MHz

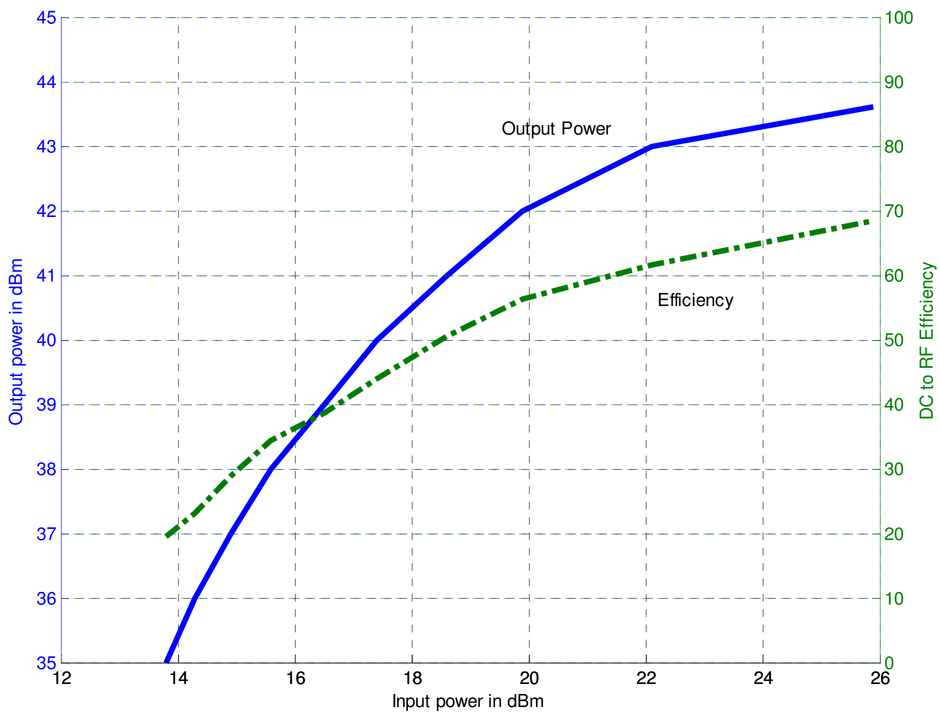

Figure 10. Output Power and Efficiency at 220 MHz

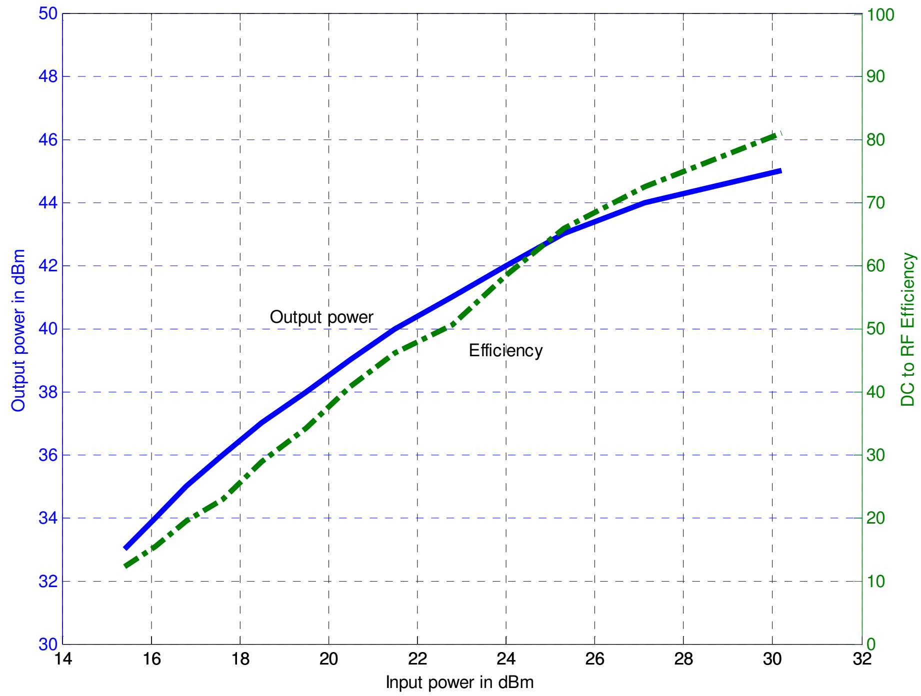

Figure 11. Output Power and Efficiency at 440 MHz

Table 1. Saturated Output Power and Efficiency Summary

Frequency	Psat, dBm	Psat, Watts	Drain Current @ 27 VDC	DC-RF Efficiency
50 MHz	39.8	9.55	.76	46.4
146 MHz	43.0	19.95	1.00	73.8
222 MHz	43.6	22.91	1.24	68.3
440 MHz	45.0	31.62	1.44	81.2

IX. AO51 Operation

In FM communication systems, operation of the power amplifier in saturated mode is possible. Saturated operation of the amplifier would not be acceptable in AM or Single Sideband due to the distortion caused by intermodulation products. Dual band hand held transceivers such as the Kenwood TH-D7A can be operated in full duplex mode for satellite operation. Because of the excellent efficiency and single ended supply operation, it is possible to power the amplifier for portable operation. Operation with a portable, split boom antenna such as the Arrow II can experience receiver desense. This is due to the higher output power from the HPA and minimal isolation between the VHF and UHF antennas. To overcome this it is helpful to install a VHF low pass filter on the output of the HPA and a UHF high pass filter on the input to the receiver. The VHF low pass filters serves to reduce the transmit output noise power density in the UHF downlink band. This filter is also helpful for reducing harmonic energy from the HPA. The UHF high pass filter further reduces the HPA output noise coming through the UHF antenna. A duplexer is used to combine the uplink and downlink bands to a single feed for connection to the TH-D7 handheld transceiver. The duplexer will provide an additional degree of filtering of the VHF output signal from the UHF input. The filters are mounted to a bracket behind the antenna handle. The HPA and power supply are mounted to a tripod. The antenna can also be mounted on the tripod via a ball socket that allows full azimuth and elevation movement of the antenna. Using the TH-D7A at its ‘low power’ setting presents a good drive level for the HPA.

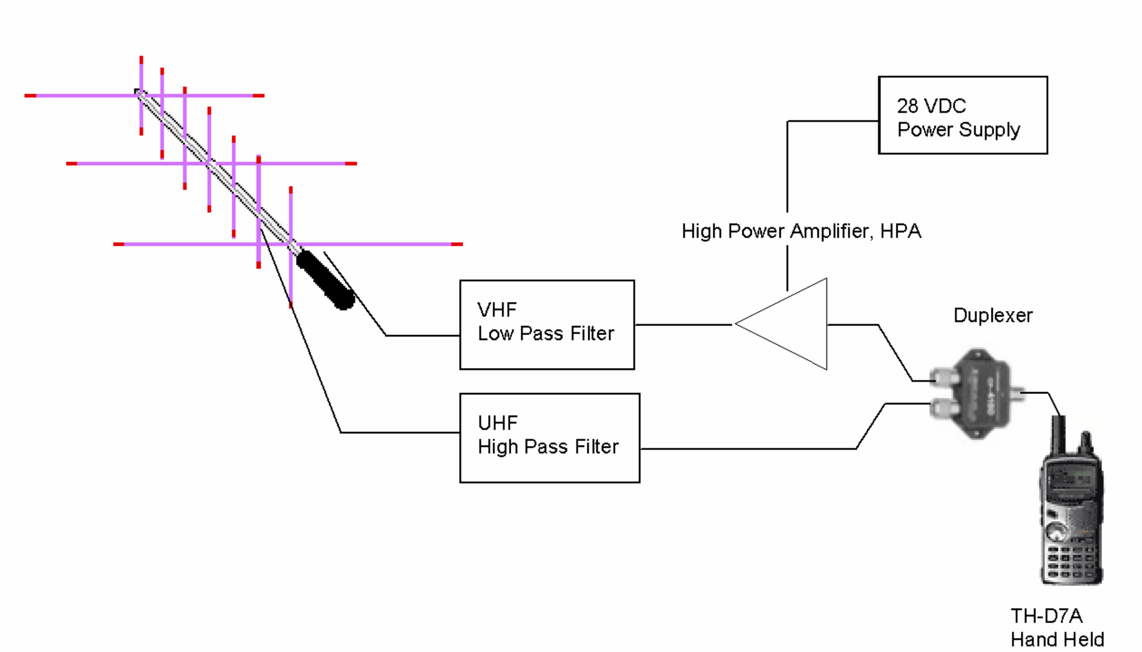

Figure 12. AO51 Station Configuration

X. Filter Design

Fortunately the Ansoft Designer SV program includes a filter design tool. This greatly simplifies the design of the VHF low pass and UHF high pass filters. A fifth order Chebyshev topology was chosen for the VHF filter with a cutoff frequency of 150 MHz. Air wound inductors were homebrewed with .050 inch diameter bus wire while chip caps were used for the shunt capacitors. The filter was built on the same RO4003 substrate as the HPA and fitted with solder-on SMA connectors.

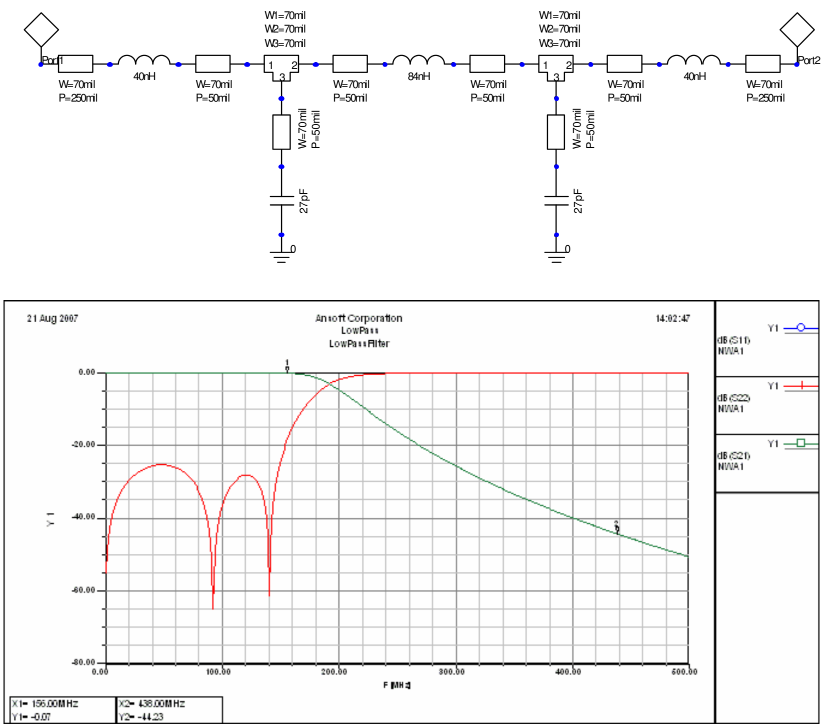

Figure 13. VHF Low Pass Filter schematic and simulated response

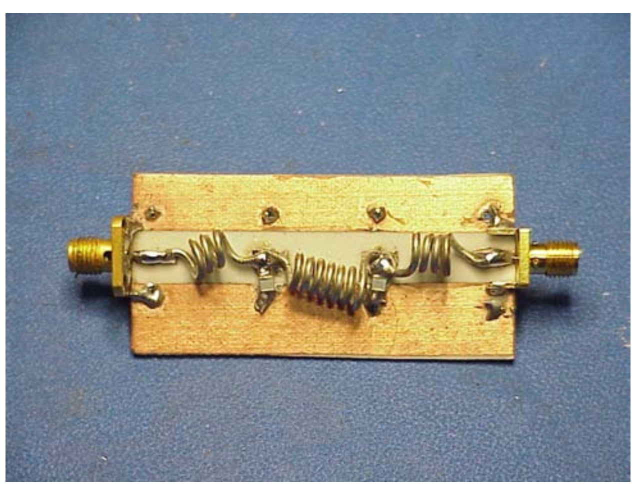

Figure 14. Assembled VHF Low Pass Filter

A seventh order Chebyshev topology was chosen for the UHF high pass filter with a cutoff frequency of 400 MHz. This filter was built on .030 inch thick Duroid substrate on an aluminum carrier. The carrier was fitted with flange mount SMA connectors.

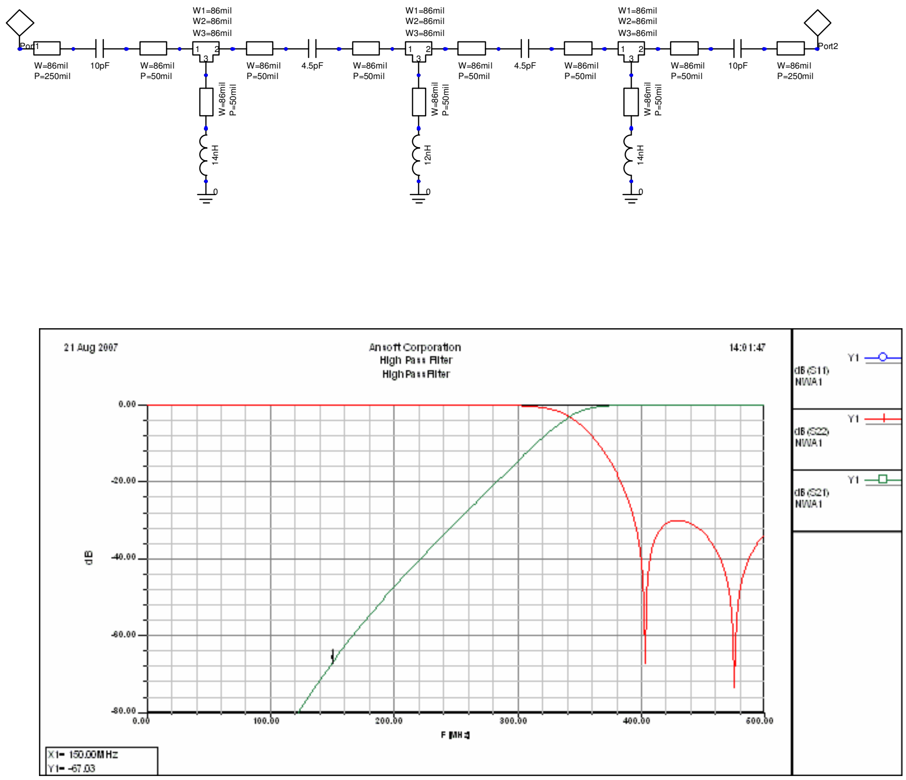

Figure 15. UHF High Pass Filter schematic and simulated response

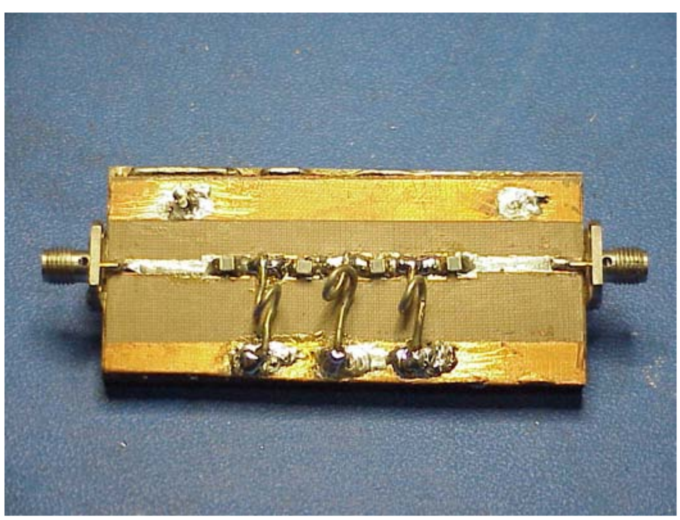

Figure 16. Assembled UHF High Pass Filter

XI. Summary

A broad band VHF/UHF amplifier has been presented. The amplifier has successfully achieved nearly a decade of instantaneous bandwidth. Biased for linear operation and having 20dB gain and 20W output power capability makes this amplifier an ideal driver amplifier for the RF lab. This amplifier will be used to assist in the test and evaluation of much higher power devices.

The amplifier has also been demonstrated to be an effective 20W amplifier for VHF/UHF dual band handhelds with 1W output capability. We have successfully made several AO51 contacts using the amplifier.

Freeware and low cost software was used throughout the design process to encourage students and amateur radio operators to participate in RF circuit design.

Using a GaN HEMT device along with overdriven (saturated) operation makes this amplifier suitable for FM radio operation. It should be emphasized that this amplifier has been designed for linear operation using small signal design techniques. No particular effort was made to load match the device for high efficiency. Reasonably good drain efficiencies have been achieved without the use of a higher class bias setting, harmonic terminations, or large signal output matching. Despite this, the efficiencies presented are comparable to much of the published efficiencies of class D, E, and F power amplifiers. This shows the promise of GaN technology in the realization of high efficiency amplifier design.

Future work will focus on optimizing the efficiency and linear operation for AM and SSB applications.

References

[1] Steve C. Cripps, “RF Power Amplifiers for Wireless Communications,” Artech House, 2006
[2] “The ARRL UHF/Microwave Experimenter’s Manual,” Chapter 6, 1990

Author bios

Stephen Turner is a long time Amateur Radio Operator with particular interest in operation above 50MHz. He holds an Extra Class license and is a member of AMSAT, ARRL, and QCWA. He is presently the VP of Engineering at Paradise Datacom, focusing on the design and manufacture of high power amplifiers from S band through Ka band.

Charles Turner is an undergraduate student at the University of Pittsburgh’s Department of Electrical and Computer Engineering. Charles presently holds a General Class amateur radio license and is a member of the ARRL.

Receiving and Displaying the AO-51 Telemetry Downlink: a Sound Card DSP Software Modem and a Matching Telemetry Display Program

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Abstract

The author presents a sound card DSP modem used for receiving and displaying satellite digital signals along with a matching visual telemetry program for viewing and analyzing the satellite telemetry from AO-51.

Introduction

Satellite telemetry is a collection of measurements that the spacecraft makes and then transmits to the ground. In the particular case of the satellite AO-51 (formerly "Echo"), the telemetry measurements include temperatures, voltages, and currents from various subsystems and components such as the solar panels, the batteries, and the radios as well as a collection of status bits and control values. The telemetry tells us all about the spacecraft, and it is the only way for us to know what is happening to it: How hot (or cold) is the spacecraft? How long are the eclipses lasting this month? How much power is available to run the radios and experiments? How fast is the satellite spinning? Telemetry provides the answers.

All of the telemetry measurements are collected together into a packet and sent out via radio signals. AO-51 transmits its telemetry on 435.150 MHz at 9600 baud as AX.25 packets that are sent using G3RUH modulation. A typical satellite ground station for receiving the telemetry uses a narrowband FM receiver. The audio from the receiver's discriminator is sent to a TNC. The TNC acts like a modem to convert the audio back into bits, reassembles the packet and checks to make sure that everything is received correctly. If it was, then the TNC reformats the packet and sends the packet over a serial cable to the computer. On the computer, a telemetry program listens to the serial port for the incoming packet and then parses out each of the measurements. For each measurement, a calculation is performed to convert the received value (for example, nineteen) back into the actual measured value on spacecraft (perhaps eight degrees Celsius). With over sixty telemetry channels measured per packet and several packets per minute, you really want a computer to do all the calculations. After all of this, we can see the measured temperatures, voltages and currents.

There are a few challenges, especially when it comes to acquiring all of the necessary pieces and getting them to work together. The beginner is unlikely to have all the pieces all ready. Radio receivers are common enough, but you also need a TNC with a 9600 baud modem. Modern computers, especially laptops, are less and less likely to have a built-in serial port for talking to the TNC. In addition, the telemetry itself is less interesting if you don't know what it is, what it means, or even what the measured thing looks like. The telemetry is more interesting when you can see what it is that's being measured instead of just a bunch of columns of numbers. Lastly, once the data comes into the computer over the serial port, it typically goes to the telemetry program, and that's the only place it goes. There usually aren't any options for sharing the serial port with another program.

Willow and Sabins

Willow is a digital signal processing program that either reads an audio recording or receives audio from a sound card and then demodulates 9600 and 38400 baud AX.25 packet signals, including the telemetry packets. The received packets can be displayed in any of several user-selectable formats including TNC2 style, optionally with a hexadecimal dump of the packet. Packets with a good CRC will be displayed in green, and packets with a bad CRC will be displayed in red or not at all if desired.

For demodulation, the modem incorporates a numeric oscillator, an interpolator for 38400 baud, a pair of moving-average peak detectors[i], and a fractionally spaced equalizer with decision feedback. The demodulated raw bits are NRZI decoded and unscrambled[ii], framed up into AX.25 packets, and checked for valid CRCs. Willow is designed to be very versatile. When a valid packet is received, it can be processed in multiple ways simultaneously: the packet can be displayed to the screen, reformatted as a KISS packet and sent out a serial port, sent out a second serial port, sent over TCPIP, and saved in KISS format to a .KSS file.

One interesting use of the TCPIP connection is to send the AX.25 packets to a telemetry program running on the same PC. Originally, I wrote a simple program called Sabins[iii] to display AO-51 (Echo) telemetry received over TCPIP from the sound card modem. The sound card modem could easily send the same data at the same time to both Sabins and another telemetry program such as tlmEcho. Sabins receives the TCPIP data, and tlmEcho receives serial port data over a hardware null modem cable between two serial ports.

A Picture is Worth a Thousand Words

If you want to get another amateur radio operator or a student interested in the telemetry, then you probably need more than a few columns of changing numbers. Displaying the telemetry as a series of numbers organized by the telemetry channel number is easy enough for the computer but somewhat less interesting to the human. What do the batteries that we are measuring *look* like? What do the satellite radios *look* like? This battery control thingamajig, what does *it* look like?

As a telemetry display program, Sabins was written with the idea that the telemetry should be visually presented in context. Telemetry values for the solar panels should be displayed on a screen next to pictures of the solar panels themselves. Likewise, the telemetry values for the batteries should be shown on a page with pictures of the actual batteries that are in the satellite (All photos are used with permission.). Hopefully, this puts the telemetry in context for the beginning telemetry student. For the hard core telemetry watchers, Sabins has another page available with just columns of changing numbers.

But wait, there's more...

Sabins will receive the telemetry "live" over a TCPIP connection from the sound card modem Willow or from a telemetry server on the Internet. The latter will allow you to watch live telemetry even if the satellite is on the other side of the world, as long as someone on that side of the planet is feeding the data to the telemetry server. The telemetry server is a work in progress that I hope to be able to demonstrate soon.

To review and analyze historical telemetry, Sabins can also read .KSS files (both flavors) and whole orbit data files (WOD files). When reading these files, you can "single step" through the telemetry file one packet at a time and watch the changes in each of the telemetry windows as that packet is decoded.

Okay, so how does this all work?

There are several ways to connect together all of the piece parts depending on what you want to do and how you want to process the resulting telemetry:

Method #1 - offline processing for standalone systems

This is a simple way to get the telemetry yourself. I used this method originally with just a nineteen inch piece of wire stuck in the N-connector of a preamp on top of my car roof. The car's roof makes a nice ground plane. The preamp went to a scanner with the discriminator tapped and fed to the laptop sound card. The success of this method depends on several factors including the power output from the satellite and the elevation of the pass. Willow receives the audio, records the audio, and demodulates the AX.25 packets. This works well if you have a very slow computer or you don't have Internet access, or you want to experiment with different modem settings. In the latter case, you can repeatedly tweak the modem settings on the same recording until you get the best results or the largest .KSS file. You can then use Sabins to display the telemetry from the .KSS file.

Method #2 - a "real time" receiver

Connect your receiver's discriminator output to your sound card and run Willow as your TNC and 9600 baud modem. Willow can send the received packets over TCPIP to Sabins (in real time) as well as save the packets to a .KSS file for later analysis. You can also have Willow send the packets out up to two serial ports to other programs such as tlmEcho. In the near future, you should also be able to send the packets over the Internet to a telemetry server for distribution.

Method #3 - Real time but without a radio receiver (just Internet access)

Run Sabins and connect over the Internet to a telemetry server to watch the live telemetry (as long as someone somewhere on the planet is in the footprint of the satellite and feeding their received telemetry to the telemetry server on the Internet.)

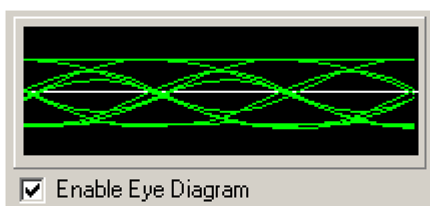
A Quick Start Guide for Willow and Sabins

1. Connect your computer's sound card input (microphone or linein) to your satellite receiver's discriminator output. You must take the output from the discriminator, not the speaker audio. Turn on the radio.

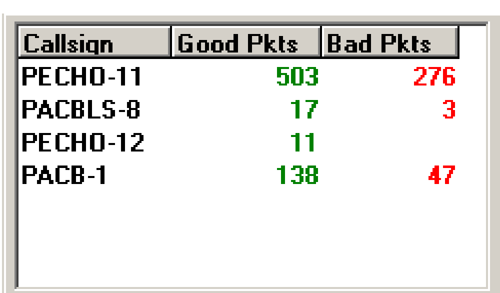
2. Download Willow and Sabins. You will also need the latest echocoef.csv file. Put all three in the same folder.

3. Start Willow by double clicking on the icon. You should see a large white window (the "Demodulated Data" window) where packets will be displayed. On the bottom left is a signal quality meter showing how well the signal is being demodulated. It is not an S-meter measuring signal strength. Instead, it takes into account the number of good characters and HDLC flags that are being received relative to the total number that could have been received. Below are LEDs for data carrier detect (DCD), for a connection on the first and second serial ports (CONa and CONb) and for a connection over TCPIP (COMip).

4. Below is an eye diagram that can be turned on or off using the checkbox below it. To the bottom right are various options you can change, and on the bottom left is a window showing the number of good and bad packets from various callsigns.

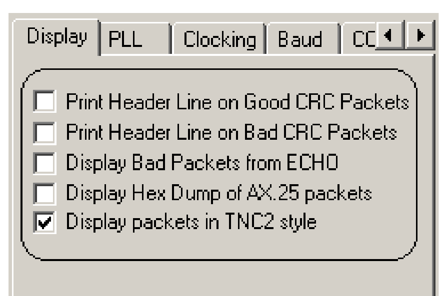


Eye Diagram



Callsign	Good Pkts	Bad Pkts
PECHO-11	503	276
PACBLS-8	17	3
PECHO-12	11	
PACB-1	138	47

Callsigns and Packets Received



User configurable options

5. Assuming that you want to run Willow "live" using audio from your sound card (not from a recording), you need to first turn on the sound card within Willow. Click on "File" on the main menu and then click on "Activate Soundcard" to start the sound card.

6. The audio input levels are crucial for 9600 baud reception. You will need to adjust your computer's audio levels until you see "Audio OK" in green in the bottom center. If you see "No Audio" or "Too Loud" then you need to make adjustments. To make the adjustments in Windows XP, click on the Windows "Start" button, then "Run", then type in "SNDVOL32" (without the quotes) and click on OK. This will bring up the Volume Control. In the Volume Control click on "Options" then "Properties" then click on "Recording" then click on OK. You should now see the vertical slider bars. Verify that you have selected the correct recording device by placing a checkmark in the "Select" checkbox. This will probably be "Microphone" but might be "LineIn" depending on where you plugged in the cable from your receiver's discriminator. To make coarse adjustments, click on the slider bar with the mouse. To make fine adjustments, click once on the slider bar to select the slider bar, then use the up and down arrow keys on the keyboard to slowly move up or down. You can watch the audio indicator or the eye diagram while you do this. You want the audio to almost always say "Audio OK" but a "Too Loud" indication only once in a while is probably fine. If the eye diagram checkbox is checked but you still only see a flat line and Willow only says "No Audio" recheck your cables and recheck which device is selected in SNDVOL32.

7. If you think you have the audio levels adjusted correctly, try a test. Verify that you have told Willow to display the packets -- on the "Display" tab in the lower right, check the box for "Display packets in TNC2 style." Then send a 9600 baud packet from another radio to your satellite receiver. You should see it displayed on the "Demodulated Data" window. (Hint: One easy way to do this is for you (or a friend) to send a 9600 baud APRS packet from an HT, but there are lots of ways.) If everything works, you should see your packet in the "Demodulated Data" screen.

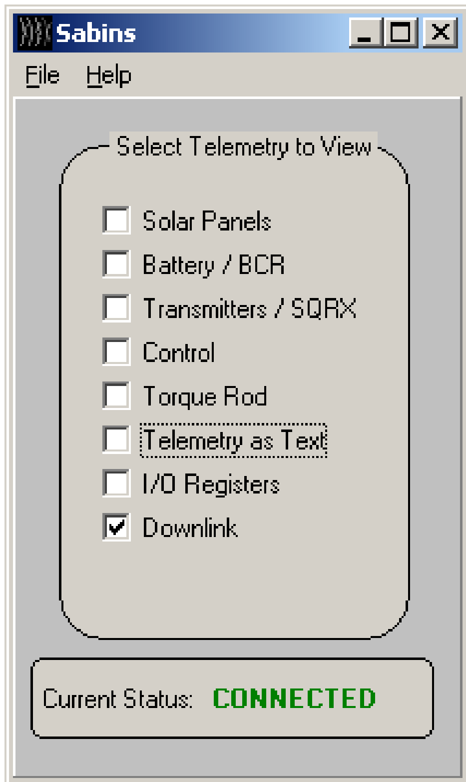
8. Next, tell Willow to send the received packets out over TCPIP. In the lower right corner, click on the arrows to scroll through the option pages until you see "TCPIP." Click on "TCPIP." On the "TCPIP" page put a check in the box next to "Send DATA to TCPIP port." The other options should be left as "localhost" and "41041."[iv] If you get a warning from Windows or your firewall program, then you will need to tell it to "Unblock" Willow to allow TCPIP.

9. You should now see a green LED on the lower left for the connection over IP ("CONip") and in the "Demodulated Data" windows you should see "Starting TCPIP Kiss server on port 41041."

10. Now that you have Willow working, you need to start up Sabins.

11. Once Sabins start, click on "File" then "Connect to TCPIP modem." The "Current Status" in Sabins should change to "CONNECTED."

12. In Sabins, click on the checkbox next to "Downlink" to see the packets that Sabins is receiving. You should see "Trying to connect to local KISS modem over TCPIP port 41041." and then "Connected."



Sabins main menu - connected over TCPIP

You're ready! As Willow receives packets via the sound card it will send them to Sabins. You can display other telemetry pages in Willow by checking the box next to the name of that window.

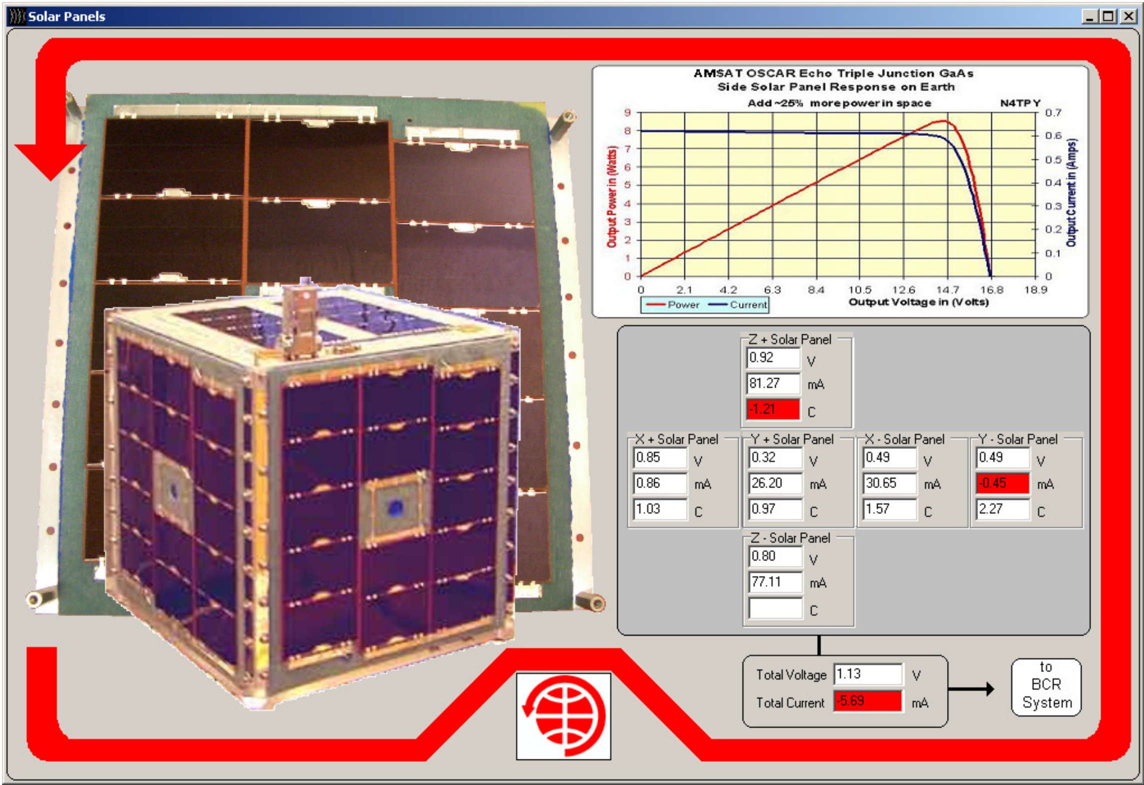


Photo 1: Sabins - Solar Panels Telemetry

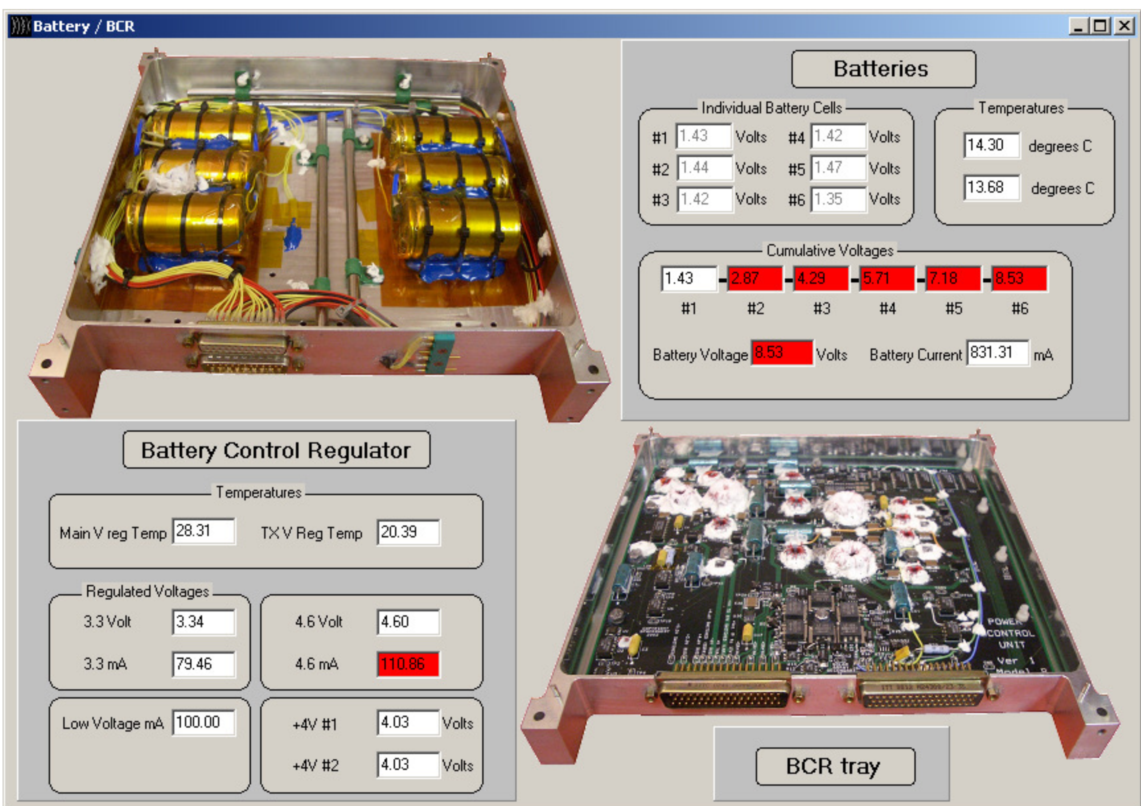
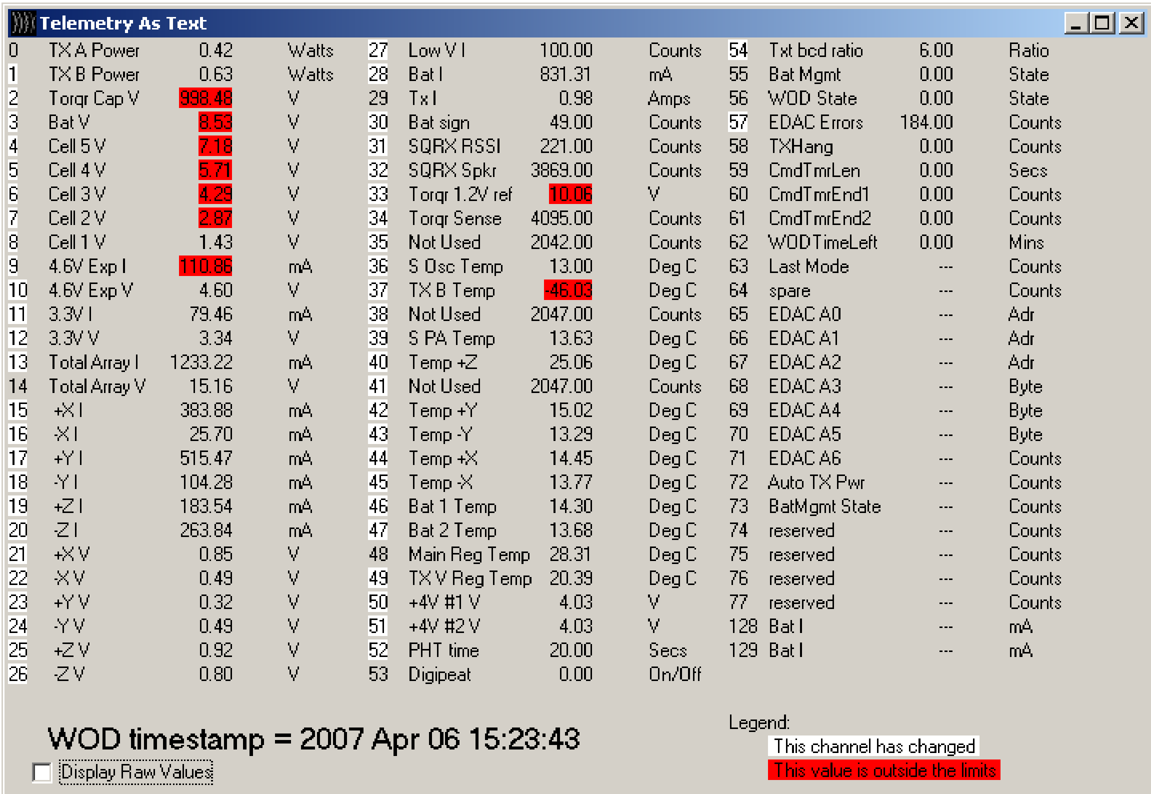


Photo 2: Sabins - Battery / BCR Telemetry



Telemetry As Text

0	TX A Power	0.42	Watts	27	Low V I	100.00	Counts	54	Txt bcd ratio	6.00	Ratio
1	TX B Power	0.63	Watts	28	Bat I	831.31	mA	55	Bat Mgmt	0.00	State
2	Torqr Cap V	998.48	V	29	Tx I	0.98	Amps	56	WOD State	0.00	State
3	Bat V	8.53	V	30	Bat sign	49.00	Counts	57	EDAC Errors	184.00	Counts
4	Cell 5 V	7.18	V	31	SQRX RSSI	221.00	Counts	58	TXHang	0.00	Counts
5	Cell 4 V	5.71	V	32	SQRX Spkr	3869.00	Counts	59	CmdTmrLen	0.00	Secs
6	Cell 3 V	4.29	V	33	Torqr 1.2V ref	10.06	V	60	CmdTmrEnd1	0.00	Counts
7	Cell 2 V	2.87	V	34	Torqr Sense	4095.00	Counts	61	CmdTmrEnd2	0.00	Counts
8	Cell 1 V	1.43	V	35	Not Used	2042.00	Counts	62	WODTimeLeft	0.00	Mins
9	4.6V Exp I	110.86	mA	36	S Osc Temp	13.00	Deg C	63	Last Mode	---	Counts
10	4.6V Exp V	4.60	V	37	TX B Temp	-46.03	Deg C	64	spare	---	Counts
11	3.3V I	79.46	mA	38	Not Used	2047.00	Counts	65	EDAC A0	---	Adr
12	3.3V V	3.34	V	39	S PA Temp	13.63	Deg C	66	EDAC A1	---	Adr
13	Total Array I	1233.22	mA	40	Temp +Z	25.06	Deg C	67	EDAC A2	---	Adr
14	Total Array V	15.16	V	41	Not Used	2047.00	Counts	68	EDAC A3	---	Byte
15	+X I	383.88	mA	42	Temp +Y	15.02	Deg C	69	EDAC A4	---	Byte
16	-X I	25.70	mA	43	Temp -Y	13.29	Deg C	70	EDAC A5	---	Byte
17	+Y I	515.47	mA	44	Temp +X	14.45	Deg C	71	EDAC A6	---	Counts
18	-Y I	104.28	mA	45	Temp -X	13.77	Deg C	72	Auto TX Pwr	---	Counts
19	+Z I	183.54	mA	46	Bat 1 Temp	14.30	Deg C	73	BatMgmt State	---	Counts
20	-Z I	263.84	mA	47	Bat 2 Temp	13.68	Deg C	74	reserved	---	Counts
21	+X V	0.85	V	48	Main Reg Temp	28.31	Deg C	75	reserved	---	Counts
22	-X V	0.49	V	49	TX V Reg Temp	20.39	Deg C	76	reserved	---	Counts
23	+Y V	0.32	V	50	+4V #1 V	4.03	V	77	reserved	---	Counts
24	-Y V	0.49	V	51	+4V #2 V	4.03	V	128	Bat I	---	mA
25	+Z V	0.92	V	52	PHT time	20.00	Secs	129	Bat I	---	mA
26	-Z V	0.80	V	53	Digipeat	0.00	On/Off				

WOD timestamp = 2007 Apr 06 15:23:43

Display Raw Values

Legend:
This channel has changed
This value is outside the limits

Photo 3: Sabins - Telemetry as text

The future - what could we do?

Years ago, when AO-40 was active, you could start up P3t or another telemetry program and watch live satellite telemetry, even if the satellite was over a different part of the planet, as long as someone somewhere was receiving that telemetry and feeding it to the telemetry server. Let's do that again, but this time let's not just do it for one satellite. Worldwide live telemetry for multiple satellites should be possible. If there's a telemetry ground station with Internet connectivity then we should be able to watch telemetry live. Telemetry ground stations could be as simple as a small antenna, a radio, and a shoe box sized appliance computer with a sound card and an ethernet jack. A dozen of these scattered around the planet should provide nice coverage. Then, from home, you could start up your telemetry program in a manner similar to Firefox's "Open in tabs" and we could see live telemetry and status updates for all the satellites we want.

Thanks

My thanks to Gould Smith, WA4SXM, for encouragement and whole orbit data telemetry for testing. And of course, thanks to my wife who assisted in the preparation of this work.

I am continuing to develop and improve the modem and telemetry program. Comments, criticisms, questions, and suggestions for improvement are all welcome. I hope this soundcard modem will encourage others and generate further interest in digital signal processing as well as telemetry collection using simple ground stations.

See you on the birds!

Further Reading

Smith, G. Gould. "AO-51 Development, Operation and Specifications."

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i For a hardware version of the peak detectors, see the 9600 modem by John Magliacane, KD2BD at http://www.amsat.org/amsat/articles/kd2bd/9k6modem/9k6modem.html

ii For a complete description of the G3RUH modulation format see "The Shape of Bits to Come" by James Miller, G3RUH, available at http://www.amsat.org/amsat-new/archive/articles/James_Miller/txt/108.txt.

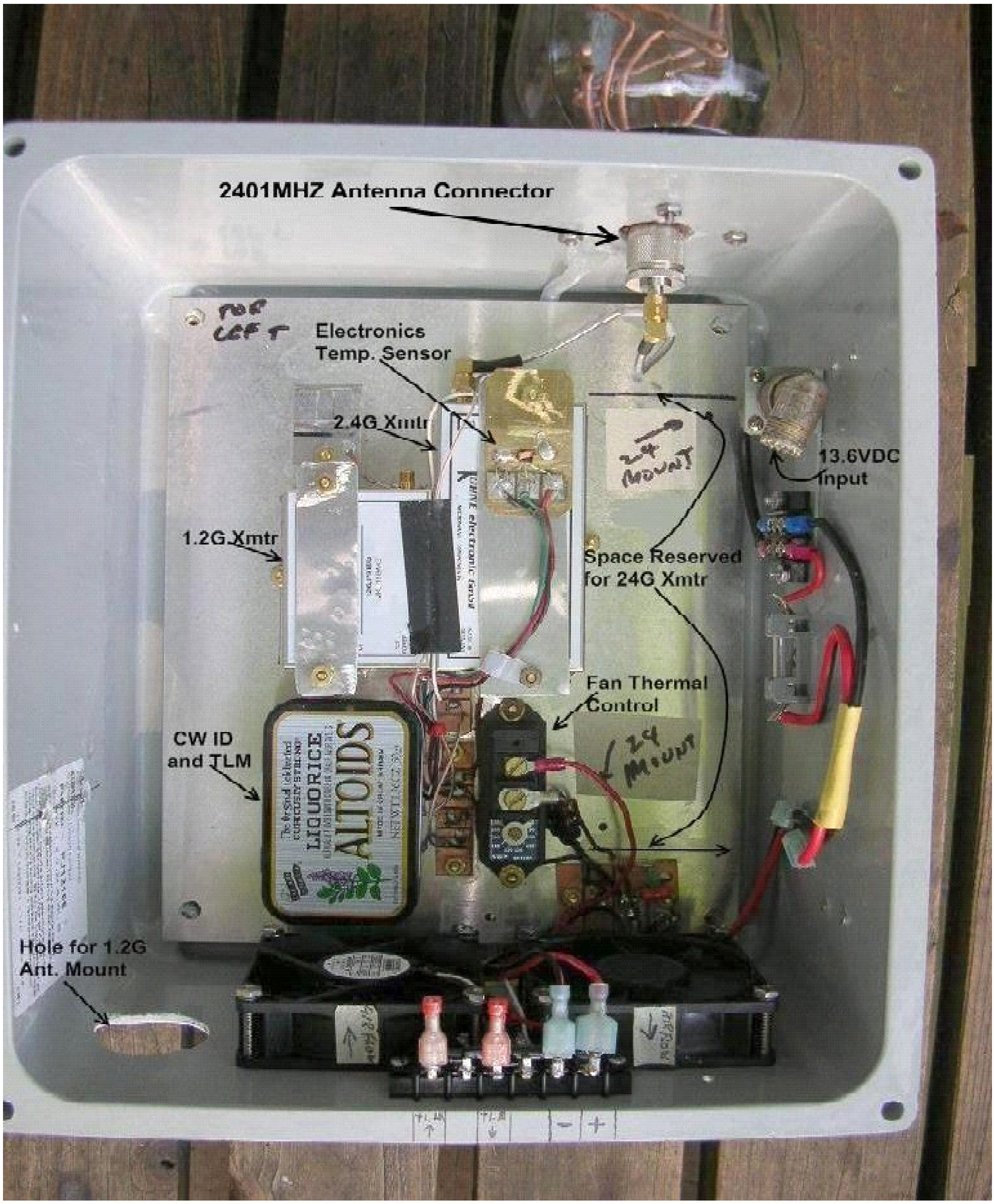
iii The Sabin in a unit of measurement for how well a substance absorbs sounds and echoes. Sabins is the name of the program that displays the telemetry measurements from the Echo (AO-51) satellite.

iv The TCPIP port number is a numeric pun. Decimal 41041 is hexadecimal A051.

Building a Beacon for 2401 Mhz

John Jamient W3HMS and Charlie Heisler, K3VDB

With no HEO Satellite for quite some time to use as a signal source, we thought a 24/7 Beacon might be useful to Folks around S-Central PA. etc



Overview

The microwave community makes extensive use of beacons for equipment and propagation checking on all bands from 6m-24 Ghz so why not do the same for satellite users? Yes, that is what we said so we set about to build a dual beacon for 1296.064 Mhz horizontal polarization and 2401 Mhz circular polarization both in the same box.

The "WE" in this case is Fred Lowe, W3MMV, Joe Lockbaum, WA3PTV, John Jamient, W3HMS and Charlie Heisler, K3VDB. We defined the tasks to be done and the purchases to be made then shared same among our group. I (W3HMS) have operated a Kuhne Electronics beacon on 10 Ghz for about 6 years now and was so very pleased with the dependability of their products which is consistent with their other products that I use for contesting on VHF, UHF and Microwaves.

Technical Summary

The heart of the two beacons is the Kuhne Electronics of Germany "Bakensenders" for each band. Each was ordered with the frequency specified. Each uses F1 FSK keying in lieu of classic "make and brake" keying as this promotes better short term stability. The frequency will change a few KHzs over time as the crystal ages. W3MMV volunteered to fabricate the horizontally polarized Alfred Slot antenna for 23 cm from "scratch" as did K3VDB for the 13 cm circularly polarized Lindenblad antenna. The slot antenna gain is about 4 db and the Lindenblad about 3 db; both antennas are housed in radomes. The 10 Ghz experience told us that we wanted to use a WW2R keyer with telemetry so we could remotely monitor the health of each beacon which is keyed by the same keyer. We use two blowers both for air flow and dependability turned on and off by a thermostat set to about 80 degrees.. All is mounted in a waterproof box designed for the electrical trade to house both beacons. The 23 cm antenna is below the box and the 13 cm antenna is on top. A single coax cable feeds 13 VDC to the beacons. The 23 cm beacon has an output power of 1.5 watts and the 2401 beacon, 1 W

Telemetry (TLM).

TLM has 4 positions of information. It was designed, built and the PIC programmed by Doug Robinson, G4FRE/WW2R in Texas. All the details are available on his Web site which I found with "WW2R" in Google. W3HMS and WA3PTV have used several of his keyers in past for various functions, all with superb results. The keyer with telemetry is called an "Intelligent Keyer" and it is viewable on his site under this title with schematic. Doug programs your desired message at purchase time. It is possible to send any TLM sensor value which can be expressed in the range 0-5 VDC.

Beacon Message.

We decided we wanted to send ….W3HZU/B W3HZU/B FN10PA FN10PA QSL to W3HMS@aol.com (then the telemetry in 4 groups of three numbers like) 056 049 234 032.…then recycle.

a. **DC Bus Voltage**. The DC voltage on the beacon bus is calculated by a formula a bit too complex to use in your head but easy to define in an EXCEL spreadsheet for common values. Let's say you copy the first group number 056, that is equal to 12.60 VDC at the beacons.

b. **Thermometer.** The second set of 3 numbers is the thermometer mounted on the beacon xmtr cover. One half of the temperature in F is sent in CW. As a example, 049 is sent so 049 x 2=98 deg. F. The thermometer is the reasonably priced LM34DZ.

C. **Vent Fans**. If the 2 vent fans are ON, the numbers are more like 231 than 000, as the latter indicates the fans are off. The fans cycle on and off about every 6 minutes at an outside temperature of 70 degrees F.

D. **Outside Temperature**. The temperature outside the beacon is sent as defined above for beacon temperature.

Performance

The beacon entered service at a temporary site on 6 June 2007. Initial tests from the W3MMV QTH confirmed good operation but the signal was weak at any real distance. K3VDB was able to obtain temporary permission to mount the beacons at a height of about 1130 FAS on a tower in Red Lion, PA, grid square FM19qv.

The beacon signs W3HZU and FN10PA as that is the ultimate destination on their 200 ft tower at about the 150 foot level. We have had excellent reports on the 23 cm beacon out to about 100 miles. The 2401 Mhz beacon has been heard at about 75 miles. The Weak Signal Group has asked why not 2304 Mhz and we have explained the needs of satellite operators at 2401 Mhz. An EXCEL spreadsheet has been developed by K3VDB to record telemetry data in a scientific manner, and is available on request.

Cost. These beacons are quality instruments and as such are not cheap, HI! We will be happy to discuss this aspect with serious prospective builders.

Photos. We have included photos of the complete beacon package with the two antennas.

Signal reports are welcomed. For further information and technical details, please contact Charlie Heisler, K3VDB at EMAIL k3vdb@amsat.org or John Jamient, W3HMS at w3hms@aol.com.

Factoids of the W3HMS 1.2Gig and 2.4Gig Beacons

First on the air June-6-2007
Beacons were purchased from Kuhne Electronics (DB6NT) and are collocated in FN10pa Just East of York PA. on the W3HZU Keystone VHF Club's Tower

Freq. of the 1.2G Beacon=1296.079 MHZ
Freq. of the 2.4G Beacon=2401.00 MHZ

Voltage at the Power Supply =13.79V DC
Voltage at Beacon=13.67V DC @ 1.38A

Note: (~) Indicates About, or to the best of our knowledge
1.2G Antenna is an Alford Slot, ~4db Gain, Horizontal in PVC Radome
2.4G Antenna is a Lindenblad, ~3db Gain, R/Hand Circular in Glass Radome

The 1.2G Beacon Output=~1.5W
The 2.4G Beacon Output=~1.0W

Some Temperature Observations;
With an Outside Temp of ~90ºF the Electronics Temp is ~108º W/Fans On.
(At this Temp. the 2.4G Freq. is ~2401.00MHZ)
At ~70º the Fans Cycle On and OFF about every 6 Minutes, the Electronics Temp lowers about 4-5º when Fans come on.
(At this Temp. the 2.4G Freq. is ~2400.998MHZ)

The AFSK CW ID and Telemetry (TLM) message is:
W3HZU/B (Two Times) FN10pa (Two Times) QSL to W3HMS@aol.com XXXXXXXXXXXX Then ~ 14 Seconds of Key down (Then it repeats)

The eXes are Beacon TLM numbers reporting Beacon Health. They are to be read in groups of 3. The first group indicates P/S Volts, To decode the numbers you would Divide it by 51.2 then Multiply by 11.283. The second group is the electronics Temp, multiply this number by 2. The 3rd group indicates fans on or off, Any number around 250 indicates Fans On, below 250 Fans Off. The 4th group is outside temp, multiply by 2 to get outside trmp.

An MS Excel Spreadsheet is available for decoding TLM.

K3VDB August 3, 2007

GENSO: A Global Ground Station Network

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This paper will discuss the Global Educational Network for Satellite Operators (GENSO) project, a software package for groundstation computers which aims to drastically increase a satellites availability to control operators. This project will achieve this goal by connecting many different groundstations together via the internet, so a person in North America can use a groundstation in Europe to communicate with a satellite. This International project is sponsored by ISEB and largely managed and funded by ESA.

There are numerous benefits to the Amateur Radio community, including motivating an entirely new generation of amateur satellite operators, more control options for AMSAT satellites, and a clearer snapshot of satellite health. Frequency usage and coordination will be discussed and the opportunities for individual amateurs to become part of the network will be explained.

While these first versions of the GENSO software package will support digital modes on VHF, UHF, and S-band, there are no restrictions on satellite frequencies and/or modes that can be passed over the network. Satellite builders would only need to distribute software drivers to groundstations. Future versions of this program will include streaming audio, orbital element calculation, and live internet chat.

1 Introduction

More and more universities and private companies are building pico-satellites these days. While there are some simple “beep beep” type satellites in orbit now, a majority of them are performing real science work. The working definition of pico-satellite used in this paper is anything less than 100 kg, but author is most familiar with the CubeSat class of satellites, which are in the 1 to 3 kg range.

With slow data rates and very low power output from these pico-satellites, one could say that the biggest problem for satellite operators is the amount of data that can be downlinked. This problem can be remedied several ways, the main way being increasing the data rate. However, on these pico-satellites (especially CubeSats), this cannot be easily done. CubeSats are power-limited satellites, and increasing the data rate would drastically increase the amount of system complexity and power needed, or would require the use of very large groundstation antennas.

So if little can be done on the spacecraft side, is there any other part of the equation we can change? There is, and it involves the other end of the radio link, the groundstation. If multiple groundstations could be used to receive data from a spacecraft, data throughput could be increased dramatically. This is exactly what the GENSO project intends to do; use the internet to link multiple groundstations around the world for increased data throughput. As a direct result of this distributed network topology, spacecraft operators will have increased access to their spacecraft in case anything unexpectedly goes wrong.

This idea for a global groundstation network really started at the first Ground Station Network conference in Tokyo, Japan, in July 2006. The Japanese universities, with the help of the Japanese student group UNISEC, have a fully functional groundstation network they call Ground Station Network (GSN), and the conference was designed as a working session for their network.

While half of the conference was in Japanese and dedicated to their GSN, there was section for other groups to present. Kyle Leveque from Cal Poly State University presented on his masters thesis [1] about a Central Server Architecture for a Global Ground Station Network, Neil Melville from the European Space Agency (ESA) presented on SatNet [2], his vision for an international groundstation network, and others presented on various networking ideas. By the end of the conference it was clear that there were enough interested parties for a global version of GSN to be developed. Soon after the conference, Neil Melville started to get the ball rolling within the Education Department at the European Space Research and Technology Centre (ESTEC). A mini-conference was held in Noordwijk, The Netherlands, in September 2006 to prepare a preliminary report and management plan for the International Space Education Board (ISEB) at the International Astronautical Congress (IAC) in Valencia, Spain, in the beginning of October 2006.

At the IAC, the ISEB accepted Neil Melville's SatNet proposal, and GENSO was born. Workshops were held at ESTEC in The Netherlands in February 2007, and at Cal Poly San Luis Obispo in July 2007.

GENSO is primarily a software project. The project is broken down into 10 work packages, with different universities doing different work packages. It is a truly international project, with students at University of Tokyo, Vienna University of Technology, Cal Poly State University, Jean Monnet University, and Aalborg University, working on the project, just to name a few. Non-profit organizations are also involved, including AMSAT-UK and UNISEC.

2 GENSO Goals

There are several main goals of the GENSO network. The first is increasing the amount of data that can be downlinked from a particular satellite by increasing the available pass times. This goal can be achieved by complete automation of existing groundstations to allow unattended operation, and by building new groundstations in desirable locations around the world. Another main goal of the project is the continuing education of students in the radio amateur realm and the satellite construction realm.

One advantage of the GENSO network is that satellite operators can control their satellite from around the world, if a situation should arise that requires immediate attention, or if their local groundstations is out of commission for some reason. The GENSO network should be scalable to thousands of stations. This makes the network architecture somewhat more difficult than when only a few stations are connected together.

Other, less important, objectives include remote uplink through trusted third-party groundstations, downlink error correction via packet comparison, and creation of a standard for groundstation software.

3 Amateur Radio Involvement

While the cynical among us claim that GENSO is only out to steal amateur frequencies, in fact there are many ways the GENSO and pico-satellite communities interact symbiotically with the amateur satellite community. Many pico-satellite programs do use frequencies in the amateur satellite service, but in return the amateur satellite community gets a steady source of new satellite builders and operators and more excitement about amateur satellites.

The biggest benefit to the amateur radio community is a steady source of new licensed amateurs. Over 80 percent of the students at the Cal Poly CubeSat program are licensed amateurs, and one of the first steps that new lab personnel take is get their ham license. That way they can operate the groundstation and learn about satellite orbits, frequencies, modes, and how to track a satellite.

While it is true that most of the universities developing software for the GENSO network are not here in the States, there will be many GENSO nodes here. While in the beginning, we expect most GENSO nodes will be attached to developers universities and universities with pico-satellite programs, once the project becomes fully functional it will be open to everyone.

After the testing phase when the network is made fully available, we really mean it is open to all amateurs and receive only stations operated by non-amateurs. Anybody with a receiver and antennas will be welcome to join and receive satellite data. The network will then forward the data to the relevant Mission Control Client much in the same way that was done with AO-40. Some amateur stations will also be able to uplink commands and specific telemetry requests. The software package is open-source and can be installed on Windows, Mac, or Linux, allowing the software to be installed on a wide variety of computers and operating systems.

The GENSO network will make the role of the IARU frequency coordinators more difficult. With the limited amount of spectrum being available, at least on the VHF and UHF bands, they are presently able to reuse frequencies depending on the location of the single mission control groundstation. They will do their best to rise to this challenge but it should be remembered that it is never possible to provide a unique and exclusive frequency for each satellite.

4 Network Architecture

The GENSO network has three distinct components, and these are discussed below. They are the Central Server, which simply authenticates nodes on the network and distributes spacecraft and groundstation lists. The groundstation Server (GSS) is located at the groundstation and controls the connected antennas and radio. The Mission Control Client (MCC) is used by satellite operators and can schedule passes and collect data from individual groundstation Servers.

4.1 Central Server

There are several different central server architectures that could be used. They range from a strong centralized system to systems with no central authority at all. There are both advantages and disadvantages to both topologies.

At one end of the spectrum is a highly centralized system, such as the University of Texas at Austin’s OneStop network [3]. In this case, the central server does pretty much everything, including scheduling pass times, archiving data for future use, interpreting downloaded data, making it available in an organized fashion, calculating satellite passes, etc. While this topology is the easiest to build, it has several major disadvantages that make it unsuitable for GENSO. The biggest disadvantage is scalability. The central server can only accept so many connections from other computers. Once that magical number is reached, the network takes a big performance hit. GENSO is designed to be scalable to "an arbitrarily large number of participating groundstations and missions." [4] In the far future, this might mean hundreds of spacecraft and thousands of groundstations. Clearly one central server cannot deal with the amount of data that thousands of groundstations will provide to it.

The other extreme is where there is a very simple (or no) central server at all, such as the GSN in Japan [5]. After using a central server for network registration, GSN works entirely peer-to-peer. The advantages include limited dependency on a central server somewhere that may go down due to network issues or maintenance. However, the central server has a very limited knowledge of what is happening within the network, who is talking to who, etc.

A good hybrid of these two architectures has a somewhat stronger central server than the Japanese network. Therefore, in GENSO, we decided upon a central server that would perform network authentication and encryption, distribute satellite lists, monitor groundstation and satellite operator status and "quality", and compile network statistics [6]. We feel that these tasks are not processor intensive, and access to the central server is only limited by the bandwidth available.

Within the GENSO project, we call this central server "AUS" for AUthentication Server. Currently it consists of several very powerful servers located at Vienna University of Technology. After the alpha testing phase, two more servers will be installed, one in California and one in Japan. Each server will be able to handle all of the nodes on the network, so three servers are necessary only in case of network failure and to keep network latency low.

4.2 GSS

The groundstation Server (GSS) is the piece of software that moves the rotors and tunes the radio, so it must be located at the amateur radio station. The hardware interface for this project will use the Hamlib, which is a large software library for Computer Aided Tuning of amateur radio equipment. An abstraction layer will be provided above Hamlib for individual hams to write their own drivers for custom and/or older radios, or if the Hamlib drivers are insufficient for some reason. The Japanese GMS drivers will also interact with this abstraction layer [7].

When a GSS wants to get onto the network, it contacts the Authentication Server. From the authentication server it gets a Participating Spacecraft List (PSL). The PSL is a list of spacecraft on the network now, their status, and the frequencies, modes, and Keplerian elements. Also included on the PSL is the encryption keys of the spacecrafts MCCs so a GSS can to contact a MCC directly to transfer downlinked data.

Future versions of the GSS software will include several additional features. An Internet Relay Chat client will be incorporated, so when future cluster launches occur the groundstation operator can stay up-to-date on the current status of the launch and satellites. Incorporation of a streaming audio client, such as Skype, will allow audio to pass to the MCC to allow adjustment of frequencies and confirmation of satellite health immediately after launch. With multiple groundstations listening to the same satellite, approximate Keplerian elements can be determined using the different acquisition-of-signal times for the different groundstation.

If an individual amateur radio operator would like to use their own amateur station as they have in the past, there is an option within GENSO to disconnect from the network. The individual amateur can then use the radio and rotor control portions of GENSO for full station automation. This feature is useful when an amateur just wants to use a satellite such as AO-50 for voice communications at a particular time, but also wants the station accessible to others when sleeping or at work.

4.3 MCC

The Mission Control Client (MCC) is the application where the satellite operator can control the network's handling of a satellite. The MCC can tell the GSSs what mode the satellite is in, what frequencies, etc. It also has a prediction section where the satellite operator can predict which groundstations their spacecraft will pass over, and contact the appropriate GSS for booking passes.

Each spacecraft will have one MCC, and it can reside on any computer hooked up to the internet. It doesn't need to be physically located anywhere, like the GSS computer. Included in the MCC is an optional graphical user interface, but there is also a built-in "wall plug" interface where individuals can make their own graphical user interface that just plugs in to the MCC [7].

When a MCC registers on the network with the Authentication Servers, it gets a groundstation Server List (GSSL), which includes all of the groundstations on the network, their location, what frequencies are available, and other groundstation parameters. Upon registration, the MCC becomes responsible for pushing updates to the authentication server about what modes the satellite is in, keeping the Keplerian elements updated, etc.

5 Standard Groundstation

In order to simplify the start up of the GENSO network, a "standard" groundstation hardware specification has been developed by AMSAT-UK. It includes common rotors and radios that are commercially available now. It is intended to provide a high performance and very robust and reliable station capable of successfully operating in extreme environments. One or two of these "standard" groundstations will be built by ESA for testing purposes and as their contribution to the network.

It should be made very clear that this "standard" groundstation is not in any way trying to restrict or encourage what hardware will be supported by the network. All different types of amateur radio stations will be supported by the GENSO network. One only needs to write software drivers if their radio or rotor does not already have drivers written for it. This "standard" groundstation configuration is only meant to ease the development of radio and rotor drivers during the testing phases. With Hamlib's drivers for 152 amateur radios from all various vendors, the finished GENSO network will accept a wide variety of rotors and radios.

Due to the open-source nature of the project and extensible architecture, it will be extremely easy to write drivers and add them to the project. For example, if a new radio becomes available that needs new drivers for the network, a software-inclined person could write a driver and add it to the software repository. Once the driver is added, any person using that radio could download that driver and use it.

6 Conclusion

The GENSO project will allow much more data to be downlinked from pico-satellites, encourage a new generation of students to become radio amateurs, and allow remote uplink of commands. It will accomplish this goal by connecting hundreds of amateur groundstations together using the internet. This international software project will begin limited testing in the end of 2007, with a finished product available for download by the end of 2008.

7 Bibliography

[1] Kyle Leveque. “A Central Server Architecture for a Global Ground Station Network.” *In Proceedings of the 1st International Ground Station Network.* University of Tokyo, Japan. July 2006.

[2] Neil Melville. “European Perspectives on a Global Educational Ground Station Network.” *In Proceedings of the 1st International Ground Station Network.* University of Tokyo, Japan. July 2006.

[3] Gregory Johnson. “OneStop: A System for Satellite Coverage Optimization for Networks of Groundstations.” *Masters Thesis.* University of Texas at Austin. September 2007.

[4] Global Educational Network for Satellite Operators. “System Design Description.” Issue 4. July 2007.

[5] Yasuhisa Oda, Tatsuhiro Sato, Nobuaki Kinoshita, and Yuya Nakamura. “A report on student’s Ground Station Network Project in Japan.” *In Proceedings of the 1st International Ground Station Network.* University of Tokyo, Japan. July 2006.

[6] Global Educational Network for Satellite Operators. “Human Readable Functional Block Diagram.” Revision 616. July 2007.

[7] Global Educational Network for Satellite Operators. “Functional Block Diagram.” Revision 616. July 2007.

Using GO-32 for Mobile APRS Satellite Operation

Figure 1.GO-32 Gurwin TECHSAT-1B

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As of mid September 2007, the GO-32 Satellite TECHSAT-1B team has enabled GO-32 for experimental 9600 baud APRS access for mobile and tactical APRS on a not-to-interfere basis with the existing PACSAT BBS. Other than some experiments via ECHO, AO-51, this is unique, since normally APRS has used 1200 baud for satellite operations on short mission duration spacecraft. The possible presence of GO-32 as a permanent, reliable APRS digipeater in space has great potential for the global and wilderness traveler.

User Satellite Equipment: The reason APRS via satellite has so much potential for the wilderness or global traveler or for emergency communications, is because it takes nothing more than the APRS HT in ones pocket to send your position/status and to send a short one line message or email. The ubiquitous APRS TH-D7 HT and TM-D700 radios shown to the right are ideal for this application. This is because they can operate at 9600 baud with their internal TNC and they can originate messages and data from the keypad and they can receive and display messages and position data on the front panel without any other attachments.

Figure 2.The TH-D7 and TM-D700 9600 baud radios

Access Times GO-32 is sun synchronous and so it comes over everywhere on the planet about three times between about 8 AM to Noon and again between 8 PM to midnight local sun time. During these two windows at least one pass each will be an overhead pass which might also work for an HT. The other passes will be lower to the East or West and will work fine for a 50W mobile as further detailed below.

Mobile Satellite Antennas: Like other Low Earth Orbiting (LEO) Amateur satellites with ranges in view between 1000 to 3000 km, the 2 meter uplink is possible with as low as 5 Watts in the absence of any interference during the center or a pass. Unfortunately, also like, the other LEO satellites, the UHF downlink is 9 dB worse to an omni antenna and requires tuning over a range of 10 to 20 KHz for Doppler. This usually requires a beam for reception. But GO-32 does have one of the stronger PACSAT downlinks and should be better in this regard.

If the objective is not continuous communications, but periodic position or status reporting for a wilderness traveler, the mobile will be able to take advantage of the short duration when the satellite is closest to him as shown in figure 3 below.

Thirty percent of all of the time that a satellite is in view, it is below 10 degrees and is at the limits of the horizon, usually up to as much as 3000 km away. But at higher elevation angles, the satellite is significantly closer. Almost seventy percent of the time, the satellite is below 20 degrees. But fortunately, for the 30% or so that the satellite is above 20 degrees it is also much closer. Usually from 6 to 10 dB closer than it was on the horizon

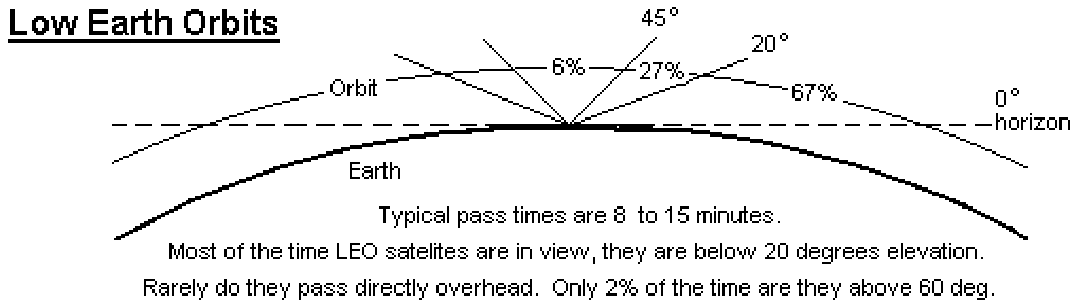


Figure 3.The pass geometry of LEO spacecraft spend most of their access time below 20 degrees.

This means that a mobile with an omni-directional antenna on its roof during this central part of a pass, can perform almost as well as a full size OSCAR array does at the horizon, but for much less time. However, if the mission of the APRS mobile is only to get his report into the APRS-IS system, he does have that potential during this small window of opportunity.

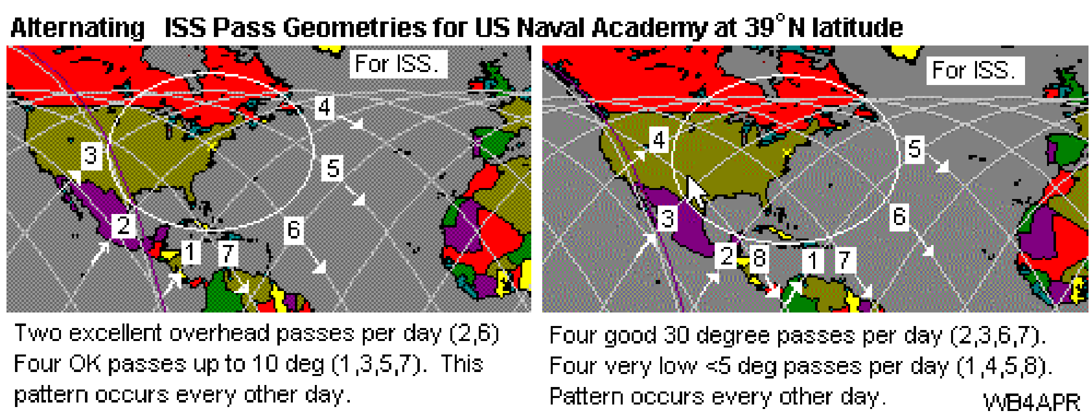


Figure 4.Satellite pass geometries are repeatable and consistent.

Another significant aspect of LEO orbits is that they have some relatively common repeatable pass configurations for each ground station as shown in figure 4. Although this is shown for the ISS orbit, it is similar for GO-32 except that the passes are more north and south. Looking at the left image, the point is that the first northbound pass of the day will be to the east. Then the second pass can be nearly overhead, followed by a third pass to the west.

But if the first pass is very low to the horizon, then there may be 4 ascending passes as shown on the right above. The second pass will be much higher, but still to the east, and the 3rd will be high to the west, with a final pass low to the west. Of course, after these ascending passes, twelve hours later, there will be a comparable set of three or four descending passes again starting from the East and moving west.

What this means is that an HT can get into the satellite with a 19.5" whip when the satellite is above 30 degrees because the satellite is much closer. This can satisfy the minimum reporting requirement of a wilderness traveler who can get a minimum of two and a maximum of four such passes every day. The concept of operations is shown in the figure 5 below:

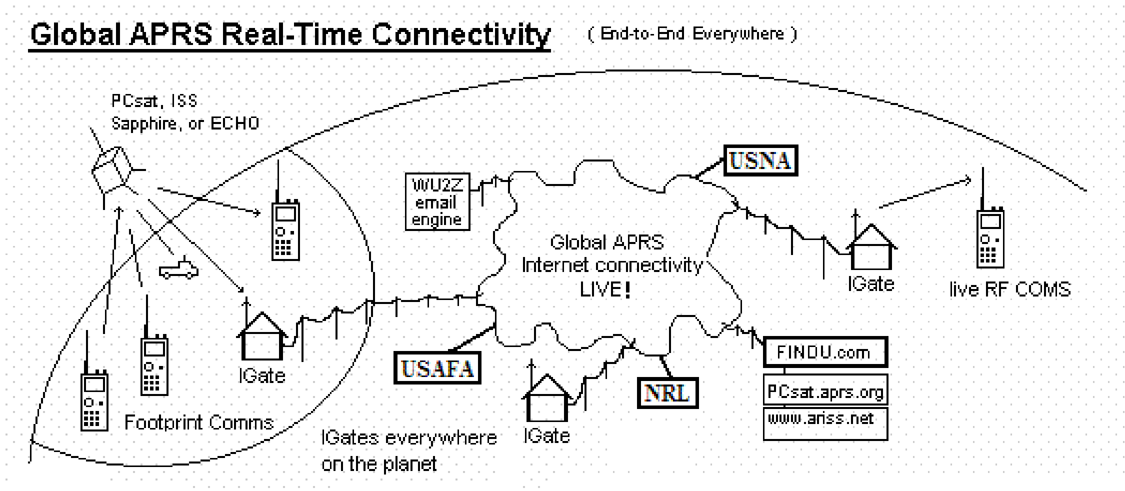


Figure 5.The APRS Satellite Operations Concept consists of mobiles, portables, ground stations and the Internet.

SATgate Operations: Normally for mobile position reporting and tracking, the APRS uplink objective is to get the packet out and received somewhere else via the global APRS Internet System (APRS-IS). In this case, mobiles concentrate on being heard, and permanent satellite gateways focus on receiving the downlink and feeding it into the APRS-IS. To date, all APRS SATgates have only been monitoring the 145.825 APRS and 145.800 ARISS channels for APRS and ARISS packet activity. Since there has been little 9600 baud APRS satellite activity to date, it will take a while for stations to gear up for this new frequency and 9600 baud operation. We hope volunteers will surface with permanent SATgates. Until we have more SATgates, do not expect to see yourself on FINDU.COM. Enjoy ham radio, make a Live contact instead!

HT Operations: Experimental testing shows that an APRS HT with a 19.5" whip can get a lucky shot into this satellite (but not when there is congestion on the uplink). With a handheld beam, it should be no problem for an HT, and the beam is needed on reception anyway. Fifty Watt mobiles should have no problem using a stock mobile whip. Due to the absence of APRS signals to date, however, we do not yet have good statistics on reception in a mobile...

Full-Duplex Issues: Operating on a 9600 baud FULL DUPLEX APRS satellite is *much* different than ARISS, or any of the other 1200 baud APRS satellites, because the turn-around is so fast, that the user cannot see their own digipeated packets on the same radio (usually). This is because most previous 9600 baud PACSAT protocol satellites keep their transmitter on all the time to maximize throughput and minimize key-up delays.

Fortunately, GO-32 is the first PACSAT protocol bird to use “ptt” mode where the satellite transmitter will drop if there is no data for downlink. If a packet does need to be transmitted and the transmitter is not up, then there will be a key-up delay of 1.25 sec in average (it is the first packet in the transmission queue). If the transmitter is up there is the delay of transmitting all the preceding packets in that queue. On GO-32, this key-up delay makes it easy for half-duplex TNC’s to hear their own packets in the downlink.

Unfortunately, when there are users logged onto the GO-32 PACSAT BBS system, then the carrier is always up, and this delay is not present, so APRS users may not see their own packets unless there is enough data in the downlink queue to hold off packets for several milliseconds.

Carrier-Detect (DCD) Issues: Another issue because of the satellite transmitter being on all the time, is the usual carrier-detect collision avoidance of most user packet systems. They will not transmit until the channel is clear. But on a full–duplex system, this is not needed since the uplink and downlink are independent. Most TNC’s have a Carrier Detect OFF or FULL-DUPLEX setting which will allow the TNC to ignore CD and transmit whenever it has data. Unfortunately, the D700 and non(g) model D7's do not have the CD OFF or IGNORE command. Since the year 2000 or so, however, the (g) model of the TH-D7 has been configured for satellite operation and does have DCD IGNORE added to its menu.

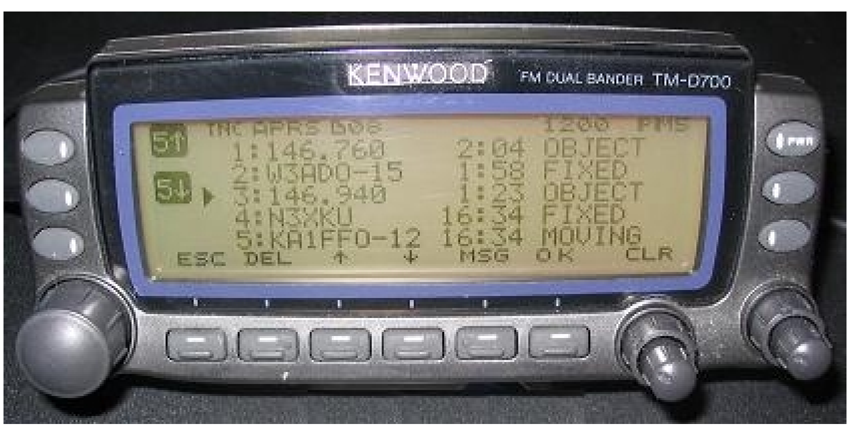
If you do not have a D7(g) model, and you want to both send and receive via GO-32, you will have to use separate radios, or momentarily QSY the RX channel so that the TX will key up. Then return the RX channel to the satellite downlink. Another method is to set TX mode to PTT and when you want to send a packet, kerchunk the microphone PTT button and your packet will go out then.

For Transmit only position and status reporting, stick to the recommended transmit rates and know that you are getting in if you stick to the protocol. Sticking to the recommended rates also keeps channel loading low, so that everyone gets in with less congestion.

Hearing 9600 Baud: By ear, 9600 baud sounds almost exactly like open squelch, though the tuned ear can soon distinguish the difference. Before the pass, set your squelch normally to quiet the speaker. When you hear the satellite, the squelch will open and you may see up to 3 bars on your S meter during the strongest near overhead pass. Keep tuning for Doppler to the "best sounding" (least distorted) noise.

Downlink Frequency and Doppler: Depending on how low to the horizon you can see, the satellite approaches 10 KHz high at 435.235 MHz... But it is may be 3000 km away. As it gets higher and 6 dB closer, it will be on 435.230 MHz, passing through 435.225 published center frequency at the middle point, and then drop down through 435.220 and ending at 435.215. But since it is 6 to 10 dB closer (and stronger) towards the center of the pass (800 km overhead), the mobile antenna is probably only going to hear the middle 435.230, .225, .220 portion easily. So I would start my reception at 435.230... You do not need to make any adjustments to the uplink, because on 2 meters, the Doppler is only +/- 3 KHz maximum and with deviation set low enough, the energy pretty much stays within the 2m passband.

TH-D7 and TM-D700 Satellite Setups: The easiest way to get on GO-32 with 9600 baud APRS is to use a Kenwood D7, D700 or D710 radios as noted above. These radios since 1999 have been satellite 9600 baud ready, just waiting on a satellite! The screen shot below is the station list page. Each station then has a full page of additional information. In addition to the station page with position, course, speed, grid square, direction and distance from own station, there is also the MESSAGE list which then points to full page displays of messages to and from other stations. Sorry I did not have time to get a photo of a satellite QSO page before this paper deadline. But Satellite Mobile is possible with GO-32, let the fun begin.!



The following list details the settings for these radios for GO-32 APRS operation:

- Set APRS Baudrate to 9600 baud.
- Set A band to data uplink on 145.93
- Set B band for data receive 435.225 +/- 10 KHz
- Set the TNC to TX on A and RX on B

- Set Path to be via 4XTECH
- Set MYCALL to a unique SSID (to distinguish these packets from your other APRS packets)
- Set TX method to AUTO
- Set TX RATE 1 min for HT, 2 min for D700. 5 Minutes for unattended.
- Set Position Comment to SPECIAL or PRIORITY. (this is required)
- Put something useful in your STATUS text maybe describing your setup: "50W mobile, 1/4 wave, 2m rate" or "5W HT, long whip, 1m rate"
- Save in a PM for use anytime you are outside of the terrestrial APRS network.

Future Possible GO-32 APRS Enhancements: The GO32 uplinks and downlinks are primarily for the PACSAT store and forward system and users. APRS is on a secondary basis and should not be operated unattended at any rates above one-packet per 5 minutes. One way to help APRS users tell if the PACSAT BBS is busy is to monitor the PBLIST packet that is transmitted once every 20 seconds if the BBS is in use. If APRS users see that the BBS PBLIST is full of other PACSAT users, they should hold off and not enable their APRS since the uplink will be busy. The problem is, that the PBLIST is not in APRS format so you cannot see it unless you are running normal packet mode.

The TM-D700 user can monitor these packets by pressing his front panel PMON button so that all UI packets are displayed. But they come pretty fast and furious. The D7 user does not have any similar way to monitor non APRS UI packets.

In the future, we hope that an APRS version of the PBLIST packet can also be transmitted, so that APRS users can see how many stations are in the PACSAT BBS queue.

Uplink Channels and Protocols: GO-32 is capable of supporting general APRS on only one of it's uplinks as shown below. Not only does this make sure that PACSAT users can operate with no interference on one exclusive channel, but it is also due to a unique hardware feature common to all of the 9600 baud pacsats. Here are the channel assignments on GO-32:

- 145.85 Dedicated APRS uplink channel only
- 145.89 Dedicated PACSAT channel
- 145.93 PACSAT channel and APRS Mic-E packets only

All of the PACSATs have a brute-force front end packet filter that monitors all potential packets and ignores all packets that do not have a destination address that starts with the same character as the first character of the satellite's own address. This assures that the spacecraft processor does not waste valuable processing power in trying to decode noise that might begin looking like a packet but later on will not have a valid checksum. By ignoring all junk that does not appear to be a packet starting with the right character, the processor is able to ignore 255 out of the possible 256 possible starting bytes. This is an excellent front end filter.

Unfortunately, GO-32, with the call sign of "4XTECH", then ignores all packets that do not have a destination address starting with "4". Problem is, all APRS packets, in general, begin with the letter "A". This is the reason that APRS has not been workable on so many 9600 baud PACSATs. Fortunately, the TECHSAT-1B team modified the software so that on one uplink channel, 145.85 MHz, packets beginning with "A" will be decoded. This permits all conventional APRS packets to work normally just like they do on the ground through any digipeater…. Except for the D7 and D700 radios! (See below!)

The APRS Mic-E Format: Normally an APRS packet contains human readable position data in a verbose LAT/LONG format. This makes the packets as long as 80 bytes plus the 21 byte header overhead for a packet length of about 100 bytes. To allow for shorter packets for special high density applications, APRS also developed the Mic-E protocol (Mic Encoder) which shortens the packet to as small as only 9 data bytes. It does this by putting all the Latitude information in the AX.25 Destination address which is otherwise not needed (because an APRS packet is assumed to be addressed to everyone). The remaining information, Longitude, Course, Speed and Symbol type are compressed into the 9 byte data field.

The Kenwood D7 and D700 and many other efficient devices use this Mic-E protocol, and so the AX.25 Destination address does not begin with "A". In fact, it begins with the first digit of Latitude! Fortunately, anyone living between 40 and 49 degrees north or south latitude could use GO-32 as is, since their packets would begin with the digit "4". After initial successful testing, the GO-32 team modified the flight software so that another uplink would not just be limited to the original "4" but would actually accept packets that were in the range of "0,1,2,3…7". The reason it does not go to 8 and 9, is because APRS users above 79 degrees latitude are too cold to operate APRS anyway. Only two people can be at 90 degrees (at the North and South Pole. Notice that this uplink channel does also accept the original "4" so that is why this channel can be shared between PACSAT users and APRS D7 and D700 users.

More Wrinkles: Another small wrinkle, is that the Mic-E protocol does stuff three more bits of information into the AX.25 header. These three bits allow the very short Mic-E packet to contain one of seven possible pre-defined "comments". Off-duty, Enroute, Committed, Returning, Special, Priority and EMERGENCY. These bits are encoded in an ASCII shift in the first three bytes of this AX.25 destination address. So only if the first bit of these comment bits is a "0" will the first byte of the Latitude digit show as a real "digit", otherwise it will show as a letter. This letter packet will not get through GO-32 because of the first byte filter discussed above.

For this reason, the "position Comment" in the D7 or D700 must be set to one of the three comments: Special, Priority, or EMERGENCY in order to be heard by GO-32. Obviously, never send an EMERGENCY packet unless you have a real emergency and also include TEXT in the packet to give the worldwide amateur radio community a clue as to what kind of emergency response is required.

APRS Messaging: One last "gottcha". The APRS message format is a traditional APRS packet that begins with letter "A" like all other conventional APRS packets. So when the D7 or D700 is used to send APRS messages or Email, then the packet will begin with "A". If the D7 or D700 is on the 145.93 Mic-E-ONLY uplink channel (the only place where it can be heard), then the Message will not be heard. So all D7 and D700 mobile and HT users must remember to QSY between the two uplink channels depending on whether they are sending Position/Status reports (on 145.93 MHz) or Messages (on 145.85 MHz).

Permanent Satgates: Although normally a full tracking Oscar array and Doppler tuning system is required for good reliability on the GO-32 downlink, this overlooks one important aspect of the global APRS internet linked system. That is, spatial diversity. We have APRS ground stations all over the world, and with enough of them, even though each individual station will have very limited range due to range and Doppler, all it takes is one station somewhere to hear each packet and inject it into the APRS Internet system for all to see.

A 19.5 inch, one-quarter wave two meter whip antenna over a ground plane, can also act as a ¾ wave antenna on the 435 MHz downlink. This antenna has almost 7 dBi of gain above 30 degrees on UHF as shown in green in figure 6 to the right. For comparison, the plot of a ¼ wave UHF ship is also shown. Notice that the ¼ wave whip does have better gain below 30 degrees, but the ¾ wave antenna has better gain above 30 degrees.

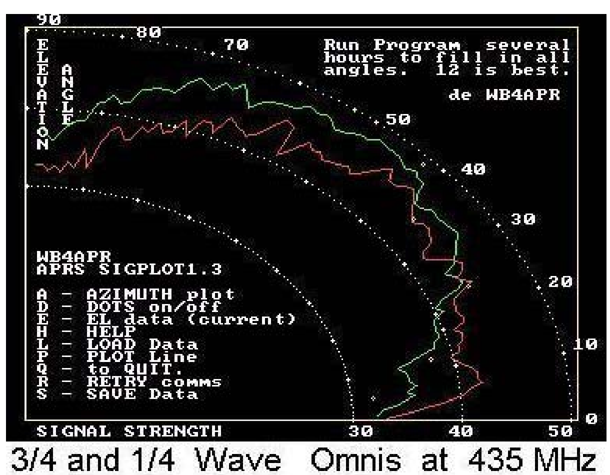


Figure 6. A 19.5 inch whip can act as an excellent UHF ¾ wave gain antenna.

This is ideal for when the satellite is at high elevations and 6 to 10 dB closer. Using this kind of Omni antenna, a very simple ground station SATgate can be assembled with no tracking and no moving parts. It can even operate without any Doppler tuning, since it will only hear the center of the pass anyway.

Here is a great place to use your D7 HT when you are not using it otherwise. Simply connect it to a 19.5" whip over a ground plane with a *short coax* and to your APRS IGate system. The antenna does not even need to be high, since it cannot hear, nor will it be on frequency for low packets near the horizon 3000 km away. Keep the cable real short to minimize loss. Set the D7 to 9600 baud RX and tune to 435.225. This Doppler setting will match the stronger signals at the center of the pass.

This 19.5" whip (3/4 wave on 435) does not need to see below 25 degrees, since its max gain (almost 7 dB) is between 30 to 70 degrees anyway. This also protects your HT from lightning, since it can be low, below all of your other antennas. Yes, your station will only see about 30% of all possible packets and only on the best two passes per day, but combined with dozens of other such unattended SATgates, all packets should be heard somewhere by someone and injected into the APRS Internet system.

If you do want to play with a beam, please keep it simple. LEO satellites do not need elevation rotators. When you look at the horizon profile of a typical Leo pass shown in figure 3 it is easy to see that gain is only needed near the horizon. It is not needed at higher elevations where the satellite is closer! Save money and hassle. Use a $75 TV azimuth rotator and set the fixed 15 degree elevation and you will have a perfect ground station for all LEO spacecraft.

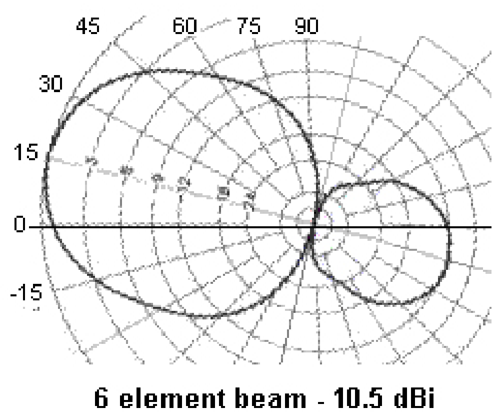


Figure 7. If a beam is used for LEO satellites it does not need elevation tracking! It only needs to be FIXED in elevation up at no more than about 15 degrees. This places all the gain on the distant horizon where it is needed most, while still providing sufficient gain above 75 degrees where the satellite is 10 dB closer anyway. The satellite is above 75 degrees for less than 2% of the overall access time.

See you on GO-32!

Bob Bruninga, WB4APR

Launching Dreams: The Long-term Impact of SAREX and ARISS on Student Achievement

Presented by

Patricia Palazzolo, KB3NMS

Abstract

At the beginning of the 21st century, NASA described its educational mission objective in terms of "inspiring the next generation of explorers . . . as only NASA can." Thanks to the dedication of the amateur radio community, over 300 successful school contacts have taken place through Amateur Radio on the International Space Station (ARISS), with a future schedule set to average one contact per week. Prior to ARISS, well over 200 school-to-shuttle contacts were accomplished via Shuttle Amateur Radio EXperiment (SAREX). Each event was filled with eager students, proud parents and teachers, and excited members of the media who could not help but be caught up in the thrill of it all! But, what happened *after* the last student squeezed in a question before the orbiter or ISS moved out of the "footprint". . . *after* the glow of that "fifteen minutes of fame" had dimmed. . .*after* the return to homework, tests, football practice, and music lessons? The question remains: Has indeed this "next generation of explorers" been inspired? Has the SAREX/ARISS experience actually made a positive difference in students' lives?

NASA's new approach to education acknowledges that inspiration provides the base, but it must lead to engagement, followed by education, and finally employment. In this "case study" paper, a veteran teacher will trace the nearly two-decade history of her students' involvement with SAREX/ARISS from their middle school days to their current careers. She will follow their paths to illustrate how their involvement in these programs at a young age contributed to the inspiration that – as NASA's current approach to education emphasizes – has continued to engage them in science and technology throughout their lives.

About the Author

Patricia Palazzolo is a grade 7 – 12 Gifted Coordinator in the Upper St. Clair (PA) School District, but is probably best known as "Pennsylvania Teacher-in-Space." In 1985, she was named Pennsylvania finalist for what was to become the ill-fated Challenger mission. In that role, she has addressed over 50,000 Americans and conducted teacher workshops from Colorado to New Brunswick. Her students have sent sea-monkey eggs and Chia Pet seeds into orbit with John Glenn, spoken with cosmonaut Sergei Krikalev while he circled the Earth as the first Russian on the American space shuttle, and contacted astronaut Mike Fincke on the International Space Station via amateur radio. Pat was the 2002 recipient of the Anne Morrow Lindbergh K-12 Aerospace Educator Award.

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1 Introduction

NA1SS, this is WB4GCS on Primary. . .

NA1SS, this WB4GCS on Primary. . .

Nothing but static.

NA1SS, this is WB4GCS on Secondary. . .

Uh oh! At that, my heart nearly stopped! Secondary. . . and still no response? What was wrong? The huge room was filled with students, family members, teachers, and members of the media . . . and all eyes were glued to the wall-sized tracking screen. We could see that the International Space Station was in the "footprint" over Pittsburgh, yet we heard nothing. Would the months of preparation leading up to this moment end in disappointment?

Once again, the calm voice of our amateur radio "wizard," Jim Sanford:

NA1SS, this is WB4GCS on Primary. . .weak but readable. . .

And then we **all** heard it!

WB4GCS, this is the International Space Station, NA1SS. Your signal is getting stronger.

The collective breath released by all, and the brightness of the grins on every face, seemed powerful enough to blast us all into orbit without a shuttle! The excited students began their Q & A with Expedition 9 astronaut Mike Fincke. . . but, in fact, the opportunity for this exchange had its beginnings fifteen years earlier with an entirely different group of eager middleschoolers.

2 Orbiting the Turnpike

Back in 1985, over 11,000 teachers completed lengthy applications in hopes of becoming NASA's first "Teacher-in-Space." After a long and grueling selection process, two teachers were chosen to represent each state and US territory. I was thrilled to be selected as one of the two Pennsylvania representatives. I was assigned to the same training group as New Hampshire teacher Christa McAuliffe; after Christa's eventual selection as America's Teacher-in-Space, I was both pleased and honored that NASA appointed the remaining state finalists "Space Ambassadors" and assigned us the task of promoting aerospace education in our home states. In the months leading up to the Challenger launch I, like the rest of the Teacher-in-Space finalists, received requests to drive ever farther across the state to conduct school assemblies, run teacher workshops, and give speeches. The public was definitely caught up in the dream.

The nightmare came that January.

3—2—1—Liftoff! I watched Challenger rise, brighter than the sun, into that clear blue sky and heard the voice of the Public Affairs Officer come over the loudspeakers at the viewing site: *Obviously a major malfunction. . .the vehicle has exploded.*

I returned to Pennsylvania to find a blur of phone calls, cameras in my face and questions -- questions as to possible damage to children's psyches, questions as to whether the Teacher-in-Space Project had been nothing more than a public relations stunt, and questions as to whether we should be spending any money at all on the space program. What I did *not* return to find was any lack of the ability of space exploration to continue to inspire students and teachers.

And so it was on a warm spring day in 1989 that I received a phone call out of the blue from Mary Ellen Chuss-Mirro, a dynamic teacher in the small Sacred Heart School in the small town of Bath on the opposite side of Pennsylvania. She had read that I was "NASA Space Ambassador" to the state and wondered if I had any ideas for "experiments" her middle school students could conduct to keep them busy so they would not "drive her husband crazy" while he drove them around the Bethlehem Raceway on a two-hour "mission" in the van that they had converted into a "space shuttle." I came up with several suggestions and, intrigued, called her back several weeks later to find out if the mission had been a success. Delighted with the outcome and bubbling with enthusiasm, she said her only concern was that she did not know how she would "top it" the following year.

"I do," I said, "Come on a mission across the entire state! My students will serve as Mission Control for your orbiter!"

The detailed planning would have made NASA proud. . . police escorts set up along the way, stops arranged at various venues on the route (including a special welcome by the Governor in Harrisburg), experiments designed, a special "rover" built to be used to explore "Planet Pittsburgh" upon the crew's arrival, and computer tracking programs written by my students so they would be able to provide hourly reports to our entire student body about the location, speed, fuel consumption rate, and likely "landing" time of the "orbiter," known as *Missioner II.*

A real coup on our part, or so we thought, was having secured the use of a cell phones for the duration of the mission across the Commonwealth. At that time, very few "average people" had ever used, let alone owned, a cell phone. We were grateful to the company that donated the equipment and usage time of this "new-fangled" high-tech device that would help our Mission Control stay in touch with the van-turned-shuttle.

After a year of preparation, *Missioner II* blasted off on April 30, 1990 and began its five-day journey across Pennsylvania . . .and for much of the mission, the "new-fangled" high tech device known as a cell phone was useless. Fortunately, a couple of local hams, Seth Ward KC3YE (SK) and his son Glenn N3EKW, graciously volunteered to serve as our "back-up" communications system.

Not only was their ability to communicate with the van-turned-shuttle instrumental to the mission's success, it provided excitement and a genuine "Mission Control" feel to our site. The students loved seeing the radio equipment and hearing the details of the orbiter's progress across the state over the speakers. As the "shuttle" drew closer and closer to Pittsburgh, we began to hear other hams talking about it over the radio.

Did you just see that? Is that a space shuttle on the Turnpike?

On "final approach," I was a bit concerned about *Missioner II*'s clearance coming through one of Pittsburgh's famous tunnels. After hearing our ham radio volunteers discussing our tunnel situation, a ham listening in from a station in a rival school district could not contain his curiosity. He called to ask us just *what* we were trying to bring in through the tunnel. He had assumed it was some kind of big truck. . . until he heard the words “wingspan” and “tail height.” Our students got a good laugh when they heard him joke, “That’s Upper St. Clair for you . . . always having to show off!”

The excellent work of our amateur radio volunteers saved the day. Our eighth grade Mission Control team was able to track the shuttle to a perfect landing at our front entrance. The entire school stood outside to cheer her arrival. She was indeed an amazing sight moving down the street with a motorcycle police escort, firing 40,000 cubic feet of non-toxic smoke out of the main engines! (Yes, the firing of the main engines should not happen during a landing, but middleschoolers who have been meticulously tracking an unseen object for almost a week want to see smoke and hear noise at the end.) *Missioner II* impressed even former astronaut Joe Allen, who was kind enough to join us for the event. (My “Mission Control” students had met him when they won a trip to the Hubble launch for their design of a shuttle experiment about soap bubble kinetics in microgravity.) He grinned, patted her wing, and called her a “really slick vehicle.”

The help we received from ham radio volunteers in tracking the van-turned-shuttle led to my “next generation” of students tracking the **real** thing just four years later.

3 From Mars to the Stars

During the same period I was working with the teacher in Bath on plans for *Missioner II*’s journey across the Commonwealth, I was contacted by visionary community members from a town much closer to Pittsburgh – Mars (yes, Mars!) Mars is about a 45-minute drive north of Pittsburgh, but at that time, was rather rural in nature. The members of the Mars Area Foundation for Education Enrichment (MAFEE) contributed funds to provide special educational and cultural experiences to help their students realize that they were part of the world.

So, what special experience did the students seek? They wrote to then-Soviet leader Mikhail Gorbachev to inquire, “Wouldn’t you like the Russians to be the first to visit Mars – Pennsylvania, that is!” Never believing that they would actually receive a response, they were stunned by the arrival of a brief telex stating only that “Cosmonaut Hero Sergei Krikalev will visit the children of Mars in three weeks.”

The students then wrote to NASA and said, “You’re not going to let the Russians beat us to Mars, are you?” And so it was that Astronaut Mario Runco, Jr. joined Cosmonaut Sergei Krikalev for the first US-Soviet mission to Mars (Pennsylvania!)

And so it was, too, that I was called upon to serve as a true ”Space Ambassador” . . . especially when Sergei arrived alone, had no return ticket on Aeroflot, we had no translator available, and the nation he came from was still known as the USSR. Everyone was so grateful to have him as a guest for an entire week, but so nervous about making mistakes. We need not have been concerned. From making school visits to attending Pittsburgh Pirate games to serving as the grand marshal of a community parade, Sergei charmed us all.

Therefore, everyone took interest in his next mission to Mir. He was, after all, “our” cosmonaut. It was May of 1991 -- one year after our special shuttle-van-across-Pennsylvania event. My students who had, as eighth graders, served as Mission Control were now nearing the end of their first year of high school. They had all maintained their interest in science and technology, taking high-level courses and volunteering at the science center. By this time, encouraged by our amateur radio volunteers, I had earned my own ham license.

Yes, in May of 1991, the students were excited to know someone on Mir, but that excitement turned to worry when the Soviet Union disintegrated and stories of Sergei Krikalev being "stranded" in space made headlines. I was able to see him at the Association of Space Explorers Conference in Washington DC in the summer of 1992, not long after he had finally returned to Earth as "the last Soviet citizen" . . . and the first thing he said to me was "Mars. . .the children?" He had realized that the students he had met during his visit might indeed have been concerned about his welfare. He smiled when I gave him a chocolate space shuttle made by a Pittsburgh-area candy company to take back to his little girl. I assumed that our paths would never cross again.

It was the following summer that an amazing set of circumstances came together: I learned about the opportunity for students to speak with astronauts aboard the space shuttle through a program called SAREX, I now knew some wonderful people in the amateur radio community who might be willing to help, and I found out that the first Russian ever to fly on the American space shuttle was to be, of all people, Sergei Krikalev. Best of all, despite an incredibly tight schedule, Sergei's mission, STS-60, was to be a SAREX mission. There was just enough time to get an application in! There would be no guarantee that my proposal would be accepted, let alone assigned STS-60, but it was worth a try. For equipment and technical support, I turned to the North Hills and Butler Area Radio Clubs. I then approached the Mars Area School District with an offer I hoped they could not refuse: I would do all the work in writing the proposal, finding the volunteers, and planning the event -- if they would allow me to propose a joint effort between my school district and theirs. . . with half the question askers coming from my district . . .yet set everything up in Mars. (My own district never did quite understand why I based the event in Mars, rather than my own school. I explained to them that part of the SAREX application required explaining how one would attract the media. How could anyone resist headlines proclaiming that the shuttle had contacted "life on Mars," not to mention the fact that the first Russian to fly on the shuttle had already visited that town?)

The students who had tracked the shuttle-van as eighth graders were now high school seniors. I turned to them to design a method of engaging the "new generation" of middleschoolers in SAREX. How could they develop a fair method of selecting the few students who would actually have an opportunity to ask a question? Letters would be sent home to every middle school child in the district. On the *outside* of an envelope, interested students would write the question they would most like to ask an astronaut on orbit. All identifying information, as well as a signed permission slip, would be sealed *inside* the envelope. My team of former students would go through all the questions and pick the best ones. Only then would the envelopes be opened and the identities of the question writers revealed.

I submitted our SAREX proposal . . . and waited.

When our proposal was accepted as one only five sites in the world to be scheduled for a SAREX contact with STS-60, there was joy in both school districts. With the help of some local hams, I began a series of assemblies to excite and inform all the students in both areas about amateur radio and space exploration. In the meantime, my team of twelfth graders took their assignment of question selection very seriously. They wanted to be sure to come up with the most important, most interesting, most diverse combination of questions possible. It was their way of passing their torch to this next generation of students.

When the envelopes were opened, we were pleased to find that the “official question askers” included an equal mix of boys and girls. All were excited about the upcoming opportunity. Fourteen students – half from Upper St. Clair and half from Mars, all from grade levels 5 through 8 – began to prepare for the big day that would come in February, 1994.

The morning of the contact day was electric. It seemed as if every newspaper and television reporter in Western Pennsylvania had descended on Mars Middle School. The “SAREX kids,” sporting sweatshirts with a huge STS-60 logo on the front, proudly posed before a large banner that said “From Mars to the Stars.” In between interviews, they practiced reading their questions so as to be prepared when it was their turn to hold the mike. The school’s main office had been set up like Mission Control and overflow crowds were able to watch the event from the cafeteria and gym on closed circuit television. Back in Upper St. Clair, the school was open for the public to come in to watch the event unfold on a viewing screen set up in the auditorium. As the time for contact approached, a call from NASA informed us to which crew member the students would be speaking. “Looks like it’s going to be Sergei,” said the voice. He could hear the cheer that erupted from the crowd. “I guess they’re happy,” he laughed.

We all watched the tracking program and saw the shuttle come into the footprint. Nothing. No response to our control operator’s call. Tense silence as the shuttle moved away from the footprint. Finally, the voice from NASA told us that “something had come up” with the deployment of the Wake Shield Facility and that, essentially, Sergei “didn’t have his ears on.” I was proud of the students’ response. They smiled bravely and told the media it was still exciting just to hear the radio attempts. I knew they were disappointed, but part of their preparation had been to learn that SAREX was considered **secondary** to other shuttle experiments and operations, and that a school would only have one opportunity for contact no matter what interfered. . . including other things that might “come up” on the shuttle. However, as we stood there, we heard the voice from NASA say, “Sergei would like to try again on the next pass, if you don’t mind missing 90 more minutes of school.” This time the cheer was even louder. The contact with Mars was being made via telebridge, so we were actually receiving the signal by bridge to a ham operator based in Australia and could thus wait for the shuttle’s next pass.

The hour-and-a-half zipped by. Soon we heard our control operator calling the shuttle once again. . .and once again, there was no response. Wait. . . was that something? Perhaps. . .lots of static. . .no. . . the shuttle was out of range. The disappointment was palpable this time. (We later learned that the experts had a theory that the problem had something to do with a huge aurora.) Still, the students exhibited great dignity and maturity as they spoke of how it had been a “great learning experience.”

At eleven o’clock that night, my phone rang. It was my SAREX mentor wanting to know if we would like to give it an unprecedented third try in about fifteen hours!

I began frantically calling fourteen families at midnight, trying to make arrangements for everyone to return to Mars in the morning. I made calls to the media, the volunteers, and to our dear control operator who lived almost two hours away. Everyone was willing to return.

In the morning, we woke up to an ice storm! The Mars District was closed, and my own had a two-hour delay. I kept in mind the poster I had hanging in my classroom: "You never fail unless you stop trying." There was no huge audience this time, but the amazing principal in Mars was able to get the Mars SAREX students in via police escort, our amazing control operator took a day off from work and braved the two-hour icy drive to set up the radio, and even a limited number of media returned. Unfortunately, there was no way to get my own SAREX students safely to Mars. The roads were just too bad. Then, I had an idea. I called the Johnson Space Center and asked if my kids could be patched in via speaker phone. At first, they did not like the plan, believing it would be too difficult to have first a student from Mars ask a question, followed by one from Upper St. Clair. The delay would be too great and it would be too confusing. I asked them to just please let us try. After testing the acoustics from various points in the classroom, Houston said the sound was the best when the speaker phone was placed on a chair near my desk.

As the shuttle approached the footprint (which we could not see because the equipment was in Mars), my students – on their knees – gathered around the chair, waiting for their turn to scream their questions into the speakerphone. Their parents formed a ring around the them. There was no media. We waited tensely.

Then we heard the response for which we had been hoping:

This is U5MIR.

It was Sergei! This was followed by the first question, posed by one of the "Martians." My student shouted her question into the phone as soon as Sergei had completed his answer. The back-and-forth system was working well . . . until my school began dismissing buses early due to the increasingly bad weather. *Bus 43. . .Bus 71*. . . came over the PA system. The people in Houston informed us that they were hearing our bus announcements and threatened to cut us off. At that, some parents grabbed mousepads to tape over the speakers in the room while others raced to the main office to ask the principal to cut the announcements. The student questions continued successfully. At one point, a woman took Sergei's place in answering. It was difficult for him to make out children's voices, in English, over a less-than-ideal sound system. However, having the opportunity to speak with both Cosmonaut Sergei Krikalev and Astronaut Jan Davis on the first Russian-American shuttle flight was indeed very memorable! It was also a very special example of adults modeling persistence and teamwork for students. From the ham volunteers to the school administrators to the astronauts themselves, it was obvious that the willingness to be flexible and work hard could make important dreams come true.

4 The Next Generation: John Glenn, Sea-Monkeys, and Ch-ch-chia!

My special group of seniors felt good about having played a role in exposing my new generation of students to the wonders of science and technology. They headed off to college. . .Francesca to Georgetown with hopes of medical school. . . Noah to Notre Dame with plans for medical research. . . Kevin to USC for computer engineering. . . Amy to Cornell to study planetary science and earth systems. . .Joe off to Villanova for chemistry. . .Mike on to Michigan as a physics major. . . and others off to similar pursuits. As they departed, they kidded me: They had tracked a shuttle mock-up on the Turnpike. My next group of students had communicated with the genuine orbiter. What was to follow? Would my next students get to go into orbit themselves?

Not exactly. . . but thanks to the continued efforts of this "first generation" of students, my new group did get to send a "little piece of Upper St. Clair" into orbit. Over my many years of teaching, I have witnessed the imagination, learning, and accomplishments of my former students ripple out to touch others in wider and wider circles, like the rings of water from the proverbial pebble tossed in a pond. Amy continued following her passion for space science through college. At one point, while attending one of the very selective summer NASA Academies, she became friends with a grad student who had designed a ratchetless ratchet wrench that was going to be flown as a shuttle experiment. He had just a tiny bit of space remaining in his container and was musing about "some teacher" perhaps being able to have kids think of what to do with that space. Amy immediately responded, "I know just the teacher! I know just the kids!"

I received a phone call from her the very last week of school and was told that we had one week to try to design an experiment for that small bit of "leftover space". . . and that experiment had to meet all NASA's requirements or we would lose the opportunity. In short, my students had to operate as real scientists. My middle school students at first had difficulty understanding that the experiment would be loaded into the shuttle during the summer and sit there for at least two months. . . so, no, they could not send up anything that was alive. . .and our allotted space was just a few test tubes. They finally hit upon the idea of sending Sea-Monkey (brine shrimp) eggs, since they would be able to "bring them to life" after their time in space. But they also wanted to send some flora along with their fauna. Suddenly, one of the students started singing the "Chia Pet" jingle: *Ch-ch-chia. . .Ch-ch-chia!* Why not? One never seems to see them for sale except at holiday time, so they must store well. The experiment design began in earnest, with the students working through much of the summer to meet NASA's standards. Most memorable was the day they were actually able to load their experiment into the special container NASA had sent us, and to place the mission patch they had designed themselves on that container. The patch depicted both a Sea-Monkey logo and Chia-pet sheep, as well as the students' own motto: *Let Our DREAMS Take Flight.* . with "DREAMS" standing for "**D**oing **R**eal **E**xperiments **A**dds **M**eaning to **S**cience."

This mission patch flew on STS-95 with the students' experiment.

Throughout the design process, the students had known only that their experiment would fly on “a” mission. It turned out to be “:**the”** mission of 1998 – STS-95 -- 77-year-old John Glenn’s return to space. That being the case, my little team received far more than their “fifteen minutes” of media attention. Nevertheless, the stars in their eyes were not so bright as to dim their excitement at viewing the launch and feeling humbled to realize that something they had put together was indeed being carried into orbit. And for Amy, now starting her Masters in Science, Technology, and Public Policy at George Washington University, it was another ripple in the pond. The students involved in this project began high school on fire and took advantage of every science and engineering opportunity throughout the next four years. When they were high school seniors, they finally had the opportunity to meet John Glenn and his wife Annie in person during the couples’ visit to Pittsburgh. The Glenns generously spent half an hour with us privately. As I watched these students speaking to Colonel Glenn, I realized that their resumes now included Governor’s School for the Sciences, several national awards for science and engineering projects, important summer internships, Eagle Scouts, and even the collection and refurbishment of thirty discarded wheelchairs that were then sent to poor hospitals in Vietnam. They had all been awarded scholarships to top universities – with one even having been already accepted for a full ride to medical school – and they had not yet officially graduated from high school!

5 The Adventure Continues: From SAREX to ARISS

Early in 2004, yet another opportunity presented itself.

I had a voicemail message at school asking me to call NASA . . . something about being a “crew pick” for an ARISS contact. What did that mean?

As it turned out, Pittsburgh astronaut Mike Fincke was going to be the Science Officer for Expedition 9 on the International Space Station. . . and he had selected my school with which to do an ARISS contact! I was thrilled, yet confused. I had never met Mike Fincke and he had never attended Upper St. Clair Schools. How did I get to be his “crew pick?” Why wasn’t he going to do an ARISS with his own school? Was this a prank?

I soon learned that it was a genuine opportunity! Col. Fincke had promised an Upper St. Clair grad working in life sciences/countermeasures at the Johnson Space Center that, if he ever had the chance to go into space, he would do a school contact with the school of her choice. When his flight assignment came, he remained true to his promise and she, of course, selected her alma mater for contact. Although this particular young woman, Lesley Lee, had graduated before I began teaching in the district, she was aware of the kinds of special projects my students and the supportive community had been able to “pull off” over the years. This project would definitely require skill to be successful because, unlike the SAREX which had been difficult enough to accomplish in Mars, this would **not** be a telebridge. This was to be a “direct.” Add to that the Upper St. Clair landscape, where every building was built into a hillside, and my concerns over finding a way to set up an antenna to clear both buildings and trees grew serious. For that matter, where could I even find someone with the right antenna? Where could I find someone who could set up the correct equipment?

I turned to my local amateur radio club -- WASH, the Wireless Association of South Hills who, in turn, engaged the cooperation of WACOM, Washington Area Communications. Their energy, passion, commitment, and expertise were boundless. . . even as the contact date kept slipping and everyone had to keep changing their vacation dates. They took over everything having to do with the set-up, from stringing wire through the school roof to splashy camera and sound set-ups to T-shirts. All I had to do was deal with the students.

This time, instead of middle school, I wanted to involve a range of ages. The students selected to ask questions represented each grade level from fourth through twelfth. I named them the "ARISS Ambassadors," and informed them that part of their job would be to act as my liaisons to each of their respective classes. I would call upon them to keep their classmates updated on information related to space, science, and technology throughout their years in the Upper St. Clair School system. It would also be my hope that, as they graduated and moved on to college and careers, they would continue the ripple-in-the-pond effect of contributing to others. . .including offering any learning opportunities possible to the "next generation" of students who would follow them.

. . . *This is the International Space Station, NA1SS. Your signal is getting stronger. . .*

Jim Sanford, WB4GCS, turns the microphone over to ninth-grader J.T. Gralka, who asks the first question, while Kevin Smith, N3HKQ, prepares the next student to quickly take his turn. I stand off-stage to guide each student who has asked a question safely clear of the next child leaving the platform. They are starry-eyed from the experience and I know that their minds are no longer connected to their body movements. I do not want to see a domino-style pileup of my ARISS Ambassadors! I, too, am dizzy with excitement and grateful that someone is recording Mike Fincke's answers. I vaguely realize that he is responding in ways that range from humorous to poetic, but I cannot get my mind to register anything beyond, "The kids are talking to an astronaut on the ISS! It's really happening!" I become aware that the students have had the same experience when reporters begin to ask them what they think of the answers to their questions. I almost laugh when I see the puzzled look in their eyes as they suddenly realize that they can't remember what Mike just told them. It is fine. The details will return to our brains later. For now, it is enough just to bask in the glow of a successful ARISS and thank all those who have made it possible, just as we did over a decade ago after our SAREX with STS-60. A random thought passes through my mind. . . After beginning with a contact date of "anywhere between May and September," and through numerous "slips" of the "official date" once we had been given one, we have finally made successful contact on this date. . . August 27. . . today is Sergei Krikalev's,U5MIR's, birthday.

6 The "Next Generation of Explorers": NASA's Goal of Engagement, Education, and Employment

NASA's new educational mission has set goals that move beyond simply "inspiring" children to consider careers in science and technology. It is important for students to seek strong educational foundations in these fields as a means of retaining an interested, well-trained work force, as well as to engage the public in a "vision" that supports science, technology, and space exploration. Various reports of the monumental numbers of students, teachers, and the general public who have witnessed, heard, or read about SAREX and ARISS contacts have been issued over the years. I know that after a SAREX or ARISS contact, I have had to send the ARRL reports of "my numbers" in terms of live audience, those watching from satellite locations, teachers who may have been in-serviced, newspaper article readership, and even numbers who may have viewed a news story about it on television. Those statistics reveal the tremendous outreach of SAREX/ARISS. . . and no one can watch the faces of those viewing students talking via amateur radio to an astronaut and doubt the "inspiration factor," even for those who are simply "audience members."

However, it is vital that we consider the long-term **impact** of that inspiration. The students who were actually selected to ask a question, or in some cases, to help set up the equipment, are significantly smaller in number than those reported as "audience members." Yet, if the inspiration of that hands-on experience at a crucial age can inspire these children to pursue educations and enter careers at the passionate and "high quality" level which I have witnessed among my own former students, then the positive impact of SAREX and ARISS goes far beyond any numbers found in reports. All of my students who have participated in SAREX/ARISS -- or as the original "Mission Control" team tracking *Missioner II* across Pennsylvania – have gone on to phenomenal accomplishments and careers that contribute much to society. Almost all have opted for careers in science, technology, or science-related fields (such as MBAs working for technology firms or patent lawyers). There are many medical doctors and information technology specialists. One is now an amazing calculus teacher whose classroom is next door to mine! Therefore, I will highlight just a few examples from each of my "generations of explorers." They now range in age from twelve-year-olds to professionals in their early thirties.

7 The "First Generation": *Missioner II* Mission Control Team

- **Noah Gray** – went on to Notre Dame and then finished a PhD in neuroscience at the Mayo Clinic, where he investigated vesicle trafficking and endocytosis before joining the Cold Spring Harbor Laboratory; he later conducted research at the Janelia Farm Research Campus (Howard Hughes Medical Institute) which is the world-class center known for bringing together the best scientists from many disciplines to collaborate on small teams to try to solve some of the world's most challenging problems; currently assistant editor of *Nature Neuroscience*, the top journal in its field

- **Joseph Pickel** –completed a BS in chemistry at Villanova, followed by a PhD in polymer chemistry at University of Akron; currently a polymer chemist at the Center for Nanophase Materials Sciences at Oak Ridge National Laboratory in Tennessee; the center is the first of five nanoscience research centers funded by the US Department of Energy; Joe's research group is dedicated to "making polymers behave the way we want them to" so that they can be useful in fuel cells, making lighter and stronger cars, biomaterials, and more. . .and, in Joe's words, "I'm loving it!"; has also had to become an expert glassblower, since polymer chemists often have to make the supplies they need for their experiments
- **Michael Weinberger** – finished his BS in physics at Michigan and a PhD in experimental particle physics at Cornell; currently working for Texas A&M University on the CDF experiment at Fermilab in Chicago, and the CMS experiment located outside Geneva, Switzerland; in his most recent note to me, Mike said,"I am in the middle of working right now and am actually underground in France working on electronics for the CMS particle detector as I type this."
- **Amy (Snyder) Kaminski** – studied planetary science and Earth systems at Cornell, where she also added a minor in science journalism after having attended a shuttle launch with me with a press pass; became editor of Cornell's "Science and Technology Journal"; received a Masters in Science, Technology, and Public Policy at George Washington University, specializing in Space Policy, while also authoring a book with "space law expert," John Logsdon; has published many articles on astronomy, as well as articles on space tourism; is often a featured presenter at the very NASA Academies she attended as an undergraduate; did an internship with the Rand Corporation, then worked with the FAA Commercial Space Division as the "Office Lead" on both Space Tourism and Space Debris; on the Board of Women in Aerospace and is featured in a book about 100 powerful woman in the space industry, aimed at middle school girls; currently Space Programs Examiner for the Office of Management and Budget

Amy (Snyder) Kaminski participating in a NASA Academy as a college student . Today Amy is Space Programs Examiner for the White House

8 The "Second Generation": SAREX and Sea-Monkeys

Students eager to see their experiment launch with John Glenn in 1998. Megen Vo is standing on the left, teacher Pat Palazzolo on the right. Sitting left to right are students Matt Muffly, Karl Zelik, Dan Zelik, and Dan Doan.

- **Megen Vo** – was featured in the Nickelodeon program *Figure It Out!* Panel had to try to figure out what was so special about the "pets" Megen had brought to the studio in Orlando (flying them in all the way from Pittsburgh) – of course, they were our actual sea-monkeys that had been to space with John Glenn back when they were just eggs; Megen is currently in medical school at Case-Western University
- **Matthew Muffly** – accepted into the Pennsylvania Governor's School for Health Care during high school (a highly selective summer program); has been a research assistant for a hand surgeon throughout college and has had a couple of articles published in important research journals of osteopathy; is about to start medical school
- **Daniel Doan** – became concerned about problems faced by hospitals in Vietnam which do not have enough wheelchairs for their patients; for his Eagle Scout project, he rounded up broken and discarded wheelchairs from area hospitals, took classes in how to repair them, and single-handedly refurbished thirty wheelchairs in his family's garage; faced with the problem of delivering them to Vietnamese hospitals, he was able to get the World Vision organization to send them; was granted a full scholarship to undergraduate studies *and*

medical school by the University of Pittsburgh while still a high school senior; currently in medical school

- **Karl Zelik** –completed a BS in biomedical engineering at Washington University in St. Louis; spent undergrad summers working mechanical hearts in Pittsburgh; this past year he worked developing bionic prosthetics at St. Judes Hospital ; currently working on his Masters in mechanical engineering at Michigan
- **Daniel Zelik** – received a full scholarship from Iowa to work on his Bachelors in industrial engineering, with a minor in psychology; as his co-op program, he spent months at a time working with NASA at the Johnson Space Center; currently working on his PhD in human factors engineering at Ohio State

9 The "Third Generation": The ARISS Ambassadors

- **Benjamin Burns** – perfect SAT scores, but equally strong in civic responsibility; was on the First Place Design, Engineering, & Fabrication team in high school; nationally ranked as a math student; currently an undergraduate at Harvard studying engineering

- **Matthew Boyas** – on the Future Problem Solving Team that qualified to represent Pennsylvania at the International Future Problem Solving Finals, where the team finished Fourth in the world; three Honorable Mentions from Toshiba for papers submitted for the Exploravision Contest; in January, one of of those papers will be featured in a textbook called *Nanotech 101*; has served well as an ARISS Ambassador, including assisting me in running science events for my middle school students; currently a high school junior

10 Conclusion

After more than two decades and well over 500 successful school contacts, have SAREX and ARISS served to "inspire the next generation of explorers. . .as only NASA can?" Reports that count the numbers of people "exposed" through these events to science and technology – and, more specifically, to both amateur radio and to NASA – reveal sky-high numbers. But in this paper – a longitudinal "case study" of one teacher's lengthy involvement with these activities over the course of her career – I have sought to provide specific follow-ups of the students most deeply involved at the time. SAREX and ARISS inspire engagement, education, and employment through

- providing "hands-on" learning
- making real-world connections among disciplines
- requiring problem-solving while under the pressure of deadlines
- demanding excellent communication skills
- illustrating the importance of technology and the joy that sharing one's skills can give to others
- allowing adults to model the power of passion, partnership, and persistence

My former students continue to work in exciting high-tech fields, and continue their willingness to help my "current generation" of students. Recently, I emailed a number of my old students requesting their help with an educational proposal for a shuttle downlink. The response was immediate and overwhelmingly positive. Mike Weinberger emailed me from underground in France, writing "I hope I am not too late to help with this project. I would love to help out the current students." From Tennessee, Joe Pickel wrote "I would LOVE to take part in this project. . .please tell me what you need and I will help out." Last spring, a team of my high school students made the national finals of an academic competition, for which they traveled to Washington DC. The highlight of the trip was a tour of the White House that Amy Kaminski was able to arrange for them.; more impressive than the tour, in their minds, however, was the fact that it was the "legendary Amy" herself who was accompanying them as they walked through the White House. Amy's willingness to "scramble" on last-minute notice to allow my students to participate in the tour. . . as well as Mike's and Joe's willingness to fit us into their hectic schedule. . .have roots, I am certain, that go back to the amateur radio and other volunteers who gave of their time and expertise when these students were so young.

I am but one teacher who is very proud and humbled by the accomplishments of her SAREX and ARISS students over the years. . . and especially proud of the lives they have touched and their willingness to "give back." Is there a long-term impact of SAREX and ARISS on student achievement? I am but one teacher. . .there were well over 200 SAREX school contacts, and there have already been over 300 ARISS school contacts. . .do the math.

ARISS Contact with The Arnold Palmer Hospital for Children

David Jordan, AA4KN

Introduction

Since the early years of amateur radio's existence, we have seen the experiences that it offers and the applications of our hobby evolve in many ways. Many of us have had the pleasure of providing phone patches between international parties, some enjoy the excitement of providing emergency communications in times of need. Others involve themselves in introducing ham radio to the public through Boy Scout Jamborees, special event stations, and the like, but many of us have had the unique experience of bringing amateur radio into the public eye by either leading or have helped in a SAREX (Shuttle Amateur Radio Experiment) and/or an ARISS (Amateur Radio on the International Space Station) contact.

One ham operator who took a special interest in the ARISS program was AMSAT member John Rothert, KC4IYO. John had been a resident of the Orlando area for many years and had been the lead of several ARISS scheduled contacts in the past. On August 29, 2006, after securing sponsorship from the Lake Monroe Amateur Radio Society (LMARS), John applied for the scheduling of an ARISS contact with a unique institution, a place where this had never been attempted before. A children's hospital. The Arnold Palmer Hospital for Children in Orlando, Florida to be exact. Unfortunately, shortly after application was submitted, John became ill and was not able to continue supporting the effort. Members from the LMARS group stepped up and began working with both ARISS and the Child Life Department of Arnold Palmer to make this event a reality.

Day of the Contact

On the morning of July 17, 2007, members from both LMARS and AMSAT arrived at the hospital and began setting up for the contact. Operators on hand were Mike KF4HFC, Bob KF4IMF, Lou W5DID, and myself AA4KN. Since the pass would occur over the western part of the United States, ground station communication was provided by amateur station, W6SRJ at the Santa Rosa Junior College in Santa Rosa, CA. The station director there is Tim Bosma, W6MU. W6SRJ was linked to the hospital by using a phone patch, usually referred to as a telebridge. At the hospital, a conference phone was set up with microphones hung from the ceiling and an additional hand microphone for more directional use during the actual contact. The audio of the event was carried over the IRLP Discovery Reflector 9010 and the echolink AMSAT node as is usually done for all ARISS contacts. W6SRJ was operated by Bill Hillendahl, KH6GJV and Don Dalby, KE6UAY. Will Marchant, KC6ROL, directed the Child Life staff in both the pre-contact preparation and post-contact wrap-up. Graham Lawton, G7EVY, was in charge of the audio for the IRLP connection. Child Life Specialist, Linda Jones served as the hospital moderator for the event. The contact onboard the ISS was astronaut and flight engineer, Clay Anderson, KD5PLA.

As the contact time drew closer, eleven of the hospital patients were lead into the setup area. Most were confined to wheelchairs and a vast array of health monitoring equipment. All were very eager to get started. In order to help them relax before the contact, one of the Child Life personnel played a space trivia game with them. After a few minutes, Will Marchant began preparing the children and staff by introducing them to Bill and Don in Santa Rosa, explaining the sequence of events that would take place during the contact, and very importantly, allowing a few of the children to practice asking questions of Bill as though the contact were underway. One of the most important aspects of any ARISS event is having the local media present. At the hospital's request, five broadcast news crews from four television and a radio station had responded and were on site.

[Photo by Mike Welch]

The children kept Clay busy with their questions

[Photo by Mike Welch]

A day like no other

As the moment for AOS (acquisition of signal) from the ISS approached, Bill began calling … NA1SS NA1SS this is W6SRJ. After several attempts, a voice emerged from the noise and answered … NA1SS OVER! At Bill's direction, the children, one by one, began asking their prepared questions. This Q & A session with Clay continued very smoothly and at such a pace that soon all the prepared questions had been asked. With several minutes left in the pass, the kids were asked to make up more questions for Clay. Some of these were quite thought provoking as one child asked "What do you do if a solar flare occurs?" Just prior to LOS, a loud "Thank You" was sent up to Clay from the group and the contact was terminated. Now it was the media's turn. They began interviewing the children, asking if they wanted to become astronauts and what it felt like to talk to one, etc. July 17, 2007 is a day that the children and Child Life Staff of Arnold Palmer Hospital will never forget.

[Photo by David Jordan]

Media interview after ISS contact

Final Notes

I've had the privilege of witnessing and helping in both SAREX and ARISS school contacts in the past, but none have been as moving as this event at Arnold Palmer. After witnessing the event, I have requested a meeting with the Child Life department myself at All Children's Hospital in Tampa, Florida to discuss applying for an ARISS contact at their facility. Using, at least a telebridge configuration, any facility should be able to accommodate an ARISS contact. I would like to encourage everyone to make, either as an individual or as a club effort, an appointment with the director of the Child Life or children's activity department at a children's hospital in your own community or in a near-by community. Discuss the ARISS program with them and the impact that having a personal contact with an astronaut can have on their children. Request that they allow you to apply for an ARISS contact at their facility. We have this unique opportunity as ham operators to make a difference in children's lives as was done at Arnold Palmer Hospital in Orlando.

Taking Amateur Radio into the classroom
Easier said than done!

Hans van de Groenendaal ZS6AKV
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INTRODUCTION

Taking Amateur Radio into the classroom is easier said than done. Today's youth are born communicators. As their fingers glide over the computer keyboard or sell phone they are in touch with their peers and indeed their world. Amateur Radio has to come up with new and better ideas than talk for free or talk to the world with Amateur Radio. It may ultimately attract their attention but we first have to tune their antennas to receive the message. And that is were we have to compete with so many other gadgets and activities. In their vocabulary "we must make amateur radio cool."

One area that seems to still attract their attention is space. Mention man in space, man on the moon, and communicating by satellite and you may find that you have touched on a subject that figures in their sphere of interest.

There is of course in some quarters the notion of "so be it". If they are not interested in amateur radio why should I care? Wrong! We need young people to join our aging ranks and take the exciting developments that are still coming from the amateur fraternity to next generations. We are in the unique position to deploy amateur radio to influence career choices and act as catalysts to interest young men and women to become engineers, scientists and astronauts. In the words of the late Bill Orr W6SAI: *"the spirit of adventure lies buried in very man's soul. Strike the spark and ignite the soul and the impossible is accomplished".*

We have to strike the spark!

The world has invested valuable radio spectrum into amateur radio but to sustain this they also like to see some return.

As satellite and space enthusiasts we are in the unique position to attract the attention of the young people. The success of the ARISS programme is a perfect example. We however need more International space station contacts to sustain that interest, more SuitSat's and more amateur satellites that can be deployed to host youth projects.

SUMBANDILASAT – taking young people into space

South Africa's entry into the space age was in 1999 with the launch of SUNSAT 1, a modest satellite built by students and lecturers at the University of Stellenbosch. The satellite carried various experiments and an amateur radio transponder that delighted radio enthusiast world-wide.

Soon South Africa will get another voice in the sky when the second satellite, named Sumbandila is launched in December. The naming of the satellite is an interesting story. A competition was held amongst high school students. Entries in various languages were received but ultimately the Venda language version was chosen "Sumbandila". It means showing or pointing the way. Freely translated into English *"Pathfinder"*

Sumbandila Sat is sponsored by the South African Department of Science and Technology and is being built at SunSpace, a company that flowed out of the SUNSAT satellite project.

Sumbandile Payloads

The main payload is a multi-spectral imager with a 6.5m Ground Sampling Distance (GSD) with 6 spectral bands and will be supported by an on-board storage of 6 Gigabyte, expandable to 24 Gigabyte. In additions there are several experimental payloads.

When SA AMSAT was granted the opportunity to build one of the experimental payloads it was decided to build on the success of SUNSAT which include a FM transponder and a parrot repeater. I often relate the story told by my good friend and one of the most loyal AMSAT supporters Keith Pugh W5IU who takes satellites into schools very serious. Keith used the parrot repeater in his school demonstrations and on several occasions requested SUNSAT ground control to place the satellite in the parrot mode.

The Amateur Radio Payload on SumbandilaSat will be operating in conjunction with the University of Stellenbosch Software Defined transceiver project as it will share the VHF receiver and UHF transmitter which is one of the other experimental payloads.

SA AMSAT designed and built a control system to facilitate the following operations:

- V/U voice transponder with an uplink in the 2 metre band and a downlink in the 70cm band.
- A parrot repeater (voice digipeater)
- A voice beacon

The control unit will command the various function of the transponder and handle the parrot and beacon messaging. On receipt of a tone from the VUCU VHF receiver, the CTCSS tone will be decoded and depending on the tone received the unit will command the VU transponder operation or the parrot repeater. In the transponder mode the satellite will act like a cross-band FM repeater and allow two way communications with other stations on the ground.

If the tone received indicates parrot operation, the interface unit will record 20 seconds of audio on its VHF uplink receiver and replay the recorded audio on the UHF downlink.

Should, for a predetermined period, there be no tones received, the controller will initiate a voice beacon, transmitting a pre-recorded message at regular intervals. This facility will offer many opportunities for educational projects.

SA AMSAT held a competition in which students were asked to write the first beacon message. The person whose message was chosen received a laptop computer. Many entries were received. The wining one was submitted by Anton Coetzee, a learner at the Kimberley Technical High School. The message reads: "***This is ZSOSUM in space. I am the voice of the South African youth. We are knocking on the door of opportunity, marking our place in the orbit of space research and communication. Hear us! Listen to us!***

The amateur payload fits in well with the overall mission of the satellite project which is the development and growth of people and institutions, providing satellite data for applications addressing the needs of society and understanding the modalities of a small satellite programme in order to inform the space policy process in South Africa.

Unusual Launch

SumbandilaSat is scheduled for launch on a Shtil launch vehicle from a sub-marine. The Shtil is a 3 stage launch vehicle that uses liquid propellant. It is the first launch vehicle to successfully launch a payload into orbit from a submarine, although launch from land based structures is possible as well. TubeSat was successfully launched on a Shtil (meaning Calm Weather). The launcher has a remarkable track record with 51 successful launches and only 1 failure.

The launch has been delayed several times due top some diplomatic paperwork that seems to take a long time to complete.

The launch delays forced us to look at other alternative projects to keep the momentum going. To get a slot in the ARISS programme takes a long time and then the slot is 10 minutes or so. We came up with the idea to ask an astronaut to give an hour or so of his time to talk with young people about space.

16 June is national youth day in South Africa and to celebrate this we set up a number of amateur radio stations in schools and other public areas, using a teleconference facility as a backhaul we linked in Bill McArthur. Bill answered questions from some 30 young people for almost one and a half hour. The kids had, ball and I believe Bill and the facilitators did also. Bill is a natural with young people and created lots of enthusiasm and interest. The event resulted in several new candidates to write the radio amateur examination.

INTO SPACE WITH AMATEUR RADIO

Into Space with Amateur is what the programme is now called. For Spaceweek 2007 we arranged a link up with the South African Astronaut, Mark Shuttleworth.

We are installing a number of Amateur Radio Stations in school assembly areas and will again use telephone conferencing for the back haul.

This time we have added a more competitive spirit. Students have been invited to write an essay about "The future of Space in support of mankind. The best 3 students in each school will get to talk to Mark Shuttleworth and the best overall essay will win the entrant a laptop computer.

(At the conference I will share some of the highlights of the event which will be held well after the closing date for the publication of the paper.)

Cricket Sat

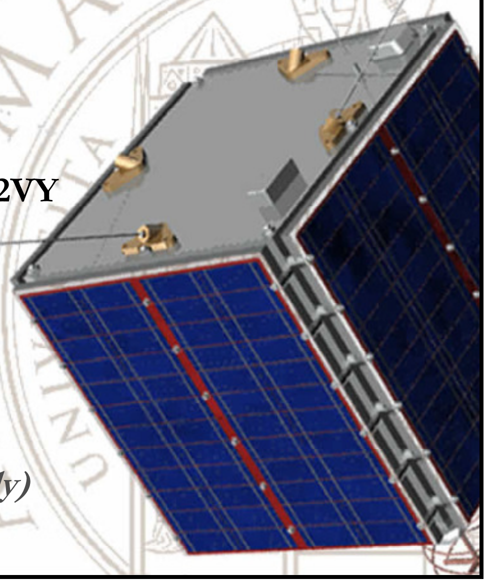
At the 2006 AMSAT NA Space Symposium Prof Robert Twiggs presented the cricket Sat idea. A small 70cm telemetry beacon that can be sent up on a number of helium filled party balloons. We are planning this as part of the 2008 South African Radio League road show called Radio Technology in Action. We are planning to launch a cricket said on the Friday afternoon prior to the conference and inviting a large number of students from local schools.

We are always looking at new ideas to bring amateur radio to the attention of young people and would welcome input from satellite and space enthusiasts. Please drop me a line if you would and share some ideas on how to empower the youth in Amateur Radio.

ends

ALMASat Alma Mater Satellite

ALMASat Microsatellite
Platform for Small Scientific Experiments in Orbit



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ALMASat Alma Mater Satellite

ALma MAter Satellite

Summary:

- ALMASat Laboratory
- The Microsatellite Program in Forlì
- The Forlì Ground Station
- ALMAtraker
- S-Band subsystem tests
- ALMASat-1 Microsatellite
- Conclusions

ALMASat Alma Mater Satellite

University of Bologna, Forlì Aerospace Campus

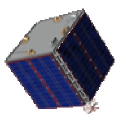
Main research and educational buildings

Microsatellite Laboratory

ALMASat Alma Mater Satellite

Available facilities

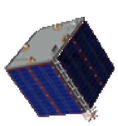
- A VHF/UHF/S amateur ground station;
- Digital electronics prototyping (PC, power supplies, oscilloscope, function generator @ 15MHz, JTAG emulator for Atmel® AVR microcontrollers;
- RF prototyping (at VHF, UHF and S bands);
- A test bench for the experimental validation of micropropulsion systems, a 15l, 200 bar, Nitrogen tank, pressure regulators, micro-valves, digital and analogue manometers and data acquisition systems;
- A glove box (100x100x150 cm) for solar panels assembly and integration;
- A Hardware-In-the-Loop (HIL) simulation test bench;
- A momentum/reaction wheels test platform
- A rotating platform for calibration of attitude sensors (accuracy of 1/100 of a degree)
- A temperature-controlled vacuum chamber (20°-150°), vacuum level ~10^{-2} mbar



The microsatellite program in Forlì

- Design, assembly and set-up of an **amateur radio station** → **fully operational**
- Design and assembly of a **Multi-mission satellite platform,** modular configuration
- Launch of the first microsatellite prototype, **Alma Mater Satellite - ALMASat** (in the second half of 2008)

ALMASat Alma Mater Satellite



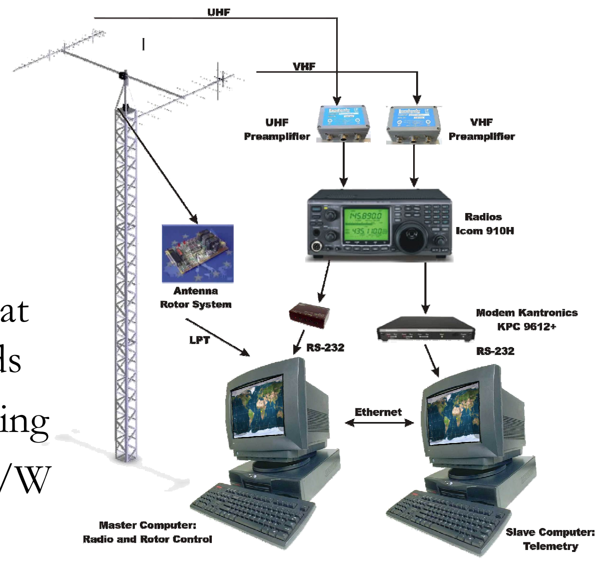
The Alma Mater Ground Station (AMGS)

- **2003:**
  - ***Design e setup of the ground station***
    - External mast, rotors, UHF and VHF antennas
    - Hardware assembly for station control and signal RX
    - Commercial software
- **2005:**
  - ***S-band downlink channel implementation***
    - Installation of an integrated receiving system
    - Hardware updates
    - New S/W for station control simultaneous RX in multiple bands
- **2006:**
  - ***Design and implementation of a new electronic board for rotor control***
    - Software updates

ALMASat Alma Mater Satellite

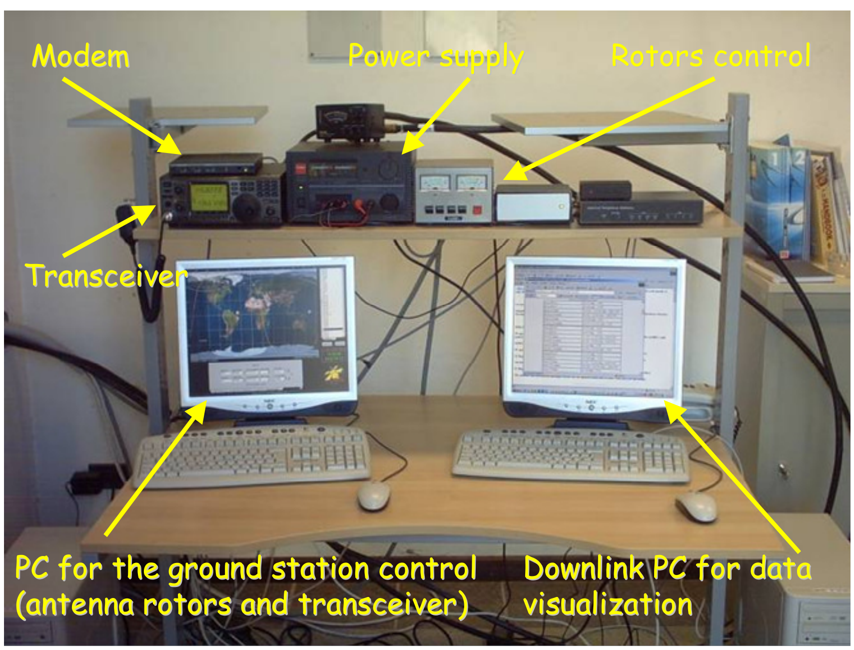
AMGS in 2003 (1/2)

- C.O.T.S.
- Communication at UHF/VHF bands
- Automated tracking
- 3 management S/W

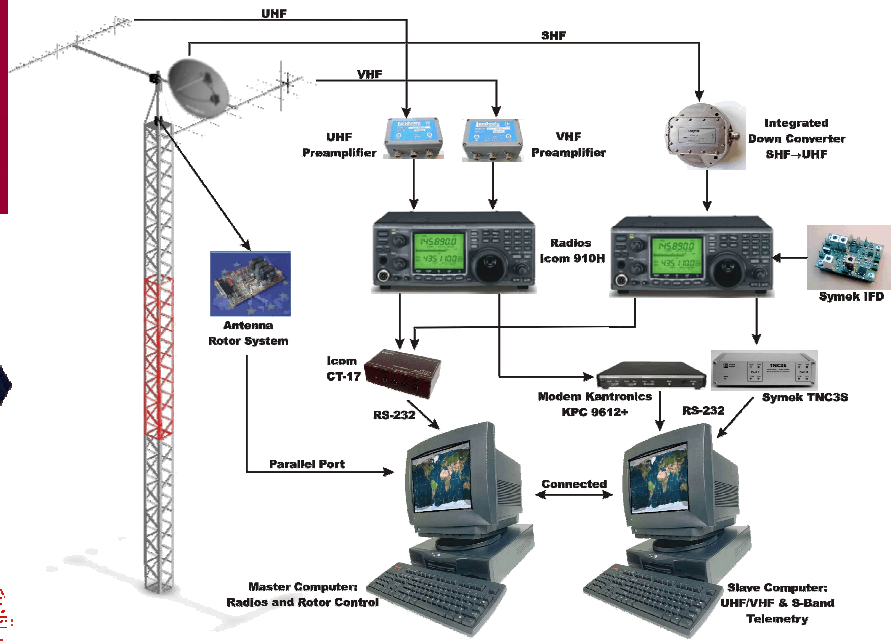


ALMASat Alma Mater Satellite

AMGS in 2003 (2/2)



AMGS in 2005



External instrumentation upgrade in 2005

Technical characteristics:

- Polarization: RHCP
- Diameter: 70 cm
- λ: 0.245
- f/D: 0.35
- Mast diameter: ø 40 - 60 mm
- Input frequency: 2407-2409 MHz
- Output frequency: 437-439 MHz
- Gain: 36 dB
- Noise figure: typ. 0.9 dB
- Operational voltages: 11 - 15 V

- **Down-converter and mast support assembly**
- **Positioning at 50 cm from vertical mast to avoid misalignments**

ALMASat Alma Mater Satellite

S/W upgrades in 2006

S/W upgrades for the new rotor control system

- Ready for Voice and Data S-band reception of AO-51 and other satellite

ALMASat Alma Mater Satellite

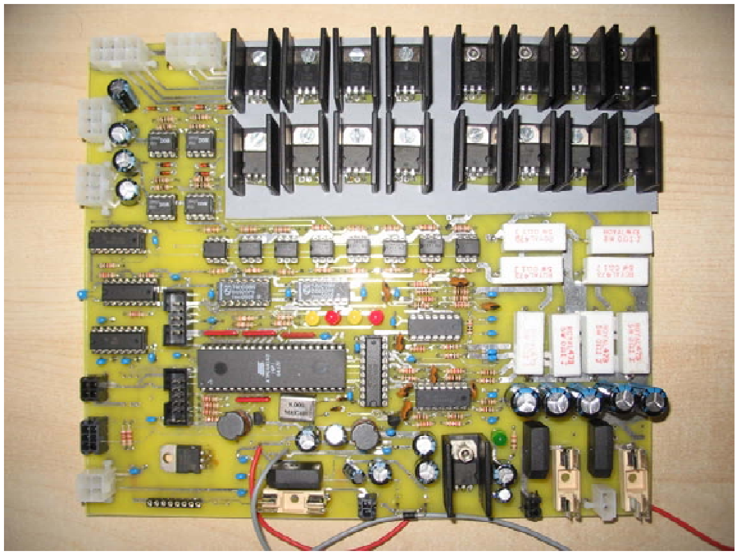
AlmaTracker

High precision (~0.01°) tracking system for satellite ground stations

ALMASat Alma Mater Satellite

AlmaTracker

Prototype of control board for AlmaTracker



ALMASat Alma Mater Satellite

S-Band satellite subsystem

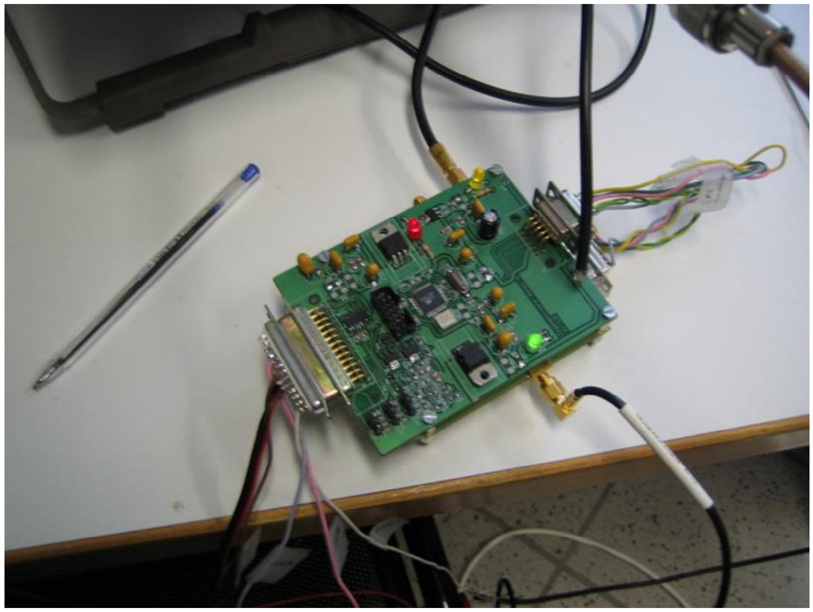
- Modulator CX72302 Dual Fractional-N Frequency Synthesizer
- 2407 Mhz RF Power Amplifier
- Quadrifilar Antenna

Test , developement and other issue by:

Giulio Pezzi iz4fvw@iz4fvw.net and

Ing. Gianpaolo Candini gianpaolo.candini@unibo.it

S-Band satellite subsystem test



FFSK 2.4 GHz Modulator

ALMASat Alma Mater Satellite

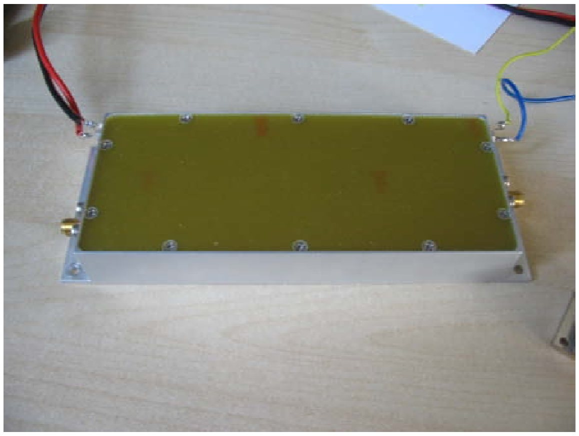
S-Band satellite subsystem test

Data Clock Generator

S-Band Transmission test

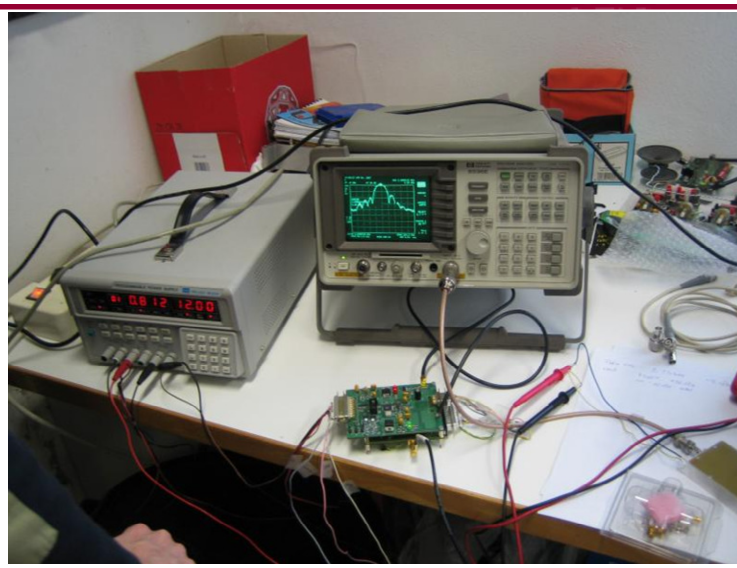
KU 2425-LEO2

S-band Power Amplifier



KU 2425-LEO2, Amplifier
Center frequency: 2400 MHz
Operation bandwidth: 50 MHz
Gain flatness: +/- 1dB
Nominal input power: 0 dBm +/- 0,5 dB
Input overdrive: +10 dBm
RF Input interface: SMA connector female
Input VSWR less than 1,6:1
Output power: 35 dBm, +/- 1 dB
over the operating bandwidth
Output power stability: +/- 1 dB
(ambient temperature range 10 - 30 °C)
Gain compression: at 35 dBm output power over the
whole bandwidth not less than 3 dB
Output is protected with an isolator
Harmonic levels shall be not more than -30 dBc
Output interface: SMA connector female
Output VSWR less than 1,6 :1
Noise figure: 12 dB
Operating voltage: 12 ... 13,8 V (intern linear stabilized)
SSPA efficiency: approx. value will be around 22%.
Weight: approx. 300 g
Dimensions: 156 x 59 x 20 mm
Telemetry Interface: Monitor output and calibration curve

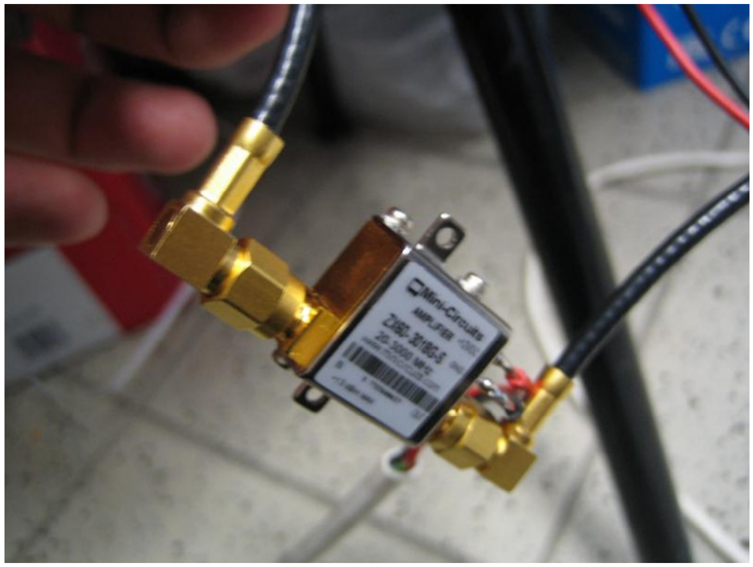
S-Band Transmission test



Test of modulator "on air" with no preamplifier before the power amplifier

ALMASat Alma Mater Satellite

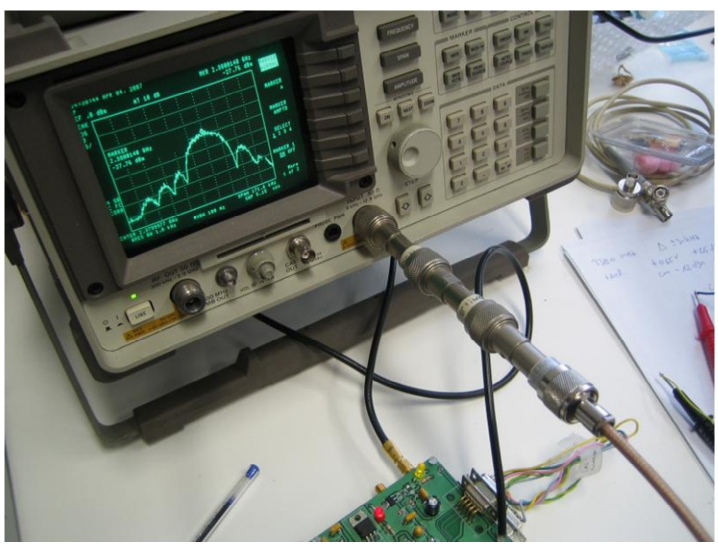
S-Band satellite subsystem test



ZX60 Mini-Circuits
input preamplifier

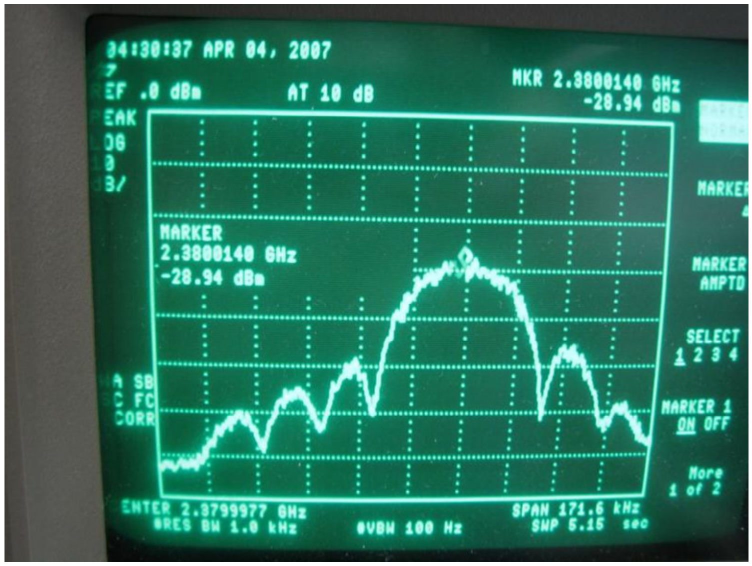
ALMASat Alma Mater Satellite

S-Band satellite subsystem test



System test with attenuator before the
spectrum analyzer input

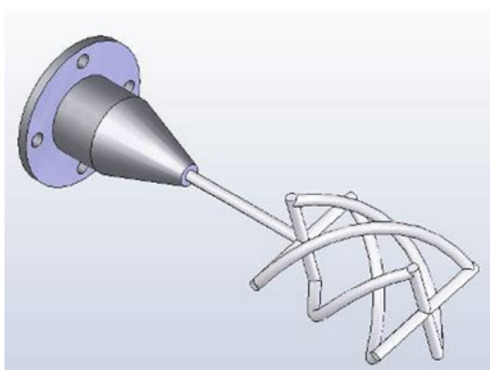
S-Band Transmission test



Output signal with attenuators

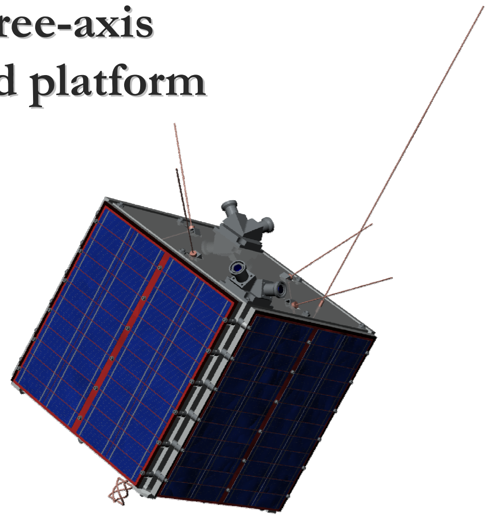
ALMASat Alma Mater Satellite

S-band quadrifilar antenna



ALMASat-1 Microsatellite

ALMASat
is a three-axis stabilized platform



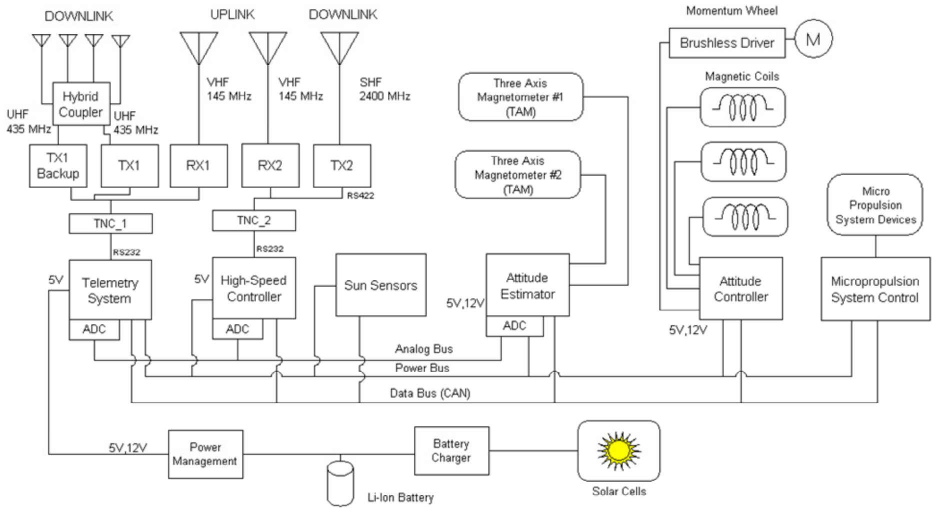
ALMASat Alma Mater Satellite

ALMASat-1 Subsystems Layout

- Final layout of S/C subsystems:

ALMASat Alma Mater Satellite

ALMASat-1 Electronics and RF block diagram



ALMASat Alma Mater Satellite

ALMASat-1: Launch Options (1/2)

- **ALMASat-1** can be launched by a converted SS-19 intercontinental missile from the **Baikonour Cosmodrome** (Kazahstan)
- The **DNEPR** program was started by a Russian-Ukrainian collaboration in 1999 focused on the civilian conversion of former nuclear weapons
- **University of Bologna** has a memorandum of understanding with Kosmotras

ALMASat-1: Launch Options (2/2)

- **ALMASat-1** can also be launched by the new small European launcher **VEGA** from **Kourou** (French Guyana)
- The **VEGA** missile has its maiden flight scheduled for 2008, fully compatible with our schedule
- **University of Bologna** has undertaken preliminary contacts with **ESA** for a lift to space on the 1st VEGA flight

The End …

73 from ..

Giulio Pezzi

IZ4FVW - AB2VY

RF Engineer

Team collaborator of:

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The WinCube Project

Stefan Wagener (VE4NSA)[1], Jeff Cieszecki (VE4CZK)[1], Barbara Bowen[2], Wayne Ellis[3], and Norm Lee[4]

[1]Manitoba Satellite Interest Group (MSIG), Inc., WinCube Project Team
[2]Manitoba Aerospace, WinCube Project Team
[3]AppSpace Solutions, WinCube Project Team
[4]MindSet (Manitoba Network for Science and Technology), WinCube Project Team

Manitoba High School Students involved in pico-satellite construction, amateur radio and high altitude balloons

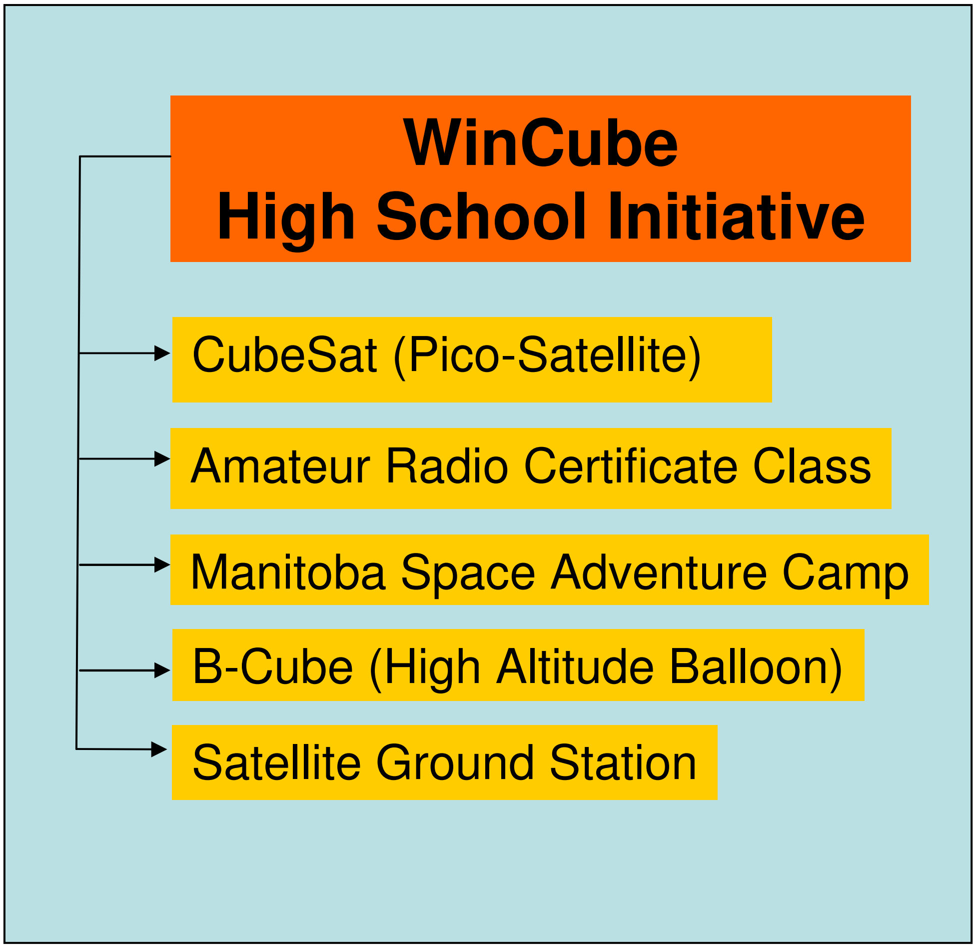
Abstract

The WinCube Project is a cooperative effort among Manitoba high schools, the Manitoba Satellite Interest group (MSIG), the Faculty of Engineering at the University of Manitoba, Maples Collegiate Space Exploration Academy, the Manitoba Aerospace Human Resources Coordinating Committee and numerous aerospace industry partners.

Through a mentorship program, Manitoba high school students will be involved in the design, construction, and launch of a pico-satellite with technical support provided by aerospace faculty and engineering students. Basic system design and construction experience for the high school students is provided by the construction and launch of high altitude balloon payloads. Students learn first hand about space mission design, telecommunications, programming, electrical and mechanical engineering and amateur radio through a summer camp program, ongoing workshops and courses.

WinCube

The WinCube project is a multi facetted approach of exposing high school students to amateur radio, aerospace, science and technology. It's core areas involve a satellite project (CubeSat), an annual summer space camp, a high altitude balloon project (B-Cube) and annual amateur radio classes combined with hands-on construction projects, as well as the operation of existing and future amateur radio satellites through a new satellite ground station.



Picture 1: WinCube Project Components

1. CubeSat Project

The CubeSat Project was initiated in the Spring of 2006 by the Manitoba Satellite Interest Group (MSIG) Inc., and MindSet the Manitoba Network for Science and Technology to provide Manitoba High School Students with the opportunity to be involved in the design, construction, and launching of a pico-satellite.

Initial funding for the project was obtained through NSERC (Natural Sciences and Engineering Research Council of Canada) and MindSet, the Manitoba Network for Science and Technology as a program of Manitoba Science, Technology, Energy and Mines. The project is designed to challenge students in the fields of science and technology. The pico-satellite is based on the California Polytechnic State University (CalPoly) CubeSat Program design and specifications of a cube satellite with the dimensions of 10x10x10 cm and a maximum mass of 1 kg. These small, relatively inexpensive satellites are capable of real data gathering as demonstrated by their utilization by universities and space researchers as an economical method of research.

To achieve this lofty goal of creating and launching a pico-satellite, a number of key factors need to be put into place for the high school students:

- Mentorship through aerospace industry and university students
- Gaining experience in payload design and construction through high altitude balloon work (B-Cube Project)
- Defined educational goals
- Amateur radio certification and ground station operation

For high school students to create a CubeSat, the Faculty of Engineering at the University of Manitoba with assistance by Bristol Aerospace provided initial design support for the satellite. This is necessary to meet the CalPoly specifications for a space worthy satellite. A Preliminary Design Review (PDR) Report was created by a cohort of 4th year Engineering Students at the University of Manitoba during the 2006-2007 school year [1]. The PDR proposes the design of the satellite and includes:

- Structure
- Electrical Power
- Communication System
- Command and Data Handling
- Attitude Control
- On Board Science
- Integration and Testing

The "on-board science" [1] will be responsible for gathering scientific data that will be transmitted back to earth for analysis. The science component of the satellite is what the high school students will contribute directly to. When the CubeSat is in orbit, participating high school students will communicate with the satellite via amateur radio. Data gathered will be processed and published by the high school students.

High school students will also take an active role in the construction of the CubeSat. Starting in the fall of 2007, students will be mentored by University of Manitoba Engineering Graduate Students during the next phase of construction and testing of the satellite utilizing the new University of Manitoba space lab. To prepare the high school students for the satellite construction, they will gain experience in satellite design by constructing and testing a scientific payload for a high altitude balloon launches. The high altitude balloon work is referred to as B-Cube.

2. Manitoba Space Adventure Camp

It is necessary to increase students' basic knowledge of space studies and related concepts before they begin their work on a satellite. Students in the program range in grades from 10 through 12. It is necessary that students have the basic concepts and vocabulary necessary to understand space science. A "space camp" experience is provided to bridge students' knowledge of high school physics and the concepts and vocabulary they will encounter during their CubeSat experience. The "Manitoba Space Adventure Camp" as it is called has been held for two years at the Canadian Forces School of Aerospace Studies, 17 Wing, Canadian Forces Base Winnipeg. It is designed to make high school students more aware of science and technology as it relates to aerospace. The Manitoba Space Adventure Camp actually involves two separate camps: a first year camp and an advanced camp for returning students who continue their participation in the CubeSat project. While most of the activities take place at the Canadian Forces School of Aerospace Studies, students also have the opportunity to build and launch model rockets, operate satellite navigation devices, participate in a research balloon launch and work with amateur radio via satellites. Our other activities include tours and lectures, geocaching and various lab sessions (http://appspacesol.com/spacecampmain.html).

The key event of the 2007 Manitoba Space Adventure Camp was the successful "school" contact with the International Space Station (ISS) which took place on July 12, 2007. The maximum elevation of the ISS was 70º and the contact lasted for over 9 minutes. Astronaut Clayton Anderson answered 18 questions on a variety of issues and some of students who took part in the 2006-07 winter amateur radio class had their first ISS QSO as certificate holders (http://www.msig.ca/iss%20contact.html).

Picture 2: Manitoba Space Adventure Camp, 2007 – Successful ARISS contact with the ISS.

3. B-Cube (High Altitude Balloon) Project

The CubeSat student design team from the University of Manitoba and MSIG identified a number of key engineering areas for the satellite. As stated earlier, the technical expertise required for a space-ready satellite is beyond the skill set for most high school students and science teachers and since the first year of satellite design was primarily theoretical a real life hands-on project was developed to provide a basic understanding of the intricacies of payload design and fabrication. High School students are given the challenge to create a payload for a high altitude balloon. Some of the similarities between the B-Cube payload and the CubeSat are taken from the Preliminary Design Review (PDR) Report by the University of Manitoba's Satellite Team [1]:

- Payload Frame
  - Structure
  - Thermal Design
  - Passive/Active Thermal Control Systems
- Electrical Power
  - Power Budget
  - Active/Standby Mode
- Communication
  - Requirements
  - Amateur Radio Use
- Antennas
- Command and Data Handling

The CubeSat once constructed will undergo a number of tests to evaluate its space readiness including exposing the craft to a hard vacuum, extreme temperatures, and vibrations. For the B-Cube, testing will include physical impacts, cold temperatures, and systems tests. The B-Cube tests can all be carried out at each high school by the students.

- Payload Frame -

The engineering points listed are those that only apply to the B-Cube design concept. For example, in designing the B-Cube payload frame, students must take into consideration temperature drops and how the electronics within the payload react as the balloon reaches a potential altitude of 30 km and external temperature drops as low as -60oC.

Areas for consideration in the B-Cube structure by high school students include the material for the walls (aluminum, foam core, foam insulation) [2], type of adhesives for the structure walls (silicon adhesive, hot glue, Velcro, aluminum tape) and the dimensions of the structure. Students may need to refine payload dimensions to effectively contain all equipment necessary for the balloon launch, yet limit the mass of the structure to the overall 1 kg payload mass. The design of the B-Cube structure must also allow for the venting of the internal volume to adjust to external atmospheric pressure changes, internal heat loss/gain, and possible moisture damage from clouds [2].

- Electrical Power -
High school students will also learn about electrical power budgets in the design of their B-Cubes. The B-Cube payloads are expected to operate for 2.5 hours of flight and run an audio beacon upon landing for an extended period of time to aid with ground retrieval. The choice of batteries will also require investigation and testing for suitability.

- Communication -
Communication plays a key role in the tracking and data gathering of both the satellite and the B-Cube payload. The high school students are required to obtain their amateur radio certificates since balloon to ground communication will utilize amateur radio frequencies similar (VHF, UHF) to those planned for the satellite. The certification will allow the students to communicate directly with the future CubeSat while in orbit via a ground station located in Winnipeg. First hand application of amateur radio operation is done by having the B-Cube payloads tracked by a GPS radio beacon that is transmitting on 144.390 MHz based on APRS (Automatic Position Reporting System). The students will use amateur radio transceivers and computer software to track and retrieve the balloon payloads.

- Command and Data Handling -
Command and Data Handling of the B-Cube payloads will be done with Basic Stamp chips. The Basic Stamp is reliable and uses PBasic programming. Students will create programs that meet the needs of their mission designs. This includes the timed operation of a balloon flight termination device, as well as the control of on-board cameras. Future projects will involve real live ATV transmissions.

B-Cube payloads are tested for impact survival. Students construct a number of prototypes of payloads that contain a mass that places the test container to a total of 1kg. Payloads are first tested by dropping them (e.g., off the school roof) to evaluate the structures impact survivability. Payloads are then dropped off with various dimensions of parachutes, comparing the time of descent. The third drop test involves a drop from an elevated altitude with the use of a kite or a tethered balloon. The payload is released via a cut down mechanism (termination device), and the payload floats to the ground with the use of a parachute, again recording the time of decent and the altitude it was dropped from. In all of these tests, students are determining the relative strength of the payload structures and best dimension of the parachute design for optimal results versus mass constraints.

A key component for any payload is to be able to operate in extreme temperatures. Both the WinCube and B-Cube must have measures taken to allow the operation of the electrical system at all times during flight. In the case of the B-Cube, extreme drops in temperature are an issue, as low as -60^{o}C. The B-Cube payload can utilize either an active or passive thermal control system, to be determined by the students. One possible test for temperature is to place an operational payload in a cooler filled with dry ice [2] or a freezer. In either case, the payloads should be running during the tests, with internal and external temperatures of the payload continuously monitored.

In order to help High Schools in Manitoba and beyond to engage in a high altitude balloon project (independent of the satellite project), funding was obtained from the Canadian Space Agency (CAS) to design and construct a ready-to-be-assembled B-Cube kit. Currently, preliminary prototypes of the kits are being developed and tested. These kits will be available in the beginning of 2008. This “plug and play” approach is very important for many science teachers in order to quickly incorporate such a project into the ongoing science curriculum of their school and guarantee a certain level of success.

One of the key elements of high altitude balloons using APRS is the possibility to closely work with local amateur radio operators for the purpose of testing payloads, radios, balloon tracking and recovery. These “balloon chase” events are very popular and significantly enhance the working relationships of local hams with high school students and teachers.

Picture 3: B-Cube-1 ready for launch

4. Educational Goals

Educational goals for the WinCube project were developed from the Common Framework of Science Learning Outcomes (Pan-Canadian Framework) written by the Council of Ministers of Education, Canada (CMEC) [3]. General Learning Outcomes (GLOs) from the Pan-Canadian that apply directly to the WinCube Project include Skills, Communication and Teamwork.

Pan-Canadian GLO for Skills includes planning investigations to record and analyse data using a variety of techniques [3]. For the B-Cube payload design or the science component of the satellite, students will develop the function of these payloads while attempting to address a scientific issue.

The GLO for Communication and Teamwork involves the effective communication with others in regards to issues and ideas, and comes up with a strategy that has a consensus to move forward on [3]. For the B-Cube component, students will work as a team to design a payload within a high school. The satellite will require students from participating high schools to discuss and agree upon what the science component will accomplish once in orbit.

Specific Learning Outcomes (SLOs) from the Pan-Canadian Framework found in the WinCube Project include Initiating and Planning; Performing and Recording; Analyzing and Interpreting [3].

Initial BCube payload designs will be very basic, to simply launch and retrieve a payload. Subsequent payload designs will have more specific scientific goals. The SLO of Initiating and Planning involves the investigation of practical problems and issues and the creation of scientific investigations to gather data [3]. The SLO of Performing and Recording will have students carry out experiments while controlling variables, effectively collecting and compiling data [3]. With data collected, students will analyze evidence, provide conclusions, and display information using a variety of formats as part of the SLO Analyzing and Interpreting [3].

Further educational opportunities include ongoing certification in amateur radio and potentially high powered rocketry. During the 2006-2007 school year, participating high school students took part in classes for amateur radio certification. Amateur radio is a key component of the WinCube project that allows students to track their B-Cube payloads and communicate with amateur radio satellites including the WinCube CubeSat. The amateur radio course will again be offered during the 2007-2008 school year.

A planned additional course to be offered to participating students in the fall of 2007 is a junior certification in high powered rocketry. The rocketry course will provide students with a better understanding of the physics of launching payloads into space.

Conclusion

The WinCube is now in its second year and has integrated a number of different projects under one umbrella. The combination of these projects makes the WinCube idea novel and exciting for all participating partners. In addition, such a multi faceted approach has been very appealing for external funding groups and agencies and will be used to further enhance our ability to deliver these programs to High Schools in Manitoba and beyond.

Acknowledgments:

Our special thanks and appreciation go to the Winnipeg Amateur Radio Club (WARC), ARISS (Amateur Radio on the International Space Station), the 17 Wing (Winnipeg). We gratefully acknowledge the financial support provided by NSERC, CAS and MindSet and thank the following individuals for their great involvement and support:

Alan Thoren VE4YZ, Steve McFarlane VE3TBD, Dieter Schliemann KX4Y, Greg Linton VA4GL, Albert Sousa VA4AS, Geoff Bawden VE4BAW, Fred Venema VE4FV, Gerry Baker VE4GTB, Rory Winters VE4RJW and Melanie Rennie.

References:

[1] Shambrock, J., W. Whaley, B. Klimenko, P. Wheatley, D. Boyd, S. Tully, J. Eady, C. Bosecke, J. LaRue, T. vanBeek, R. Le Neal., University of Manitoba Win-Cube Project 2006-2007 Preliminary Design Review, Winnipeg, Manitoba, 2007.

[2] Koehler, Chris, “BalloonSat: Mission to the Edge of Space”,Proceedings of the 16th Annual/USU Conference on Small Satellites, Logan, Utah, August, 2002.

[3] Council of Ministers of Education, Canada (CMEC), Common Framework of Science Learning Outcomes: Pan-Canadian Protocol for Collaboration on School Curriculum, Council of Ministers of Education, Canada, Toronto, 1997.

Space and Dinosaurs for Student Educations Outreach

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Abstract
What are students interested enough in that it can compete with shoot-em-up computer games and MTV? It is often said that the most popular topics with students are space and Dinosaurs. Well, I don't do Dinosaurs, but I do space so for outreach programs that is what we take into the classroom. The Space Systems Development Laboratory at Stanford University received a grant from the California Space Authority funded by the US Department of Labor to take some of our space projects into the K-12 classroom with mentors to do hands-on projects. This paper will describe some of those efforts of that program that was started last spring, the results and the lessons learned.

Federal Funding for Outreach
What has K-12 outreach programs have to do with the Space Systems Development Laboratory at Stanford University? Since the establishment of the SSDL in 1994 there has been a conscious effort to do collaborative projects with other universities and outreach to K-12 classes. Having done this effort, the California Space Authority (CSA) solicited participation from SSDL in December 2005 to join in a proposal to the US Department of Labor to support tasks, some of which were outreach to K-12 schools to encourage students to be interested in science, technology, engineering and math – STEM. CSA was successful with the proposal and received $15M of which part was for this outreach in a program called WIRED (Workforce Innovation in Regional Economic Development).

> Project Goal: Establish a model program for K-U participation in projects that demonstrate technical capability in the design, assembly, testing and operation of electronics applications to observe local and space environments. Primary outcomes: To have students working with technical mentors on a continuum of projects that will be hands-on activities to build interest and capability for science, technology, engineering and math careers. Stanford will lead in partnership with another local college or university, with Stanford establishing a training program with mentors from industry or government organizations that will support the K-12 students in their hands-on project activities. Stanford Graduate and Undergraduate students will assist the mentors and K-12 students to carry out these activities.

Proposed plan in working with K-6 schools
The outreach of the WIRED program at the grade school level was directed to students starting in the fourth grade. Why the fourth grade? Literature and advice from educators had indicated that students start to select what their commitment to their future educational choices start as

early as the fourth grade. Our approach was to assign mentors to provide projects for the fourth grade students that would demonstrate the STEM principles. These mentors would work with these fourth grade students for the full class year. When the fall term began, the mentor would move with the students to the fifth grade. The plan was to have the mentors continue with the same students as they progressed through high school. Since the mentors were selected from the space industry, the technical content would come from their experience.

We had concerns about being accepted to provide help at a school and would the teachers provide the time with the students to do the proposed projects.

<u>The reality in working with K-6 schools</u>

What we found in our initial acquaintance with the Sherman Oaks Charter School in Campbell, California that the principal and the teachers were very receptive of our providing assistance to them.

We also quickly learned that there was very little, if any, spare time that the students had to participate in these planned projects that could be offered by the mentors. We also found that the teachers had an education plan provided by the State of California that they must teach to in each grade.

We then developed a program in working in the school as follows.

a. Mentors worked directly with the teachers to review the state requirements to develop a plan to assist the teacher with projects or additional lecture material to supplement the teacher in covering the subjects.

b. The teacher was totally in control of mentor in deciding when and where the mentor would assist.

c. The overall outcome was to assist the teacher to make their job easier and more productive with the assistance of the mentor.

Our expectations were to find a fourth grade class in each school that could be assisted by one mentor. What we did find in Sherman Oaks Charter School was that there were three classes of fourth grade students with about 25 students in each class. It was also found that it was difficult for one mentor to provide the help needed due to the mentors employer demands.

<u>How we changed our approach</u>

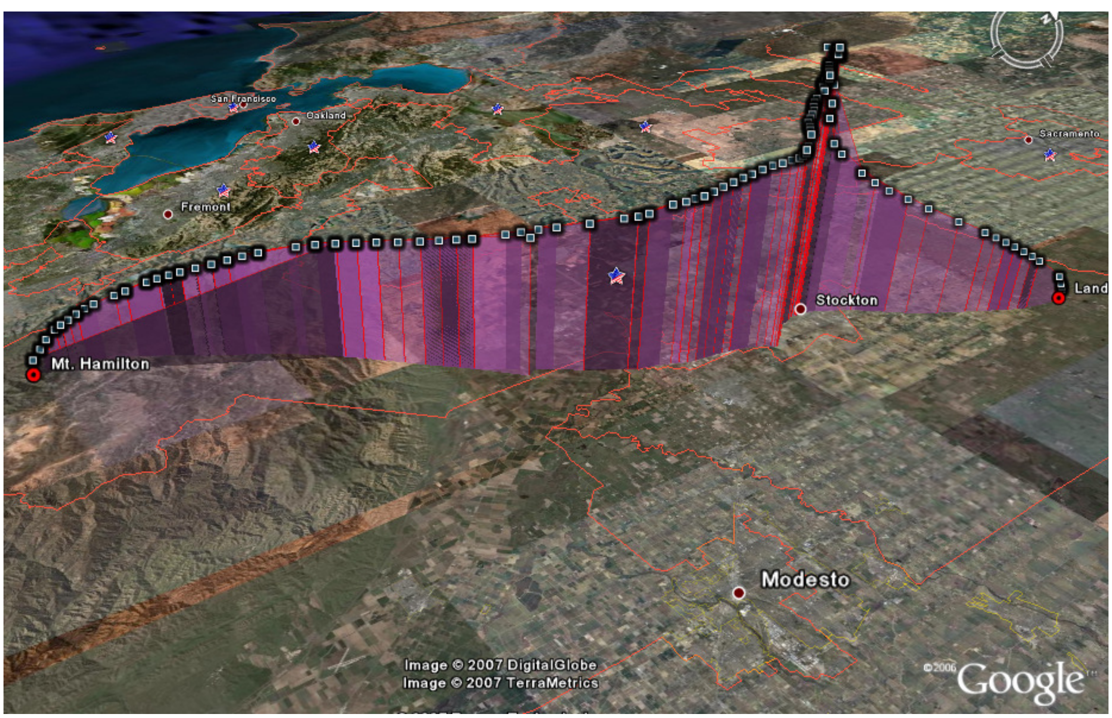
We now have recruited several mentors from the same company to support Sherman Oaks Charter School as we now are working with the same students in the fifth grade. Our hope is that have all the mentors from the same company is that the company my adopt this school and make sure there is continuing support with both mentors and materials funding. The funding for this level of student is expected to not exceed $5,000 per year.

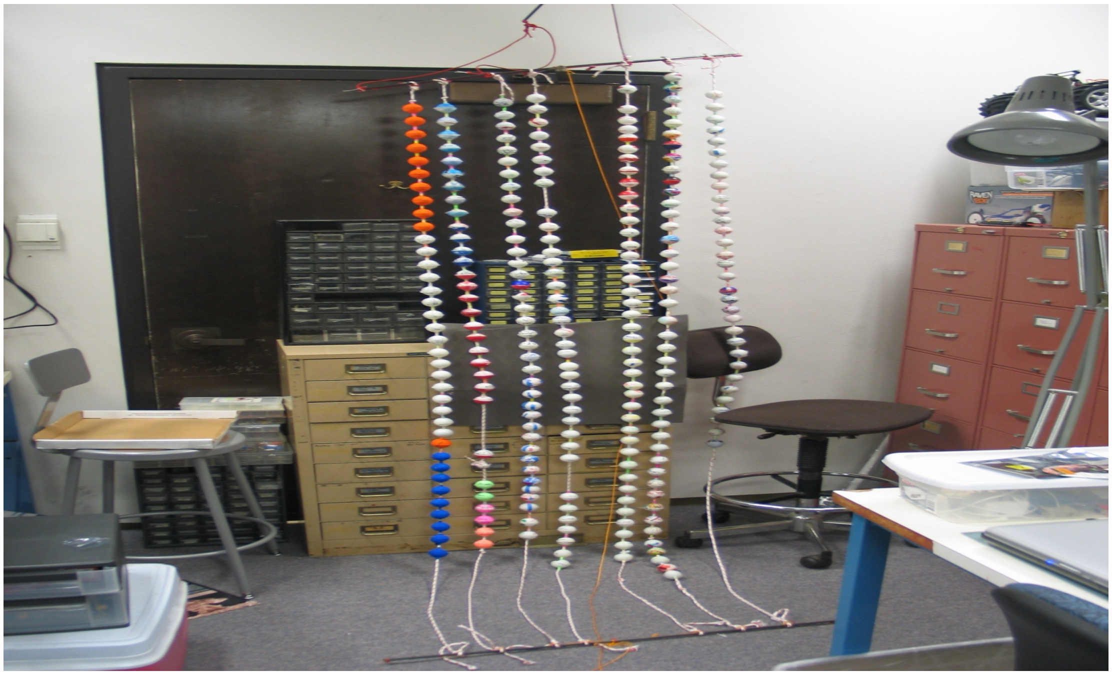
Programs done with the Sherman Oaks students

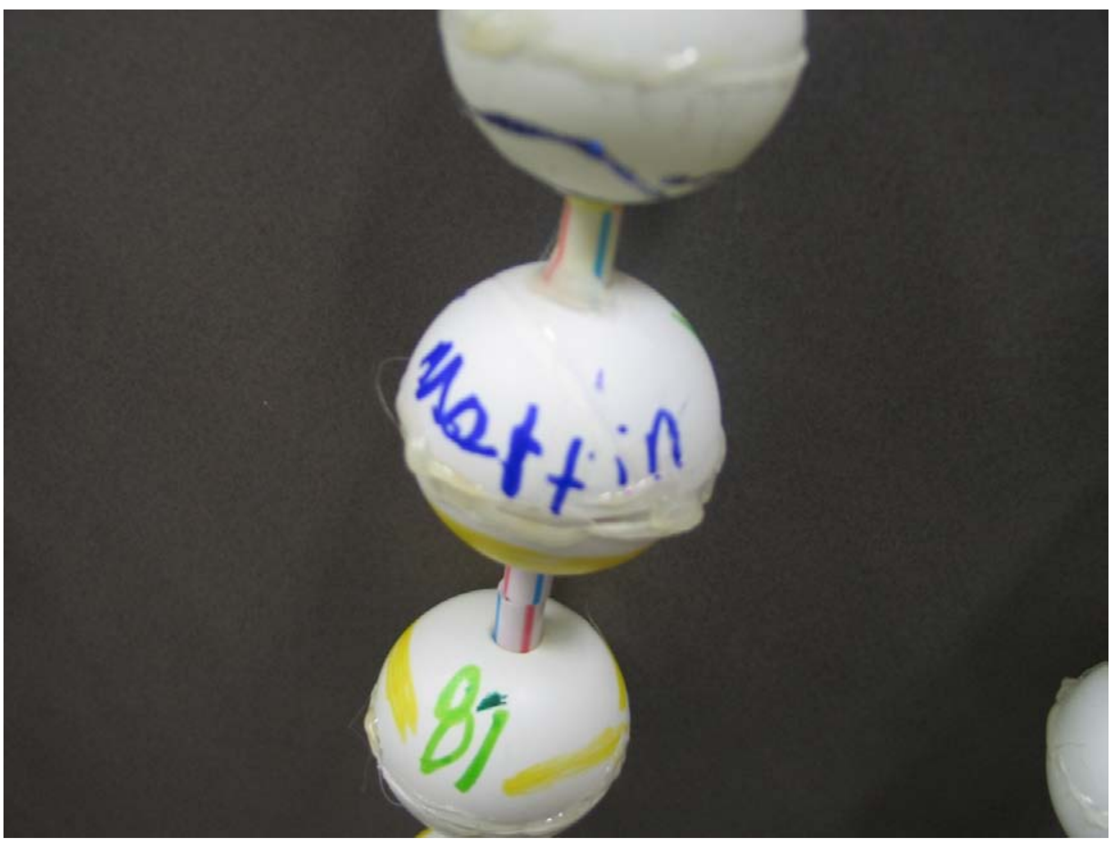
We started with Sherman Oaks in March and had only two month in May and June to work with students. Besides some lectures by the mentor on space and satellites, there were two projects done at Sherman Oaks. The fourth grade students had time allocated for a science camp. The mentor used some of this time for the science camp to take all three fourth grades classes through some exercises with protoboards that demonstrated series and parallel circuits. A simple series circuit with a battery and an LED was built. A switch was added, then a potentiometer and Piezo buzzer was added in parallel.

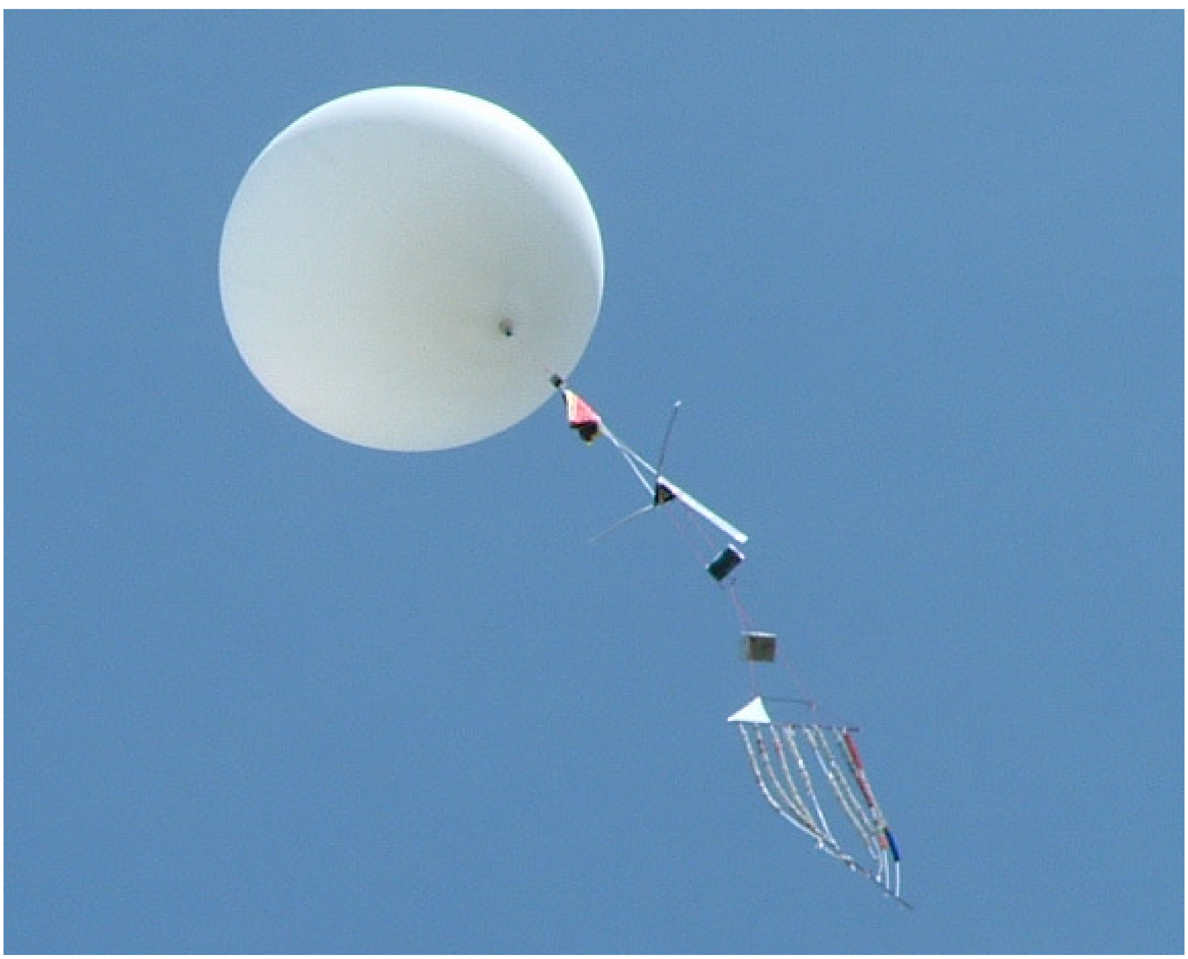
The second project that was proposed was to do a PearlSat experiment with the fourth grade students. The PearlSat experiment uses a ping pong ball that the students put an experiment of their choice in the ping pong ball. We then attach these ping pong ball to a balloon experiment flown by the Aero Astro student from Stanford that would take the ping pong ball to about 100,000 ft and return them. Students were briefed about the conditions the ping pong ball would encounter on the balloon flight. The principal was so excited about this experiment that she asked if all 500 students in the school could participate rather than just the fourth grade students. We eventually negotiated one ping pong ball for each two students, but still flew about 300 ping pong balls for teachers and friends.

Results of this experiment are summarized in the photos below.









Results of Program at Sherman Oaks

The fourth grade students were required to take the state grade level exams. From these brief projects with the students, the test scores of the fourth grade students increased by 45%. The total overall score indicated that 90% of the fourth grades were above the average in science proficiency. This was a significant improvement from the fourth grade from the year before.

Was all this due to the projects that the students were involved in? We believe that the increase was also do to the students receiving additional attention from the mentors and those there were associated with and experinced in the PeralSat project.

Can you do outreach?

We have learned some good lessions so far in our efforts, but from significant improvements in state test scores for the fourth graders at Sherman Oaks Charter School just being at the school, talking to these students and caring is a great motivator.

Conclusion

Go do it!

Cansat, Educational Hands-On to Learning about Satellites
Ivan Galysh, Stensat Group LLC

Professor Robert Twiggs of Stanford University developed the concept of Cansat in the late 1990s. The purpose of cansat was to allow students to experience a space program on a small affordable scale. A cansat is a simulation of a satellite the size of a soda can. Students build a satellite that can fit into a soda can to perform some mission. The cansat is launched in a high power rocket to some altitude such as 12,000 feet and is ejected from the rocket. The cansat floats back to earth for several minutes performing its mission and transmitting telemetry or accepting commands to perform specific tasks. The first cansat launch occurred in 1999 in Black Rock, Nevada. Over time, the cansat concept has spread around the world. The cansat has been used as a stepping stone to the cubesat satellite which was also developed by Professor Twiggs. Cubesats are picosatellites that can be as small as a four inch cube at 1 kilogram.

ARLISS

ARLISS, A Rocket Launch for International Student Satellites is where cansat started. Every year since 1999, Stanford University led by Prof. Twiggs and the AeroPac rocket club have launched cansats up to 12,000 feet for students from various schools including Japan. The launch is held at the Black Rock, Nevada.

The ARLISS launch has been attended by high school and university teams. The event is not a contest but an event providing students the opportunity to have their cansats launched to high altitudes. The students design and build their cansats to perform a mission they define themselves. The Aeropac rocket club provides the rockets and launch support.

Cansat designs have ranged from simple temperature measuring cansats to robotic type cansats.

Pictures from the Third Annual Cansat Competition in Amarillo, TX

National Cansat Competition

In 2004, a university level cansat competition was created. The competition organization committee consisted of the American Astronautical Society, American Institute of Aeronautics and Astronautics, Naval Research Laboratory, NASA Goddard Space Flight Center, and the Jet Propulsion Laboratory.

Each year, the committee defines a mission for the competition with the current theme being planetary exploration. Universities around the country apply to the competition and start designing their cansats. The teams are required to hold preliminary design reviews and critical design reviews with the committee members usually by teleconference. In June, the teams go to the launch site and launch their cansats on rockets provided by the competition.

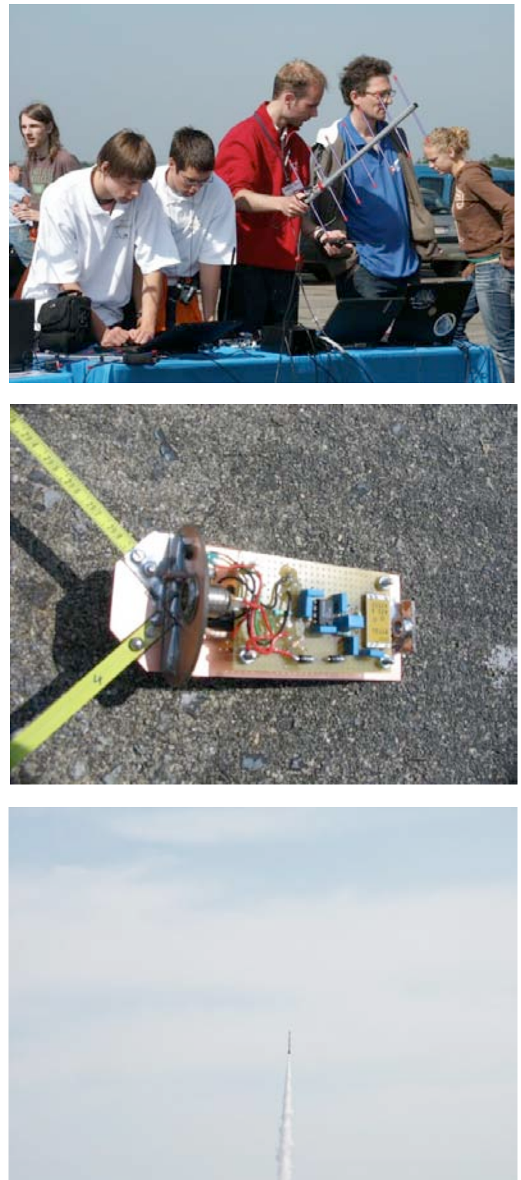
The first launch was held in June 2005 near El Centro, California. Seven teams applied and only three teams came to the launch to fly. The mission was to measure atmospheric pressure and temperature and to measure the distance and direction from the landing site to the launch site. None of the teams recovered their cansats. The cansats were launched to 5000 feet.

The second launch was held in The Plains, Virginia with the same mission but a lower deployment altitude of 2000 feet. At this event, thirteen teams applied and seven made it to the launch. Two teams successfully completed the mission.

In 2007, the third competition was held in Amarillo, Texas. The mission was changed to require more mechanical and aerospace engineering efforts and less electronics. The cansats had to land and be in an upright position. Twenty-six teams applied and fifteen teams attended the competition including a team from Hawaii. One team successfully completed the mission with a second team almost completing it. Vegetation was an issue.

Cansat Around the World

The cansat concept is spreading around the world. The largest organized international event is in the Netherlands. Delft University of Technology and Innovative Solutions in Space (ISIS) company have organized a national cansat competition similar to the American competition. Their purpose is to increase interest in exact sciences and technology and to increase enrollment for the Bachelor and Master studies at Delft University. Other organizations involved include The NAVRO (Dutch Amateur Association for Rocket Research) which organizes the launches, DARE (Delft Aerospace Rocket Engineering) which develops, builds, and launches the rockets, and WO-Sprint fund which stimulates the competition through its Sprint Program. For the next competition, the winner will travel to the United States to compete in the American competition. More information can be found at www.cansat.nl.



Pictures from the Netherland Cansat Competition

High School Cansat Launch

For high schools that want to attempt simpler missions, a regional cansat launch will be held in Maryland in 2008. This event is open to high school students only. The documentation is less stringent than the university competition. The mission is simpler but does require the students to include most subsystems of a satellite in their cansat. The students do have to build a ground station. They do get to build the rocket to launch their cansat. A rocket motor will be provided at the launch. At the launch, the teams will display a poster describing their cansat and mission. The launch is to be held in April 2008. More information can be found at www.foge.org.

Cansat Summer Camp

The Federation of Galaxy Explorers, a nonprofit organization dedicated to teaching kids about space and technology, operates a summer camp for high school students in Chantilly, Virginia. The summer camp teaches students about satellites, what makes up satellites, and how they are built and tested. During the week long summer camp, the students work on cansat kits that include many of the components of a satellite. They also build a three inch diameter rocket to launch the cansat.

The first day started out with a discussion of the subsystems of a satellite. The Clementine satellite designed and built by the Naval Research Laboratory was used as an example. Many of the Clementine satellite components were compared with the components of the cansat. The cansat had all the main subsystems; the aluminum structure, power subsystem, the data handling unit, communications subsystem, and the attitude determination and control subsystem. The students were introduced to basic orbital mechanics and learned about the different types of orbits. They used the Satellite Tool Kit software from AGI to visualize the different types of orbits and modify the orbital elements to see the effects. The students started assembling the cansat kits and programming the data handling unit.

On the second day, the students continued programming the data handling unit. By the end of the day, the students learned how to use the analog-to-digital converter and convert the solar panel measurements to voltages values. The students also started building the rockets. Each student received a rocket kit.

Students Working on Cansats and Rockets

The kit was custom designed by Hangar 11 using Public Missiles components.


Prepping for Cansat Launch

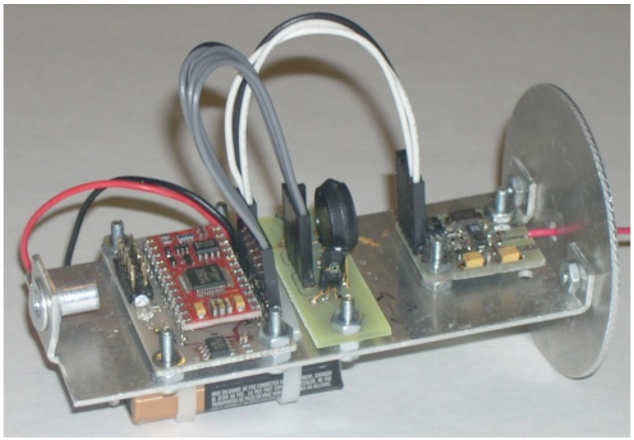
On the third day, the students started experimenting with the gyroscope. They installed the gyroscope and wrote software to measure the voltage from the gyroscope. The software then calculated the rotation rate that was linearly proportional to the voltage generated by the gyroscope. The students also learned how to program the data handling unit to control the radio transmitter. GPS data processing was also performed that day. In the afternoon, the students went outside with their cansats and tested the GPS receivers. During the whole day, the students installed all three fins on their rockets. Fifteen minute epoxy was used to keep the students from building the rockets too quickly.


Launching a Cansat

Thursday was used to do final programming, cansat check out and complete the rockets and prepare them for launch. The students also experimented with a two-axis magnetometer. The magnetometer used a different type of interface called I2C. I2C stands for Inter-Integrated Circuit Bus. The I2C bus was developed by Philips Semiconductors to provide an easy way to connect a processor to peripheral chips. The magnetometer interface behaved similar to a serial EEPROM with an I2C interface. The magnetometer measured the earths magnetic field and generated a heading value referenced to magnetic north.

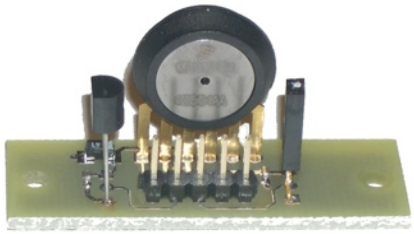
Saturday was the launch day. The launch was held at Great Meadow in The Plains, Virginia, the same field that holds the Team America Rocket Challenge. The students showed up around 10AM with their parents. Praxis Inc. provided lunch and T-shirts for everyone. The ground station was set up. One student sat at the computer to monitor the telemetry and the other student held and pointed the antenna toward the cansat. The first rocket was prepared for launch on a G80 motor. The rocket parachute was packed above the piston and the cansat was placed on top. The nose cone with its parachute was then placed on the rocket. After the rocket was placed on the launch pad, a final telemetry check was made. The rocket was then launched and the student holding the antenna pointed the antenna toward the cansat as it drifted back to the ground. With little wind, the cansats did not drift very far and was easily recovered. All five cansats were successfully launched although three rockets did crash after deploying the cansats. Some configuration changes to the rockets improved the recovery. One student added a video camera to a cansat. He even built a yagi antenna. The cansat launch went flawlessly and the video worked. The video wasn't clear but there were times in the video where the landscape was seen clearly.

Cansat Kit



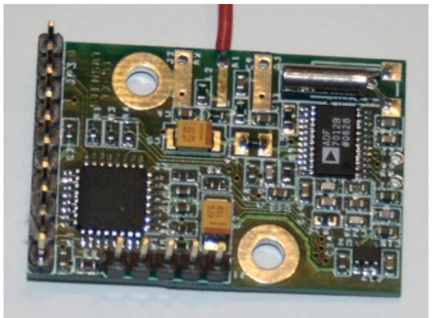
Cansat Kit

Stensat Group LCC developed the first cansat kit. The kit includes everything needed to build a cansat with detailed lesson material. The mission of the kit is to make atmospheric measurements. The kit simulates a satellite by including many of the subsystems found in a real satellite. Some subsystems are simple such as a nine volt battery for the power subsystem. The kit includes a data handling unit, a transmitter, battery power, an aluminum structure, a parachute for attitude control, and a sensor payload.



Sensor Payload with Temperature, Pressure, and Humidity Sensors

The cansat data handling unit is a BASIC Micro processor that is programmed in BASIC. The processor includes the development software. The data handling unit provides three analog-to-digital converter (ADC) inputs for the sensors and a port to connect to the transmitter.



Cansat Transmitter

The transmitter operates at 1200 baud using the AX.25 protocol and AFSK modulation. Two frequencies are available, 433.92 MHz and 916 MHz with a power level of about 10 dBm. The transmitter accepts a universal asynchronous serial data stream and converts the data stream into AX.25 packets. The first version of the cansat transmitter has flown in actual satellites such as GENESAT-1, FCAL, and Libertad. More of the transmitters will be flying soon. Due to a part becoming unavailable, a new transmitter was designed to replace the original. The new transmitter allows for longer packets and can operate at 1200 baud and 9600 baud. It can potentially operate at 38.4 Kbaud. It is currently being designed into new satellite radio systems. A few of the new transmitters have been integrated into cubesat radio boards. The new transmitter can be configured to operate in several bands, such as 6 meters, 2 meters, 70 cm, and 33 cm. The power level is about 10 dBm.

The sensor payload consists of a single board with a pressure sensor, a temperature sensor, and a humidity sensor. All three sensors generate a voltage in proportion to what is measured. The pressure sensor is made by Freescale and has a range from 10 Kpa to 115 Kpa. The temperature sensor measures from 0 to 70C. The humidity sensor, made by Honeywell, has a range from 0 to 100 percent. To get any significant variation in humidity measurements, the cansat needs to be launched to high altitudes such as 10,000 feet or more. For significant temperature variation, the cansat needs to be launched to a mile altitude. The data from the pressure sensor can be used to calculate the altitude of the cansat.

The structure consists of a rectangle aluminum plate with mounting tabs. All the electronics is secured to the plate. An aluminum disk is mounted to the plate. This is the stop for the soda can. The top of a soda can is cut off. The soda can slides over the rectangular plate and butts against the disk. A hole needs to be drilled into the center of the bottom of the soda can so an eyebolt can be secured to the rectangle plate. The parachute is secured to the eyebolt.

The lesson material for the cansat is detailed. The material walks the students through each step in assembling the kit and programming it. The lesson material explains how the sensors work and how to calculate the values of the measurements. The students learn about satellite communications and telemetry. The students program the cansat to measure the voltages from the sensors and calculate the values. The values are then transmitted to a ground station.

The ground station consists of a receiver and a laptop. The laptop runs a program to decode the AX.25 packets using the sound card. Most students use the AGW software. The receiver can be any ham radio receiver for the 70 cm band. A custom built receiver is available for the 916 MHz transmitter.

Conclusion

The Cansat concept is providing students around the world with hands-on experience in engineering and science. Cansat teaches other concepts besides engineering and science. Students learn to work in teams, communicate with each other, and learn how to coordinate their time and energies. Based on experiences at the competitions and summer camps, cansat does inspire students to pursue careers in engineering and science. Several high school students from past summer camps have enrolled in universities with aerospace programs.

The UMES/HISS Hawk HASP
High Altitude Balloon Payload

By Pete Arslanian and Michael Dunn

Created by: Students of AVSC288 at the University of Maryland Eastern Shore

Michael Dunn	Teshome Dirba	Andrew Grizzle	Andrew Gates
Danielle Simmons	Martin Jackman	Maurice Deville	Ibrahim Bodra
Tahir Ahmad	Jonathan Dews	Laeke Mirtneh	Surafel Cherinet
Galal Kamendego	Doug Young	Gordon Owens	

Construction and design assistance by HISS interns

Pete Arslanian	Tycora Brown	Michael Dunn
Richard Choquette	Lisa Dean	

Integration and launch team

Pete Arslanian	Michael Dunn	Andrew Grizzle

HISS mentors: Dr Marco Villa, Robert Davis, Charlie Lipsett

Mission Statement

Successfully select and build a device that complies with the standards set by Louisiana State University (LSU), for a small payload, to be launched on a high altitude balloon the summer of 2007. The slallooncraft will travel to about 140,000 feet for about one day. The near-space experience is valuable to UMES/HISS long range plans in engineering, CubeSats and student hands-on experience. The Hawk Institute for Space Sciences (HISS) is a non-profit affiliated with the University of Maryland Eastern Shore (UMES). This payload houses several experiments that will measure atmospheric and environmental information. The Payload was environmental tested and then integrated into the research vessel constructed by LSU. The data collected will be used for future research at University of Maryland Eastern Shore, NASA Wallops Flight Facility, the Hawk Institute for Space Sciences, and LSU.

UMES Hawk HASP

As students of University of Maryland Eastern Shore and NASA Step-up Interns, we were encouraged to participate in a joint program with LSU and NASA to launch a high altitude balloon for atmospheric and space research. The proposal for flight on HASP was lead by HISS and submitted prior to the start of the Spring 2007 Gateway to Space Course. Other Universities participating were Texas A&M, West Virginia University, University of Louisiana at Lafayette, and Virginia Tech. The UMES students were given the option of a small or large payload and chose to craft a payload no more than 30 cm in vertical height, no more than 15 cm on each horizontal axis, and weighing no more than 1 kg (the limits for a small payload). The power supplied by the LSU structure was 28 volts dc at 0.5 amps, although most devices used individual lithium ion batteries. The HASP balloon was launched the 2nd of September after a failed launch attempt on the 1st, wind being the deciding factor. The five types of devices deployed on the UMES payload to record data we felt would be beneficial to the University, NASA, LSU, and, of course, our further education were:

- Two temperature probes
- Digital Video Camera
- Still Photo 35mm Camera
- Two Solar Cells
- Pyranometer

The HISS lead Hawk HASP was a joint project between two student programs; the AVSC 288 class at the University of Maryland Eastern Shore with Hawk Institute for Space Science mentorship, and the NASA Wallops Flight Facility Step-up Summer Internship. The students at UMES began the project and were given a proposal put out by HISS teachers of the AVSC 288 course. The students were given certain requirements and problems listed in their proposal to overcome during the construction. The goals of the course were:

- Teach the students about the Aerospace Industry.
- See how each of the divisions within an Aerospace organization operates.
- Understand the processes used to build a space vessel.
- To produce a functioning payload.

The students carried the project all the way to the build phase where they ran into time constraints due to the end of the semester. The project was then handed over to the NASA Step-up Interns to complete at the Hawk Institute for Space Sciences. The Interns finished the build, tested, integrated and launched the payload. The Project is now in the final stages of data analysis to determine the results of the flight.

Report from AVSC 288

The project was a little overwhelming when it was first presented to the class, but after a few convincing speeches and job assignments all seemed to be well. The students started out at what would best be described as a crawl but the pace steadily increased with time. The divisions of work teams were reorganized several times trying to get the right combination of people for the right job. Previous applicable experience was minimal and this became evident extremely quickly when the right components were trying to be found. Many of the teams needed outside assistance to find what was needed for the experiments. Many of the people who assisted came from NASA Wallops Flight Facility, the Hawk Institute for Space Sciences, and the University itself. Parts did not begin arriving until a few weeks after midterm, which put us behind schedule. Construction and the first stages of testing began two weeks before the final days of class so with the approaching last days of class we started making arrangements to continue the project through out the summer session with the remaining student class.

From the beginning, our fledgling team has face what seemed like enormous obstacles. Most of the class expected something a little less intense, maybe if I could say a coaster class that generally overviewed the aerospace field; this is not what was given to us. So the first problem we had I would say was underestimating the difficultly of the class. Second, we had a time constraint starting with only one semester to achieve our goal of a workable payload; time was only a factor because of the lack of experience. Most of the students in the class have not seen anything related to the material we were handling. Third, the management started on shaking ground. The depth of information we were keeping track of and how to keep records of it were new to us. The processes slowly were beginning to become clear to us, and the closer we moved towards the end the more we began to act as a team. Communication has been the main factor in our inability to complete the project on time. From the beginning we have not had a solid line of communication or even shared general information with each other. The teams did begin to act as if each group were a separate entity with the laborers taking on most of the work within their group. Thankfully, the teams started acting like teams only in the last few weeks, finally making progress as a result of the arrival of the supplies. The fun also started when parts were received, allowing us to be actively working on construction.

Issues & Problems

- Completing payload before the end of the semester.
- Having lab space available.
- Lack of communication between teams.
- Delays in acquisition of parts.
- Problems in converting 28 VDC to 5 & 12VDC and not exceeding the permissible current.
- Team members lacked the necessary knowledge needed to carry out an experiment.
- Due to clashing time schedules, long distance commuting, and in some cases, lack of commitment, members within the group were at times unable to help or participate with activities. This significantly weakened the workforce and hence the team could not perform efficiently.
- The instruments needed were ordered later than scheduled due to the team's inability to readily recognize the instruments needed for the task at hand; this stalled our progress.

Achievements

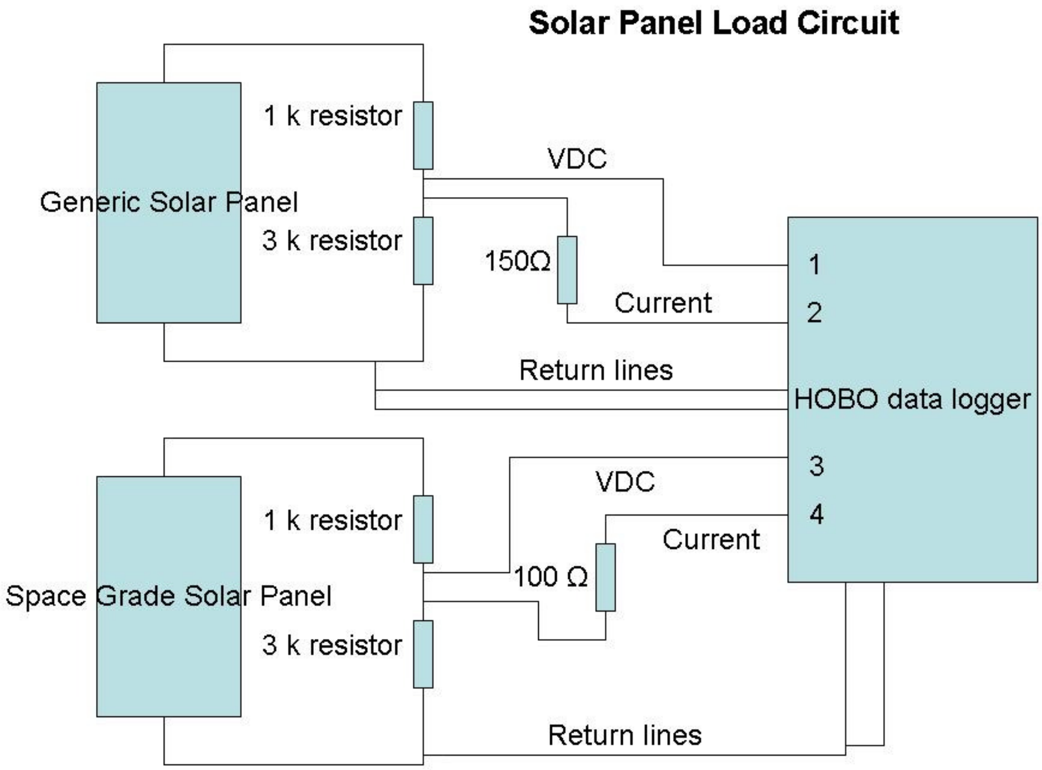
The first positive thing that happened was the arrangement of the groups, and with in two weeks each individual group was fully functional. Although the communication was neglected in the beginning, slowly inside of the groups conversation began to grow. After a few weeks each group was communicating pretty well and the necessity for the team as a whole to communicate became aware. The teams continued, throughout the project, increasing their inter-team collaboration. At the end of the semester, each team has no reserve in talking with any other member or with outside advisors. After two different class sessions, or meetings, groups were reorganized and parties were set aside to track progress. Schedules were laid out, budgets were set, and reviews were given by each team weekly. A final group discussion was conducted a few weeks from the end of the semester to help fine tune the skills we learned so that if need be we could continue the progress of the project throughout the summer semester. The teams also learned, in a very short period of time, how to use the equipment they had purchased and what equipment could and would work. Each student that has worked on the payload has become an essential part of the group and has taken great pride in the payload which is our biggest achievement. Finally our payload has started to take shape and the confidence level of the teams of students is high. Completion seems just a little further away.

Advice to Future Teams

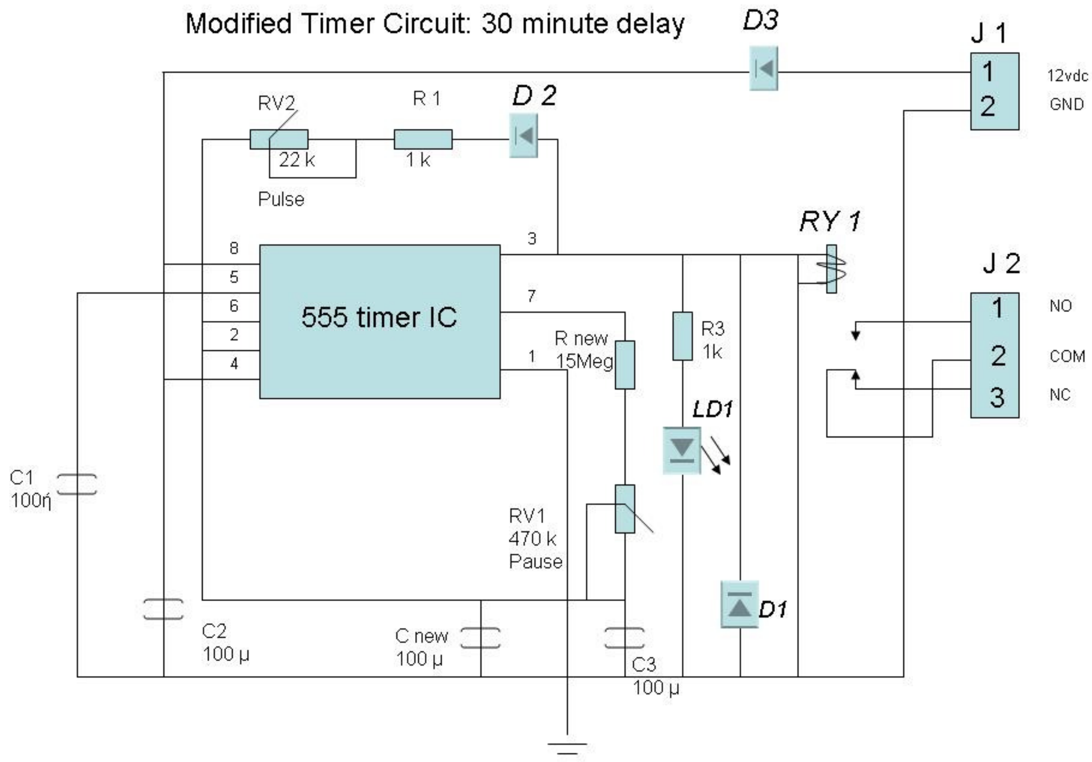
- Find out each of the strengths of the people in your Team. Everyone has something important to offer and will fit into a specific job.
- Brain Storm with the entire team .Know exactly what everyone wants to do.
- Maintain open lines of communication
- Keep a constant log of progress every time team meets including photos
- Design your experiment completely including all components. Make sure all teams know what the other teams want to do and what they want to use. Have one design team that includes a member from every area of the project.
- Take as little time as possible ordering parts that fit your design concept. You don't want the shipment of parts to delay the building.
- Find proper facilities to assembly project before starting with all equipment and tools need to perform at maximum efficiency.

The Build

Four interns were handed the project in early June with a box full of parts, a CD with the HASP project requirements and documents written by the UMES class. To say we were overwhelmed would be an understatement. There were four of us and one colleague from the UMES class would be joining the intern team in two weeks. The first order of business was for each team member to read all documents to familiarize ourselves with the project and break apart into sub teams. Lisa Dean and Tycora Brown will take on science experiments and procedures, Chip Choquette and Pete Arslanian will tackle electrical engineering. Mike Dunn the holdover from The UMES class will handle the management aspect the project depends on. This seemingly straight forward and small project to seasoned veterans in the aerospace engineering family is providing five very junior engineering, science and management students with a great platform for application of learned disciplines.

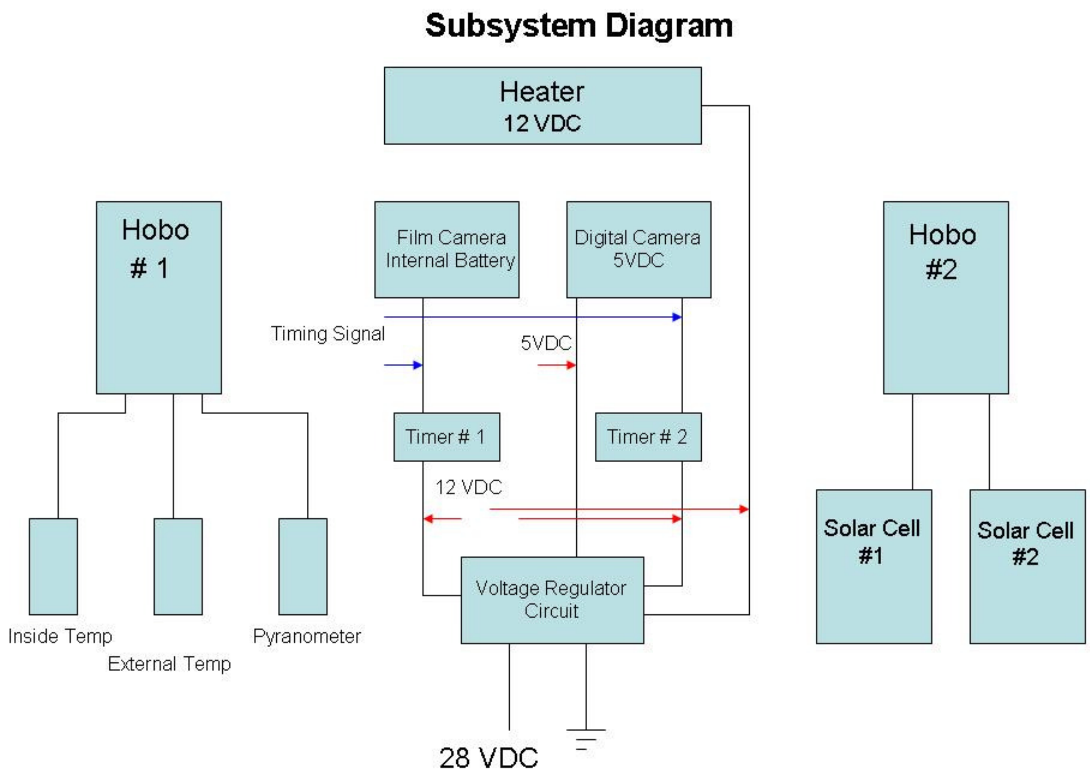


By week two the gears were humming along, the science and procedure team had studied the solar cell-radiation experiment and began writing procedures for a successful flight and data collection. The electrical team was busy designing a voltage regulation circuit for the dependent camera experiments and heating requirements. The procedures for flight went along smoothly with almost daily revisions. The solar panels were a little more difficult; the lesser quality panel had to be reduced in area to fit in the allotted area on the exterior of the HASP structure and connected to electrical wires for data collection. After many days of trial and error the solar panels; high quality and lesser quality were outputting a measurable voltage and current value that would fulfill the radiation experiment. The next order of business was to mate the solar panel data to the data collection devices that had their own parameters of values allowed. This will be handed over to the electrical team that was finding some success in the power supply venture. Data collection for the pyranometer, solar panels and temperature instruments will be handled by a finicky device called a HOBO. This device demonststed interference with some instruments and has a minimum and maximum input value that has the electrical team up at night but ultimitly solutions were relized and the ball is still moving to our ultimate goal. The electrical team has found a simple solution to divide the delivered voltage and current to the values the subsystems demand. Of the shelf voltage regulators and a simple assortment of capacitors and diodes will keep current draw under specified maximums. The timing of the digital camera is set at 45 seconds and the supplied timing circuit accomplishes this task with astonishing regularity. The still camera has only 40 exposures, to meet the 20 hour flight requirement a modification of the still camera timing circuit is necessary. A minor change in the resistance and



capacitance in the circuit will change the timing signal from a maximum of 60 seconds to 30 minutes with dependable accuracy.

We are now three weeks into the build and the HASP experiment has to be completed in



two weeks for integration. The pressure is on and many of the major hurdles have been cleared with the final assembly to take place. A blueprint was designed with all components fitting nicely in the compact frame. When the time came to fit all the subsystems it quickly materialized that some components would have to be rearranged or modified to squeeze into the quickly diminishing space. Weight considerations were always on our minds for the entire build and at this time every piece of excess material is quickly being shed. The one kilogram limit is met with a six gram deficit on the last day before environmental testing and subsequent delivery to integration. The build team has done an exemplary job up to this point and grown as young students with this very ambitious project. With a bit of good luck solid results will be returned and the learning process will continue with the analysis of the data.

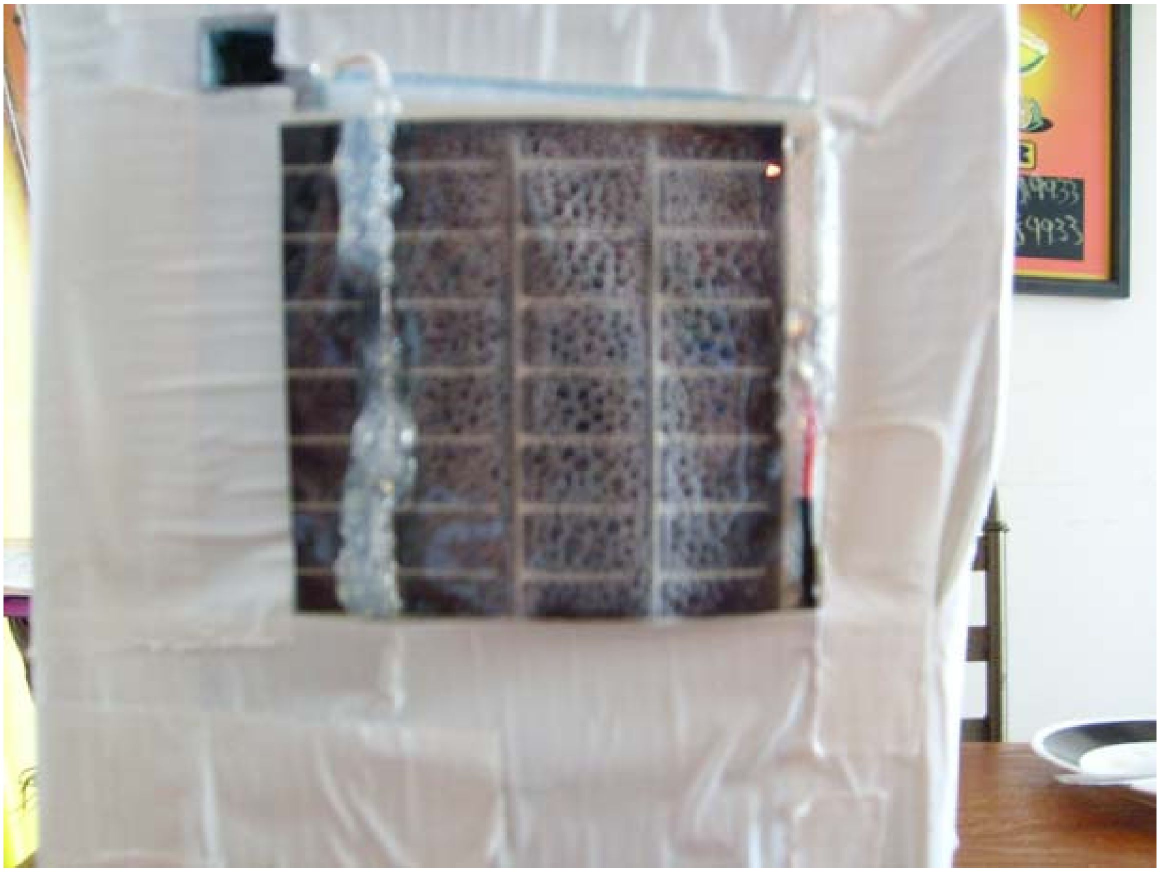
The Launch

The HASP Structure- The structure launched between 7 and 7:30 am on the 2nd of September 2007. Pre flight began around 2:30 am with a power and telemetry test. Afterwards the HASP was attached to the launch device "BIG BILL" and the outside panels were secured.

System checks were done periodically during transitional phases of the preflight.

System power was applied to UMES/HISS Hawk HASP at 6:05 am. Power was applied the digital cameras the power regulator and the timing circuits by LSU. The two data loggers were turned on as well as the one film camera by students of UMES. A final check was done at 6:15 am. The Balloon launched between 7 and7:30 am. The flight time was about fourteen hours.

In flight it was found that a small tear had occurred in the balloon. The affects of this on the launch are unknown at this time. The balloon landed in an irrigated field and sustained some damage. Most of the damage to the HASP structure happened during the removal because the ground conditions the retrieval vehicle had to drag the structure out to an adequate loading location.



On the flight line at to carry out the flight procedures and pre- release check list were Mike Dunn and Andrew Grizzle, Pete Arslanian was present prior to flight, testing and reconfiguring the subsystems to ensure a successful mission. The UMES/HISS experiment module accompanied the flight team back to the eastern shore and was opened on Sunday Sept, 16 2007 to reveal the data that was collected. Upon first inspection the low grade solar panel that is part of the solar panel efficiency experiment has considerable damage to the internal construction of the solar cell. The data loggers that recorded the solar panel values show no identifiable anomalies to pinpoint when this event took place. The Pyranometer data to correlate the solar panel values is intact; we are sure that after careful examination of all data, answers to these questions and others will be revealed. To date only one four hour examination of data has taken place. Other known failures are: the digital camera ceased operating around 60,000 feet, again after examining all data we will be able to pinpoint all failures and triumphs. The still camera succumbed to an unknown fault and the film has yet to be retrieved, successive known good batteries have been installed with the camera failing to turn on. An indication of battery power will let us know how many pictures were taken and the status of the film roll. The internal temperature readings for the ascent show that internal temperature held at 40 degrees F, so why did both cameras fail? All values collected on the HOBO data loggers looks very good, after the data from LSU is provided ,"The White Papers",(rise time, voltage and current values) a thorough explanation will be revealed for the 14 hour flight. At the initial examination power was applied to the HASP project to see why the digital camera failed and all systems checked out. The camera turned on and started to take pictures, the current draw was the same as it was prior to flight so nothing electrically failed. The still camera will be examined by the university film department to extract the film intact and answer some questions as to why it failed.

Conclusion

The amount of work to field a small payload with very simple experiment takes an enormous effort that is only a fraction of the energy needed to produce a working payload that would be attributed with NASA or the extended aerospace, scientific community. Challenging a university class and summer intern teams with projects of this nature empowers young students with the real world experience needed to enter the competitive field they are eager to join.

For more information on the UMES/HISS Hawk HASP high altitude balloon payload, see http://laspace.lsu.edu/hasp/

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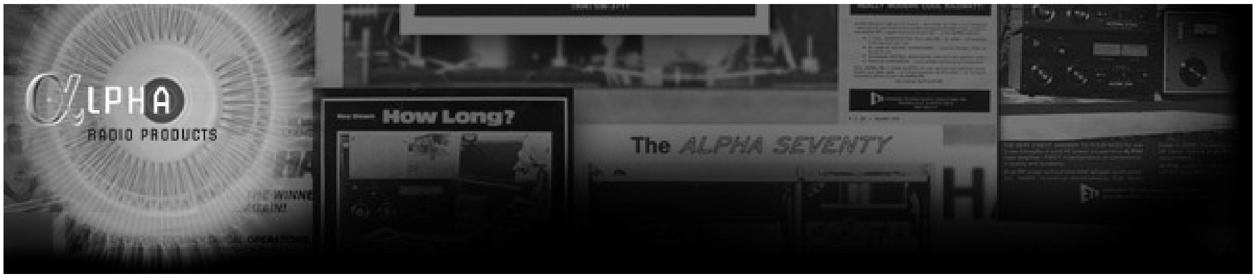

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