AMSAT®

Radio Amateur Satellite Corporation

Proceedings of the

AMSAT - North America

2006 Space Symposium

and AMSAT-NA Annual Meeting

San Francisco, CA October 5 – 8, 2006

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Contents

Dedicated to

Clifford C. Buttschardt

Clifford C. Buttschardt, K7RR (formerly W6HDO and Cliff to those of us who were lucky enough to know him) became a silent key July 30 2006. With his passing, Project OSCAR and the amateur satellite community lost one of their most ardent supporters.

Cliff was a lifetime member of both AMSAT and the ARRL, and a long time member of Project OSCAR. Cliff held the post of Vice President Emeritus of Project OSCAR and holds that position in memorium. He was a professor at several universities, and beyond that a dedicated merchant mariner.

For those of who knew Cliff throughout his life, his passing was a sad moment. Cliff mentored all he met, and he touched us like a father – he helped us find our way, and gently scolded us to stay on the right path.

Cliff left behind a legacy of mentoring many of us would only hope to rival – and inspired us who chose to mentor to follow his strong example. His constant energy as a teacher, mentor, and friend compel us to honor him today.

In his final days, Cliff was awarded Project OSCAR's highest award – the lifetime achievement award. He was also honored by California Polytechnic University - K7RRSat will one day fly. Godspeed, dear friend.

During the Banquet, we will ask that you give Cliff your thoughts and prayers in a moment of silence for this champion of the amateur satellite service.

Thank You!

AMSAT would like to acknowledge the following companies and individuals for their generous support of the 2006 Space Symposium.

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Welcome to the beautiful San Francisco Bay area and the original home of Amateur Radio Satellites!

I believe you will find this year's AMSAT Symposium exciting and informative. Project OSCAR members are very excited about hosting the 2006 AMSAT Symposium. I especially want to recognize Emily Clarke, N1DID and the members of her committee for their dedication toward making this a very successful event.

Much of the original foundation and history of amateur radio satellites started just a few miles from here by young Hams who were also involved in designing and building satellites for the government. They built and flew OSCAR I, II and III, and worked with the TRW Radio Club to help launch OSCAR IV. Some original Project OSCAR members are planning to be in attendance. I hope you get a chance to meet them and thank them for their vision, so long ago.

We have some of the original Project OSCAR history on display to remind us all just how far we have progressed in the 45 years since OSCAR 1. Please be sure to stop by the Project OSCAR exhibit and see the OSCAR III spaceframe and other memorabilia we have assembled. I am sure some of the exhibit will bring back fond memories for many of you.

Friday, Saturday and Sunday morning will be filled with interesting presentations covering everything from satellite Antennas to Software defined radios. We look forward to a lunchtime appearance by Gordon Hardman, W0RUN, a member of the OSCAR 7 team who will provide a special presentation about his experiences on the Peter I DX-Pedition. And Dr. Scott Sanford will give us a special presentation on the Stardust mission on Sunday. We hope you will find the Symposium a special time to catch up with friends and enjoy the presentations of your choice.

Those who attend the Saturday evening banquet will get a rare chance to listen to ISS Expedition 12 Commander William (Bill) S. McArthur, KC5ACR. Many of you probably made contact with Bill when he was cruising along at more than 17,200 mph working all states from the ISS. Others of you probably heard or worked him in the many other countries Bill communicated with, from space.

Please take time Sunday to see some of the bay area and take advantage of the tour and presentation at NASA Ames in the afternoon. We are extremely pleased to welcome Dr. Scott Sanford, NASA Principle Investigator, who will give us a private presentation at NASA Ames about the Stardust collect and return mission.

It is with great pride I welcome you to our California home, and please call on any of the Project OSCAR members present if we can assist you in any way to make your visit more pleasant and rewarding.

Have a great time!

Don Ferguson
President, Project OSCAR

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September 15, 2006

Dear AMSAT Member:

Welcome

It is great to be back after missing the Symposium last year due to the effects of Hurricane Katrina. This year we are fortunate to be the guests of Project Oscar Inc. that was formed in 1959 and is responsible for building and launching the first four OSCAR satellites.

This past year has been filled with exciting developments. The AO-51 satellite has performed superbly, giving many Hams their first opportunity to operate a satellite and others their first opportunity to try new modes and bands. The development of the P3E satellite in Germany and the Eagle satellites have taken some interesting turns, especially with the inclusion of software defined transponders (SDXs) as superior performing replacements for the old familiar analog transponder implementations. A demonstration of this new transponder technology at Dayton impressed all who tried it.

AMSAT's Web site and Web store have continued to evolve to serve our community better than ever before. AMSAT's efforts in support of the SuitSat mission were recognized worldwide by most newspapers and hundreds of trade journals. Dozens of schools and thousands of students, teachers and observers have experienced the thrill of communicating directly with astronauts on board the International Space Station.

The coming year will be equally exciting. We are hard at work to have P3E ready for flight. Eagle will begin to take shape with its new structure and electronics. We will be ready for an expanded SuitSat mission and new capabilities are planned for the Space Station. New software is under development to allow improved capabilities on AO-51. We are working on a new satellite integration lab. We are working hard to build new relationships with academic and government groups that will expand AMSAT's influence and prestige, and will bring new scientists and engineers with fresh ideas into our projects.

This is an exciting time for AMSAT as we start to see initiatives take shape and ready ourselves for a new era. I am very proud of all those who are helping to carry AMSAT into the future. I hope that when you leave this Symposium you will be reinvigorated and excited about the future and that you will ask yourself how you can contribute to AMSAT. We invite you to become a part of this bright future and give something of yourself back to this wonderful hobby.

'73

Richard M Hambly

Richard M. Hambly, W2GPS
President

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Our Keynote Speaker -

Expedition 12 Commander William S. McArthur, Jr.

AMSAT is excited to announce that our 2006 Symposium Keynote speaker will be astronaut **Bill McArthur, KC5ACR**, *ISS Expedition 12 Mission Commander and Science Officer.* Commander McArthur is well known to ham radio operators and during his six months aboard the ISS he became the most active radio amateur ever to serve aboard the ISS. Commander McArthur logged more than 1800 QSOs in space, including logging a Worked All States Award. His impressive track record also included a record 37 school contacts, Worked All Continents (including Antarctica) and 130 DXCC entities.

Born and raised in North Carolina, McArthur attended the United States Military Academy and earned his commission in the United States Army. After serving with the 82nd Airborne at Fort Bragg, McArthur attended the U.S. Army Aviation School and served tours of duty in Korea and Georgia (where he earned a degree in aerospace engineering from the Georgia Institute of Technology).

In 1987, McArthur attended the U.S. Naval Test Pilot School and was trained as an experimental test pilot. He was assigned to a post as a test engineer at NASA and was selected as an astronaut candidate in 1990. A Master Army Aviator, Commander McArthur has logged over 4500 flight hours in 39 different aircraft and spacecraft. He has been retired from the US Army since 2001.

Astronaut McArthur is a veteran of four space flights that include:

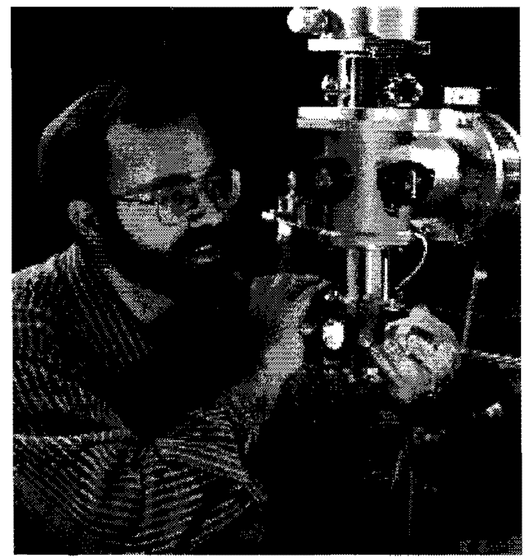
- STS-58 - October 1993 (Spacelab Life Sciences Mission 2)
- STS-74 - November 1995 (Shuttle-Mir Docking Mission 2)
- STS-92 - October 2000 (ISS Assembly Mission 3A)
- Expedition 12 - October 2005

In addition, Bill has made four spacewalks (two each aboard STS-92 and Expedition 12) and was on the backup crews of Expeditions 8, 9 and 10.

Commander McArthur is the recipient of a number of prestigious awards and honors including the Distinguished Service Medal, the Defense Superior Service Medal, the Defense Meritorious Service Medal (First Oak Leaf Cluster), the NASA Space Flight Medal, and the NASA Exceptional Service Medal.

Our Sunday Special Event -

Dr. Scott Sandford



On Sunday from 12:30 to 16:30 we have arranged a special trip to the **NASA Ames Exploration Center**, located at Moffett Field in Mountain View. Visitors can experience NASA technology and missions first hand, recently added a number of fresh and exciting exhibits open to the public at no charge.

AMSAT is very pleased to announce that **Dr. Scott Sandford**, *NASA Principle Investigator and co-director of the NASA Ames Astrochemistry Laboratory*, has accepted our invitation to provide a key presentation during our tour of the Ames Exploration Center. Dr. Sandford will speak about sample return from comets and asteroids in general and specifically about the Stardust Sample and Return Mission to Comet Wild 2.

Dr. Sandford was one of the original team members to propose capturing dust from a comet and bringing it back to Earth. Stardust was launched in February 1999, and in January 2004 approached Wild 2 within 150 miles of the nucleus, collecting samples and capturing detailed imagery of the comet's surface. On January 15th 2006, Stardust re-entered the Earth's atmosphere and successfully completed its mission after landing in the salt flats of northwestern Utah.

For Dr. Sandford, the investigation is just beginning as he and a team of 180 other scientists are hard at work to analyze the Stardust samples. This team will likely spend years unlocking secrets from the samples. Their efforts will lead to a better understanding about the formation of our solar system and perhaps even the origin of life on Earth and elsewhere in the Solar System.

SkyWave, Ionosfera and RATS

Radio Amateurs Efforts in Ionospheric Studies

Presented by

Florio Dalla Vedova, IW2NMB

Abstract

Radio-amateurs have always been involved in research on ionospheric propagation. Amsat-Italia ideated and developed since October 2000, a spaceborne programme to contribute to the international research effort on Space Weather and Ionosphere.

This programme is divided in three sub-projects: **SkyWave**, **Ionosfera** and **RATS**.

These are presented in this paper together with actual status, results achieved so far, and future plans.

Authors

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Fabio Azzarello, IW8QKU

Paolo Pitacco, IW3QBN

AMSAT-Italia

1 Introduction

AMSAT-Italia since the end of the year 2000, initiated a space-based programme aiming to contribute to the international research effort on Space Weather and ionosphere. The programme is divided into three sub-projects: **SkyWave**, **Ionosfera** and **RATS**.

In brief, **SkyWave** is the space segment of the programme : it is based on a small LEO satellite that will carry one or more scientific instruments for the investigation of the ionosphere. The satellite will obviously also carry at least one radio-amateur transponder!

Ionosfera is the ground segment of the entire mission: it consists basically in a website that will keep the international community informed on the state of the SkyWave mission. In this website (which exists already), the visitor has also access to several services relating to the prediction and analysis of the HF DX radio paths. Moreover it allows users to obtain current information on the state of propagation through ionosphere and about the Space Weather conditions.

The data required to perform predictions and analysis made available on the web site, will be collected mostly by Skywave and its payloads, but also from the European Space Agency (ESA) Space Weather data infrastructure, called "SWENET".

And lastly, **RATS** is the (main) scientific payload proposed to be embarked on SkyWave and also planned to be developed within the radio-amateur community.

Because of our strong desire to give birth to a fruitful relationship between Radio-amateurs and Scientists studying the ionosphere, our projects have been presented (and appreciated) in the two last General Assemblies of the International Union of Radio Science (URSI)

2 SkyWave

Project SkyWave was initiated by AMSAT-Italia in October 2000 with the intention to develop a satellite system which would :

1. be valuable for the Satellite but also for the HF DX Radio-amateur communities
2. hopefully also support the scientific community working on the ionosphere, hence (re-) tightening the relationship between Radio-amateurs and Scientists

Our idea was to design and build a satellite with radioamateur transponder(s) but also with some additional scientific instrument(s) that, by providing and analyzing their data together with the Scientists, would allow (us) a better understanding of radio propagation through ionosphere.

So, in order to define the satellite mission and to be able to put its capabilities within a broader programme on ionosphere study, we collected and analyzed a large amount of information on similar missions. This work allowed us to better understand already proposed mission concepts and instruments.

The study of the various reference missions relating to ionosphere provided us indeed with consolidated information about orbits of interest, kind of instruments useful to this type of mission and other general features of these spacecrafts.

By our study we noticed for example that most of these missions were based on small satellite, such information resulted highly valuable to us!

Considering all of this, our preliminary estimates led to the conclusions that our satellite could weight between 50 kg and 125 kg, this weight makes SkyWave to be of the microsat satellite class.

This class of satellite is familiar to the AMSAT Radio-amateur community as we have built and orbited not few satellites of this kind. Experiences made on those spacecrafts give us a good background on the subject.

To determine the best compromise for the mission we investigated different scientific activities that could be performed aboard SkyWave. Among various options proposed initially, we finally decided to (develop and) implement a Topside Sounder as scientific payload for SkyWave. This led us to start the design of a completely dedicated, Radio Amateur Topside Sounder (RATS) whose preliminary tests will be introduced in a following section.

But, to be an amateur satellite, SkyWave has also to meet Radio-amateur's typical interests! We then selected a nominal orbit that provide global coverage of Earth to allow all radio-amateurs to access satellite, still allowing to collect valuable data on the entire ionosphere.

In brief, the nominal orbit specifications are as follows:

- Circular orbit at about 1000 km height.
- Polar inclination (it doesn't have to be necessarily sun-synchronous)

3 Ionosfera

Aimed originally as the central point of our satellite data collection and distribution, the SkyWave project website became a reality thanks to the European Space Agency (ESA) framework of activities on the Space Weather.

ESA indeed in 2001 invited any interested entity to develop a serie of web-based services relating to this emerging and multi-disciplinary science.

Being the ionosphere a direct product of the Sun-Earth interactions (hence a Space Weather topic), used by Radio-amateurs to achieve long-range radio-communication links, and considering our goals/expertise with the SkyWave project, AMSAT-Italia answered with a proposal ... which was appreciated and selected by ESA !

The website project received the name of "Ionosfera" and it can be visited at the following URL : http://esa-spaceweather.net/sda/ionosfera/index2.htm

Ionosfera proposes itself to increase Public awareness on Space Weather thematics and on the other Pilot Projects. It also provides the user with two kinds of (free-of-charge) services:

- The provision of operational data on Radio-amateur communications and on Space Weather RF effects. Such information could be used later on by Scientists to consider the ionosphere from another point of view and to improve, by integrating it with other available data, their scientific models.
- A series of tools allowing to predict/understand (in real-time) long-range HF DX radio-communication links.

Of particular interest is our **Propagation Prediction Tool** !

We indeed wanted the website to be practical and based on the analysis of our data. So, we invited the world-wide HF DX community to provide us with log files compiled over a given period of interest. Data collection was difficult but we finally succeeded in collecting about 120.000 QSOs from 16 OMs sparse over the world. (TNX to them!)

By relating (see the graph below) these QSO data with some Space Weather indices we noticed that peaks of Radio-amateurs and Space Weather activities never coincided ... We were then able to define a simple index and with it, to quantify a limit over which, HF DX becomes more and more difficult to achieve.

The Propagation Prediction Tool is available on the Ionosfera website in the form of traffic-lights: if it turns green, go for HF DX! If not ... then it is better you do something else ;-)

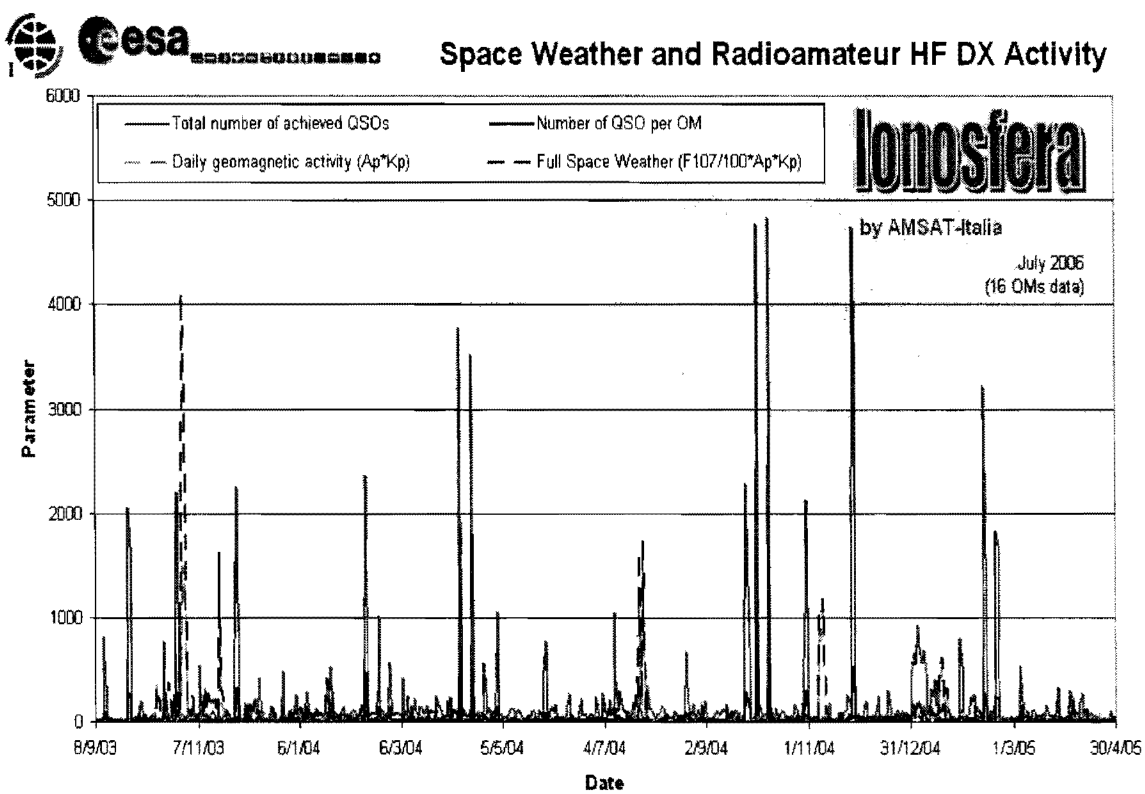

Figure 1 : Preliminary Results obtained from the Ionosfera Project

4 RATS

RATS stands for Radio-Amateur Topside Sounder. It is meant to become the Scientific payload onboard SkyWave as a replica (upgrading when possible and/or required) of the Alouette/ISIS (frequency sweeping) Topside Sounders.

Our effort on designing and developing RATS basic functions started with the master RF signal generator. We choose a new approach, using Direct Digital Synthesis (DDS) techniques to generate, control and command the carrier frequency necessary for sounding. With this approach, we intend to make a reliable and very precise and stable signal for the transmitted and received block of RATS.

Our effort was primarily devoted to verify feasibility of simple circuit for transmitter part, and next to apply same parts to receiver (for conversion master oscillator).

For test we have designed and built a first single, simple board, in order to check and validate our ideas; a single DDS chip from Analog Devices was used to generate a carrier from 0.1 and 20 MHz. This board is controlled externally by PC with parallel port, and is capable to generate a good spectral signal around entire range of interest.

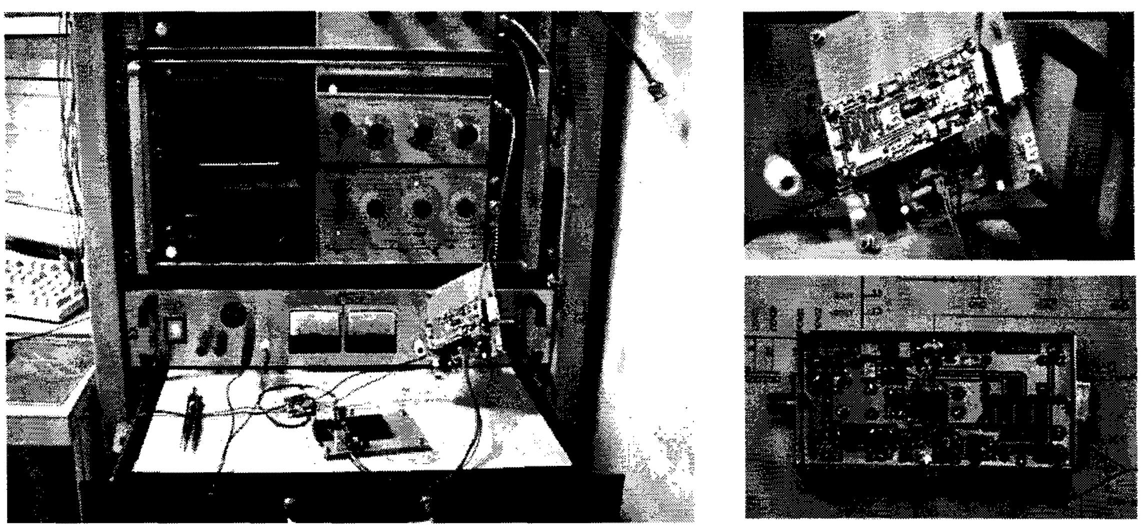

Figure 2 : Boards and First Tests on RATS

On another board, we used a small microcontroller (from Atmel) for frequency settings of the DDS, checking speed and settling time; next we reloaded a software for production of BPSK signal at various data rate.

Some PRN sequence was then used to verify the produced spectrum and all tests were successful.

On all boards and test performed, we were able to set the frequency with an accuracy below 1Hz, with more than 70dB of spurious product down.

For RATS we have to produce a sweep signal (not only fixed), so the following step was to test this purpose. With our boards, we have a step-sweeping capability (change of DDS frequency in discrete step) with some time limitations (max speed for frequency programming) so a new chip was selected in order to obtain more linear performance.

This new chip is more powerful with dual (quadrature) output; this will be extremely useful for receiver section, as feed of rejection mixer. Recently, we received some samples from Analog Devices and a new board design is on-going for new tests.

Beside electronics, the accommodation of RATS equipment has also been investigated. Topside sounders indeed require the in-orbit deployment of long booms used as antennas.

A search for long and tiny, in-orbit deployable booms was carried on and resulted in the pre-selection of the (US) STEM tip drum mechanism. By attempting to integrate four of these mechanisms in a double dipole configuration within the typical AMSAT microsatellite structure, we noticed that such accommodation could be compatible with a 30 cm wide square tray.

Such accommodation of the four booms mechanisms is shown below:

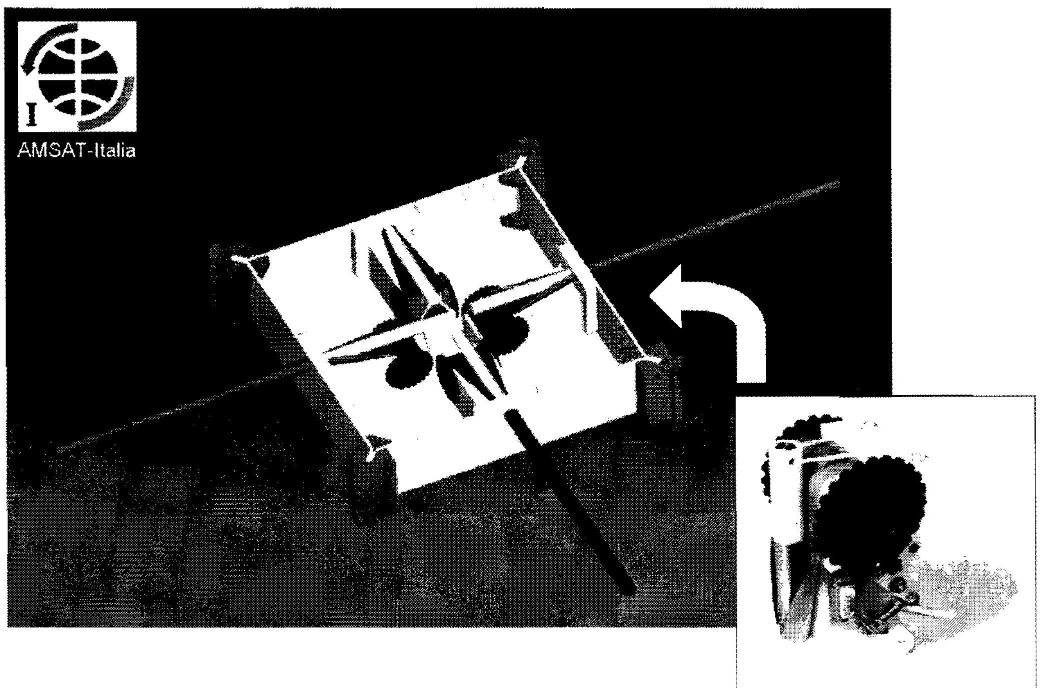

Figure 3 : RATS Antennas Tray with STEM Tip Drums

5 Future Plans

In fact, we plan to develop and launch SkyWave for the 50th anniversary of the launch of the famous Alouette-1 satellite in 2012. For that date, ways to implement SkyWave in support to the Olympic Games (in London) will also be investigated and proposed very soon.

Concerning Ionosfera, we are very proud to announce the AMSAT community, the invitation made by the Rutherford Appleton Laboratory (RAL) to collaborate with AMSAT-Italia on the analysis of the collected QSOs in the light of Space Weather!

Future plan is mainly to pursue all this ... as one of the next world-wide project of the whole AMSAT community. We believe, we are right in time and the programme is large enough to allow its decomposition in smaller projects to be assigned to the various national AMSAT societies.

One could do a part of RATS, the other a SkyWave tray ... If this programme and approach interests you, please contact AMSAT-Italia....You are *welcome !*

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PCSAT2, ANDE, RAFT and MARScom Satellites using AX.25 Packet Radio

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Abstract

PCSAT2 was activated on 3 Aug 2005 and deactivated about 2 Sept 2006 after one year in orbit attached to the outside of the International Space Station by the crew during EVA's. PCSAT2 and our next spacecraft, ANDE , RAFT and MARScom are follow-on digital communications payloads to the highly successful PCSAT-1 [1] that was launched on 30 Sept 2001. These satellites all use off-the-shelf standard AX.25 Packet TNC's for command, control and telemetry which greatly simplifies student payload design. ANDE, RAFT and MARScom are currently at Kennedy Space Center for integration with mission STS-116 currently planned for launch about mid December 2006.

These student built Amateur Satellite missions have taken advantages of synergisms in the Amateur Satelite Service, Student Education and experience, and science sponsors while operating within the rules of the Amateur Satellite Service[2]. MARScom is an experimental communications satellite for the Navy and Marine Corps Military Affiliate Radio System which is also operated by radio amateurs volunteers in that organization.

The original PCSAT-1 was a complete success and it has been used by thousands of users in its first 19 months of flight. It validated the viability of using off-the-shelf AX.25 for all Telemetry Command and Control as well as supporting a bent-pipe user communications mission. This paper summarizes the lessons and experiences with spacecraft operations from PCSAT-1 and PCSAT2 and anticipation of lessons learned from the upcoming ANDE, RAFT and MARScom missions.

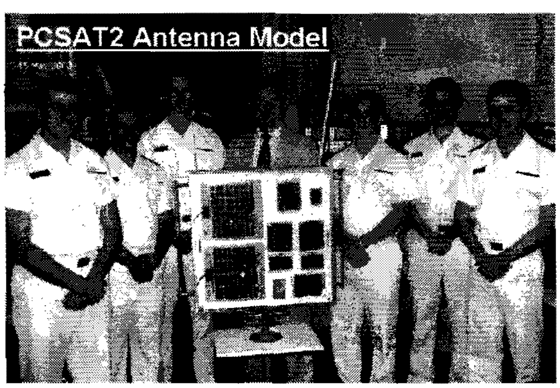


Figure 1. PCSAT2 Team at the Naval Academy

The PCSAT APRS Mission

The digital communications mission implemented in PCSAT-1, PCSAT2, ANDE, RAFT and MARScom is a generic mission using the ubiquitous AX.25 protocol used in many of the satellites in the Amateur Satellite Service. The digital transponder provides real-time message, position, and status relay via satellite to a worldwide Internet linked amateur radio tracking system. Any amateur or university payload can support this mission by simply enabling the DIGIPEAT-ON function in any AX.25 compatible transponder (TNC). The users of such a relay system can be for Boats at Sea, remote environmental sensors[3], cross country travelers, expeditions, school projects, or any other users which are far from any existing APRS terrestrial digital network.

The AX.25 satellite downlink from this mission is fed into the existing worldwide Internet linked ground system by participating ground stations. Our ultimate objective is to have all such AX.25 satellites work together as a constellation of digital transponders to provide connectivity to everyone in the Amateur Satellite Service[4].

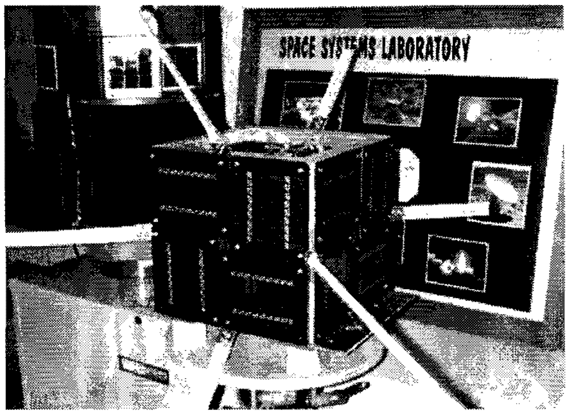


Figure 2. (PCSAT-1) with Antennas

The Space segment of PCSAT/APRS had been demonstrated a number of times in space via MIR School tests[5,6], the Shuttle SAREX[7], the SPRE mission, AO-16, UO-22 and more recently via SUNSAT and ISS and PCSAT-1 and 2. Full details of each of these missions can be found at:

http://www.ew.usna.edu/~bruninga/pcsat.html
http://www.ew.usna.edu/~bruninga/pcsat2.html
http://www.ew.usna.edu/~bruninga/ande.html
http://www.ew.usna.edu/~bruninga/raft.html
http://www.ew.usna.edu/~bruninga/astars.html

PCSATs' Mission Accomplishments

PCSAT-1 continues to operate after 60 months with no on-orbit failures except for the failed –Z solar panel on launch. This reduced power budget by over 20% caused a negative average power budget which keeps the battery system deep cycling during most eclipses. Still, PCSAT-1 is useable on every orbit if it is in midday sun. During the first 19 months of operations, it logged over 2000 users around the world and the global amateur tracking network fed all data live to the pcsat.aprs.org web page so that it was available to everyone participating live. See the PCSAT paper in last year's proceedings [8].

Also, PCSAT carried a successful GPS system which conducted several acquisition and accuracy experiments[9].

Design Validation

The following elements of PCSAT's design were validated and performed flawlessly:

- Dual Redundant payloads/systems
- Commands and Hardware redundancy
- Commercial Teflon coated solar panels
- Orbit temps within 10 deg variance
- Thermal design balanced within 5 deg
- Radiometer spin between .5 and 1 RPM
- Magnetic Stabilization
- Good link budgets
- Ground station Internet Linked system
- Fail-safe circuits and SEU recovery
- Discipline of User Service Agreement

The –Z solar panel failure was anticipated as it had had two problems during manufacture but was flown anyway because we had no backup.

AX.25 Digital Communications Protocol

An advantage of the AX25 protocol is that any node in the system can be used for relaying data between any other nodes. Thus, the TNC can not only provide the dedicated up and downlinks and command/control channels, but also serve as a generic relay for other applications on a secondary basis. Examples of TNC's on orbit are SAREX, SPRE, MIR, ISS, SUNSAT, OPAL, PCSAT-1 and 2, SAPPHIRE and STARSHINE-3. But PCSAT-1 was the first to use the TNC as the complete Spacecraft system controller with no other CPU's on board.

PCSAT2 HARDWARE REQUIREMENTS

PCSAT2 was designed around two KPC-9612+ Dual Port TNC's. These TNC's have all the latest APRS generic digipeating advantages as well as telemetry, command and control and can even cross route packets between ports and baud rates. By using standard off-the-shelf TNC hardware and FIRMWARE, on orbit risk was minimized due to the track record of thousands of identical hardware in use all across the country.

The dual baud rates of the dual port KPC-9612+ were used differently. The bulky solar experimental data was transmitted in short 1 second bursts at 9600 baud to minimize channel load while user communications took advantage of the 7 dB better 1200 baud link budget on the same port.

Further, the dual receivers and transmitters allowed for other experimental communications modes to be supported such as PSK-31 multi-user narrowband transponder and a voice FM repeater as shown in Figure 3 and later in Figure 7.

PCsat2 COMMS FUNCTIONAL BLOCK DIAGRAM

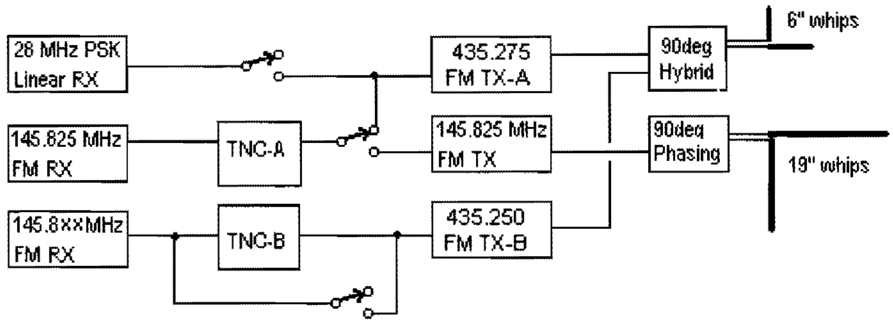


Figure 3. PCSAT2's dual AX.25 command and control system transponders can also be switched into modes to support PSK-31 and FM voice operation.

The PCsat 9600 Baud KPC-9612+

The Kantronics 9612+ TNC as used on PCSAT-1 and 2, has dual serial comm ports supporting both 1200 and 9.6 to 38.8 Kbaud. The 9612+ also offers 5 analog telemetry channels and a total of 8 configurable command or I/O bits, plus four ON/OFF command bits and one input bit. These features were sufficient to handle all of the Telemetry Command and Control for PCSAT-1 and PCSAT2 as detailed below.

PCSAT2 Design for Space Station

PCSAT2 was attached to the outside of the ISS by an Astronaut during an EVA. This presented many design challenges in the areas of power, safety and thermal. The PCSAT2 comms payload is in the back half of a suitcase like box that is opened on orbit to expose the new technology solar cells to the space environment as shown in Figure 4.

Figure 4. PCSAT2 "suitcase" during installation

The PCSAT2 solar panel is pointed straight "up" as shown in figure 5 and only gets whatever sun is available depending on ISS attitude. Fortunately, NASA likes to fly the ISS "up" most of the time, so this gives us good average power.

Figure 5. Location of PC2. on outside of the ISS

PCSAT2 EVA Safety Issues

Since PCSAT2 is on ISS, and was installed by an astronaut during an EVA, the man safety requirements were significant. The 2 watt transmit power for the PCSAT2 communications systems are considered a catastrophic hazard to an astronaut in an EVA suit. To assure safety, one switch and 3 more redundant power-inhibit contacts were required while the PCSAT2 was in the payload bay and while being handled by an astronaut. Further, once PCSAT2 was installed by a crew member, there had to be four additional transmit inhibits to prevent any inadvertent activation from the ground until the installing astronaut was clear of the device. This was accomplished via an additional 8 Hour timer and 3 more ground commandable inhibits.

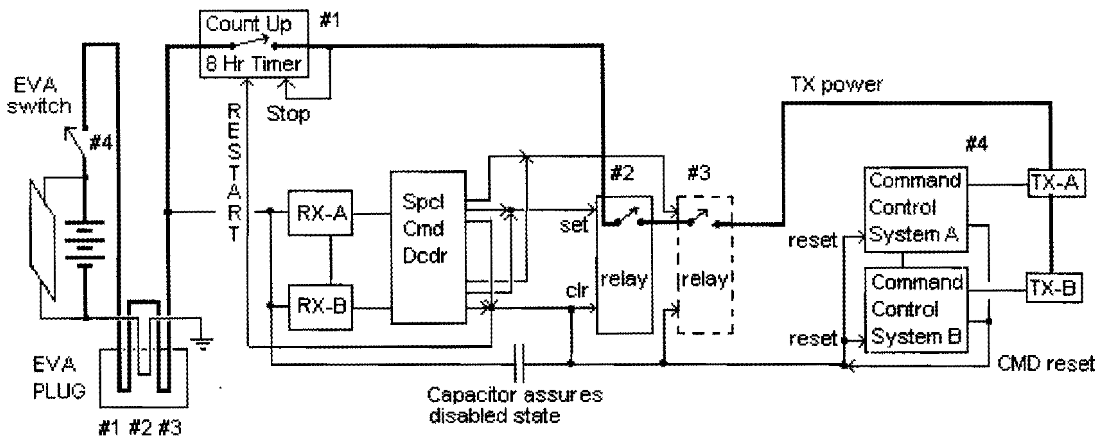


Figure 6. PCSAT2 Multiple transmit inhibits required for Astronaut Safety during EVA.

PCSAT2 PSK-31 Multi-User Transponder:

PCSAT2 was the first satellite to support a dedicated PSK-31 digital transponder[10] though the 3 year delays getting to orbit meant that the experiment was briefly carried out earlier using AO-51. Unfortunately, after only the first week of operation, the uplink power requirement on 29.4 MHz went from 4 to 100 watts and after about a month, no reports of any additional signal relays were received. This was disheartening because the PSK-31-to-FM mode offered so many advantages to users:

- Free downloadable software
- No unique hardware requirements
- FM dnlink so discrete 5 KHz Doppler was easy
- 10m uplink with under 1200 Hz total Doppler
- Multi-user simultaneous operations by dozens
- Lack of FM capture and uplink hogging

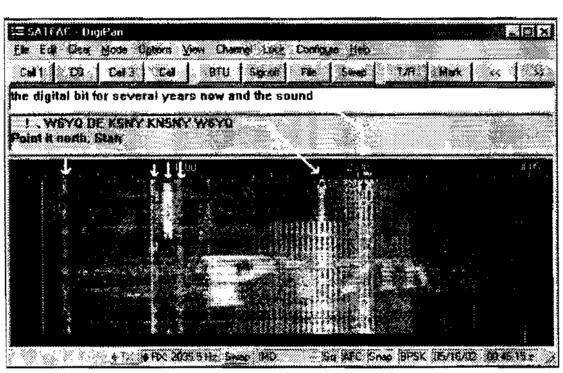
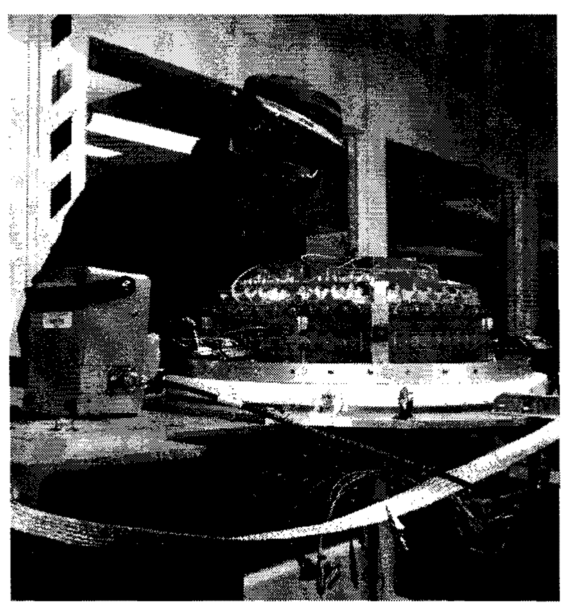


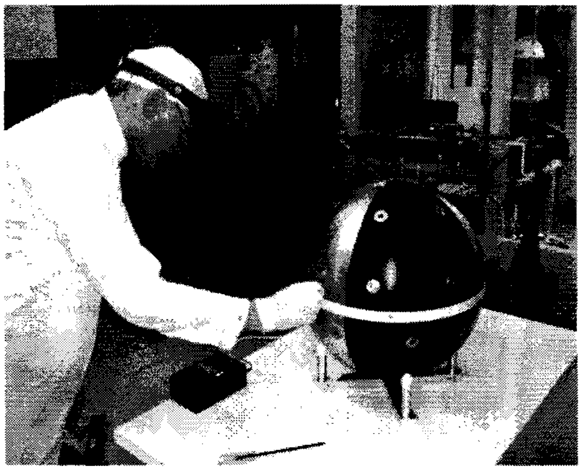
Figure 7. PSK-31 spectragram with 7 user signals.

ANDE Spacecraft Design

The ANDE spacecraft has no solar panels and no external antennas. We were able to get a ride inside the hollow perfectly spherical aluminum spacecraft by splitting the shell into two halves and using the shell as an antenna at 2 meters and by using 112 "D" cell lithium batteries.



The photo above shows the identical top and bottom stacks. Each stack consists of two battery trays and then a Comm tray and topped by a smaller laser module.

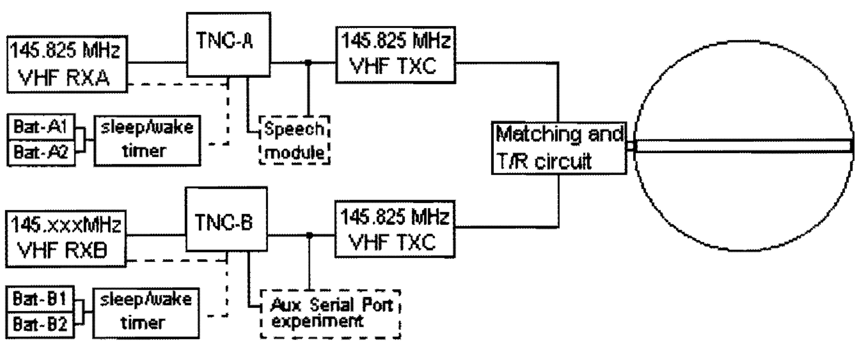


This photo shows the final SWR tweaks to bring the hemispheres into resonance. The antenna actually is more of a slot antenna formed by making 18 of the 36 bolts that connect the two halves be conducting and 18 of them being insulating and feeding the insulated half in the middle.

The black and anodized paint scheme is to make the spacecraft visible to high power telescopes and the small laser reflectors are for tracking by the Maui Laser tracking station. ANDE also has 6 orthogonal lasers that we can turn on from the ground to aid in visibility to telescopes.

ANDE COMMS Block Diagram

WB4APR



RF System: ANDE has two independed AX.25 Packet Command and Telemetry systems. The primary system operates like PCsat providing Telemetry on 145.825 and supporting users communications. The secondary is on unpublished frequenceis.

Antenna: Both systems are matched to the ANDE Sphere as a dipole antenna.

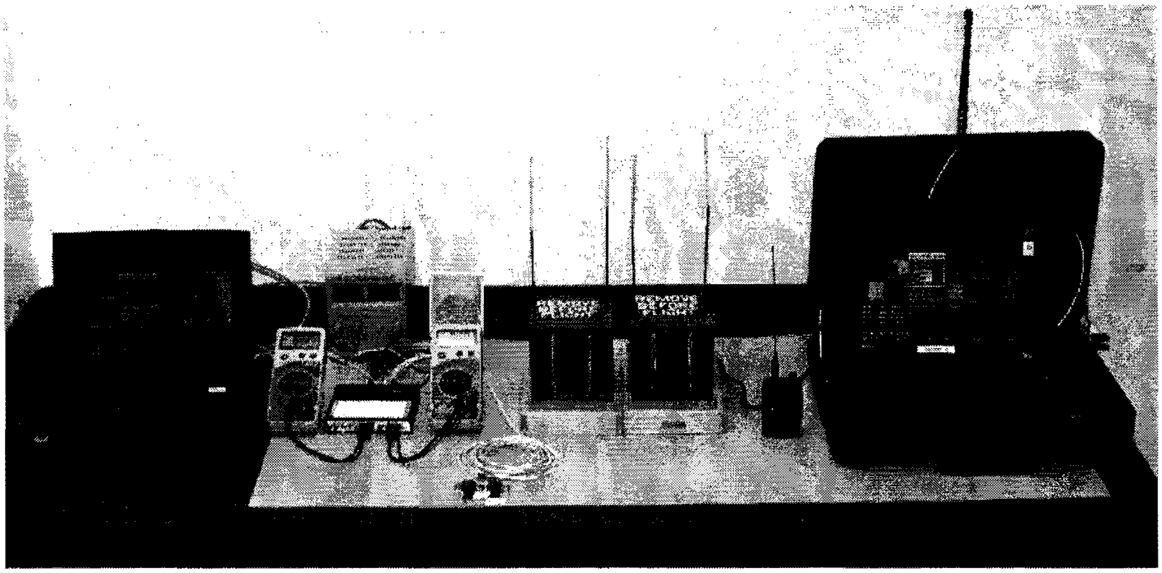
Telemetry: Each system A or B has several common telemetry items and a few items that are unique to each side.

Power: To save power, both systems sleep 90% of the time. The A side wakes for 1.5 secs out of every 15 and the B side wakes for 1.5 secs once a minute. If either detects activity, they will remain awake for a minute since the last signal heard.

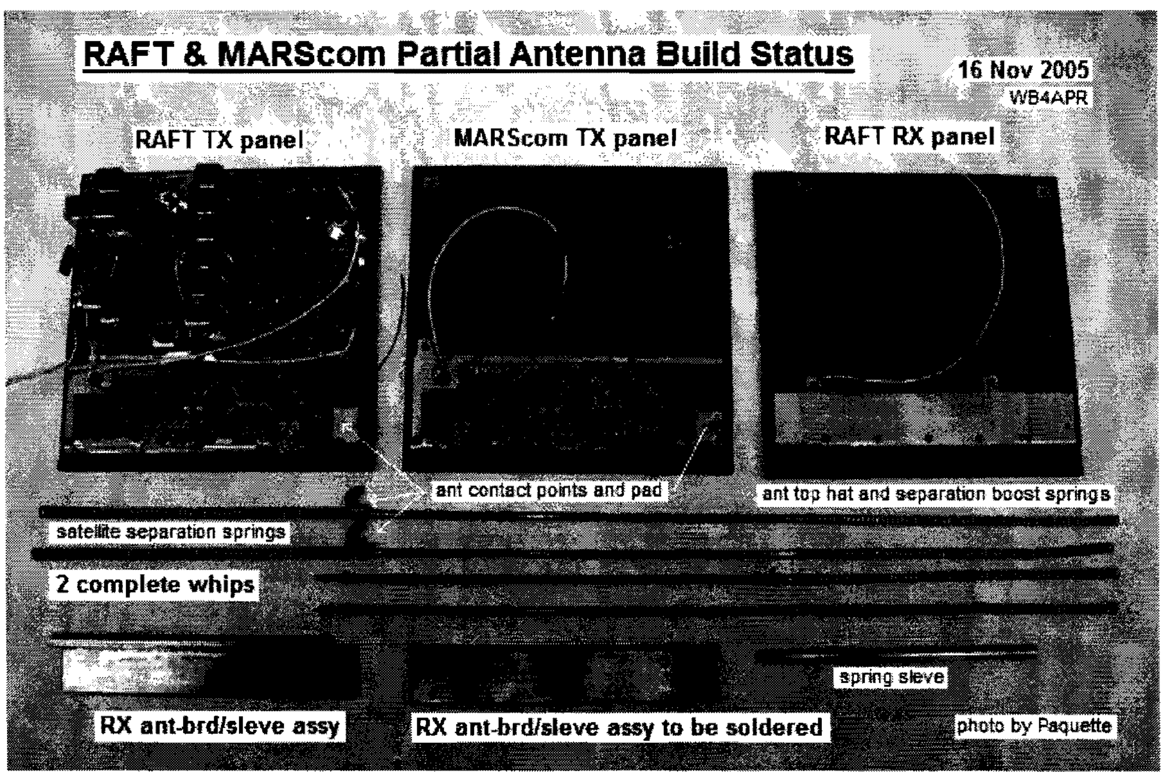
24 Feb 2004 http://www.ew.usna.edu/ande/ANDEblock.gif

The block diagram above shows the dual redundant command and control system based on a pair of KPC-3+ TNC's. ANDE also carries a test-to-speech module as an added experiment in packet-to-speech communications. The sleep/wake timers save power by keeping everything including the receivers off when not in view of ground stations.

Both transmitters feed the same spacecraft-shell/slot antenna system via a system of ¼ wave matching lines and PIN diode T/R arrangements. The lasers are not shown in this diagram.

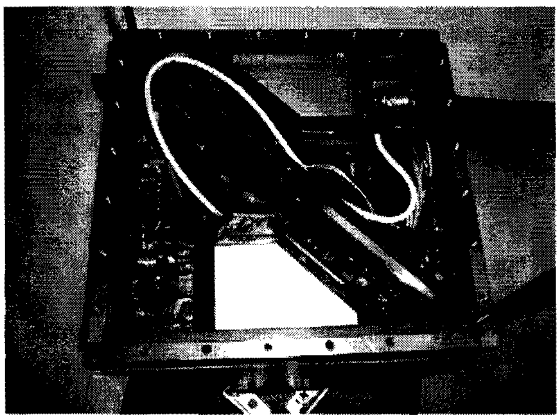


The photo above shows the RAFT and MARScom pair as they were delivered for integration and checkout. The labtop on the left connects via the umbilical for testing and the briefcase on the right is the complete RF ground station using a laptop and a TH-D7 APRS radio for the comms link. Each satellite not only has a pair of VHF spring loaded whip antennas to help separate them, but also a 4 foot deployable HF antenna.



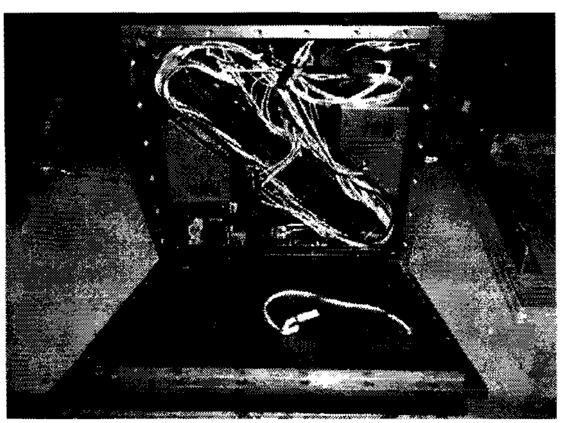
The photo above shows how we get a 10.5" whip deployed out of a 5" satellite by embedding the tip of one whip in the body of the other satellite. Not only does this give us ample space, but the springs serve the dual purpose of also separating the spacecraft and giving them enough momentum to un-spool the two 4 foot HF wire antennas. Further the long springs on the tips of the 10.5" whips serve to make them effectively longer for better matching at 145.825 MHz.

The RAFT photo below shows how the KPC-3+ TNC is wedged on the diagonal along with the PSK-10 transceiver board, both sandwitching the HF long wire deployment spool. The tiny HF whip tip magnet is visible in the exact center of the assembly. The two diagonal VHF whip antennas fit cleanly down inside the opposite satellite in its opposite corners.



The trapezoidal boxes are for the batteries and the left and right side panels contain the Hamtronics TX and RX.

The bottom view below shows the wiring harness. The areas covered in Kapton Tape are about 1.2 kg of lead ballast to try to make the spacecraft as heavy as possible to lengthen its on-orbit lifetime due to its low orbit from the space shuttle.



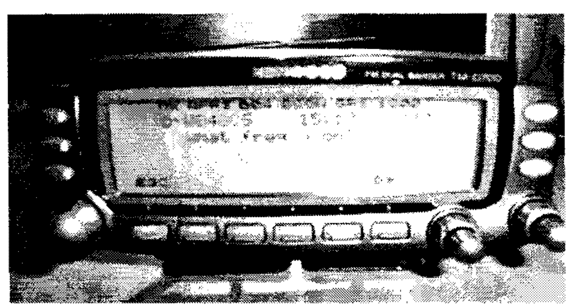
PCSAT / ASTARS BACKGROUND

ASTARS, the APRS Satellite Tracking and Reporting System evolved through a number of existing and previous satellite experiments. First was **1200 Baud PSK ASTARS** called TRAKNET [11] at the 1998/99 AMSAT conferences, using AO-16, LO-19 and IO-26. But these required specialized modems.

Figure 8. Chas Richard, W4HFZ's mobile APRS Satellite capability (including HF)

Then space station MIR carried a packet experiment using **1200 Baud AFSK**, which *any* TNC could do and this brought satellite APRS to just about everyone[6] and SAREX[7]. A week long experiment via MIR using the new Kenwood TH-D7 [5] resulted in over 55 stations with 2-way hand-held message communications.

In the year 2000, **9600 BAUD ASTARS** using UO-22 and SUNSAT and the new Kenwood 1200/9600 baud TM-D700 APRS data mobile radio were successful. In 2001 PCSAT-1 was launched and then PCSAT2 in 2005. AO-51 was finally enabled for APRS digipeating (9600 baud) in the spring of 2006.



PCSAT and the INTERNET

Unlike previous Amateur Satellite design, PCSATs capitalize on the connectivity of the Internet by linking together multiple downlink sites to provide a tremendous gain in reliability through space and time diversity reception. The Internet allows a few stations, called SAT-Gates (Satellite IGATES) to combine all packets heard into the existing worldwide APRS infrastructure for delivery to any APRS operator anywhere in real time.

FAILSAFE RESET

To recover from a SEU or other lockup condition in space in these commercial off-the-shelf TNCs, PCSAT2 uses 3 methods of hardware resets back to launch defaults. First, there is a 120 hour hardware reset timer that will reset the TNC's if it has not been contacted at least once every 5 days. Second, a hardware command via one TNC can reset the other. Third, a DTMF command system has a backdoor reset capability for each TNC.

TELEMETRY

PCSAT2 used the APRS five channel Telemetry format used in the Kantronics family of TNC's with an added 20-to-5 hardware multiplexer to allow telemetry to read as many as 20 analog values and 5 status bits transmitted in four consecutive telemetry packets.

Both RAFT and ANDE use the KPC-3+ TNC and a similar multiplexer in ANDE and just the basic 5 channels in RAFT and MARScom. To fit in these 5 inch cubesats, the TNC had to be carved down to fit diagonally with some drastic mods. [12, 13].

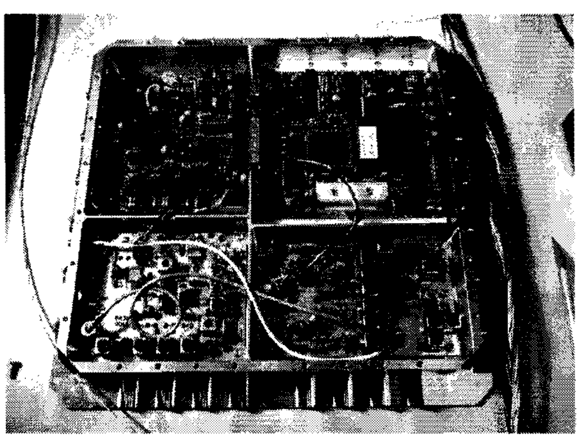


Figure 11. The KPC-3+ TNC system with Hamtronics TX and RX inside the ANDE comms tray.

Not only do these TNC's have telemetry, they also have Beacon, GPS, CW ID and packet digipeater capability as well.

LINK BUDGET

The primary driver of this APRS Satellite design was to deliver messages to handhelds and mobiles with only whip antennas. For this, the downlink needed to be at least 12 dB stronger than most existing digital satellites. PCSAT-1 accomplished this with a 2m downlink (+9 dB over UHF), but this option was not available most of the time on PCSAT2 and the ISS because of potential interference with the ARISS radio system.

Also, the digital trasnponder operates at a low transmit duty cycle so it is easy to power relatively high power transmitters. The Amateur Satellite user population only covers 10% of the earths surface and with the low duty cycle of the ALOHA style of APRS operations, less than 4% of PCSAT2's average transmit power budget is required for AX.25.

The VHF link budget on the uplink is also suitable for low power devices and other experiments. There are several student projects using stand-alone tracking devices or data collection buoys or remote WX stations such as the one built by Ronald Ross, KE6JAB in Antarctica [3].

SAT-GATE OPERATIONS

Although Mobile-to-mobile and HT-to-HT communications work well, the more useful application is linking these packets to any other APRS station worldwide through the network of many volunteer ground stations. They feed every packet heard into the APRS-Internet system (APRS-IS).

OMNI NO-TRACK SAT-GATES

Setting up a SATgate is trivial requiring nothing more than a normal packet station and omni antenna running any APRS software with Igate capability. Even without the map features of conventional APRS, the ALOGGER program by Bill Diaz provides a background data capture and SATgate capability as well. Even though a vertical whip will not provide horizon-to-horizon coverage, each such station simply contributes their packets to the same worldwide stream as all the other Igate receivers. The combination results in over a 99.96% chance of capturing every packet over the USA! Just 4 such stations even if they only have a 60% chance of decoding each packet, combine to a probability of 98%. If the original packet is replicated TWICE, then this probability becomes 99.96%! A Certainty!

CONCLUSION

Everything is going wireless. And Ham radio HT's and especially the TH-D7 HT with built-in APRS capability give ham radio operators this satellite messaging capability in the palm of their hands. This PCSAT style global digital communications capability should be a major driver for future amateur satellite and educational missions. PCSAT-1 and PCSAT2 have fulfilled this mission objective and now ANDE, RAFT and MARScom.

AX.25 transponders on 145.825 MHz are ideal for extending Amateur Satellite digital services to mobile and handheld users because of the availability of not only the off-the-shelf end user mobile and handheld fully integrated data radios but also the off-the-shelf spacecraft design demonstrated by PCSAT-1 and PCSAT2 and future missions of ANDE, RAFT and MARScom

Combining this with the recent maturity of the Internet as a global resource for exchanging data worldwide suggests that there is a unique opportunity to join the Internet and Amateur Satellites as a means of tying together SatGates throughout the world where the infrastructure exists to extend worldwide amateur communications to mobiles in areas where it doesn't exist.

By encouraging UI digipeating as auxiliary payloads on most small satellites the Amateur Satellite Service can bring all of these pieces together into the most powerful and far reaching Amateur Satellite project to date. Student projects and educational institutions can easily contribute to this capability while also serving their own needs of viable payloads and ongoing operations training.

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An EZ-Lindenblad Antenna for 2 Meters

Presented by

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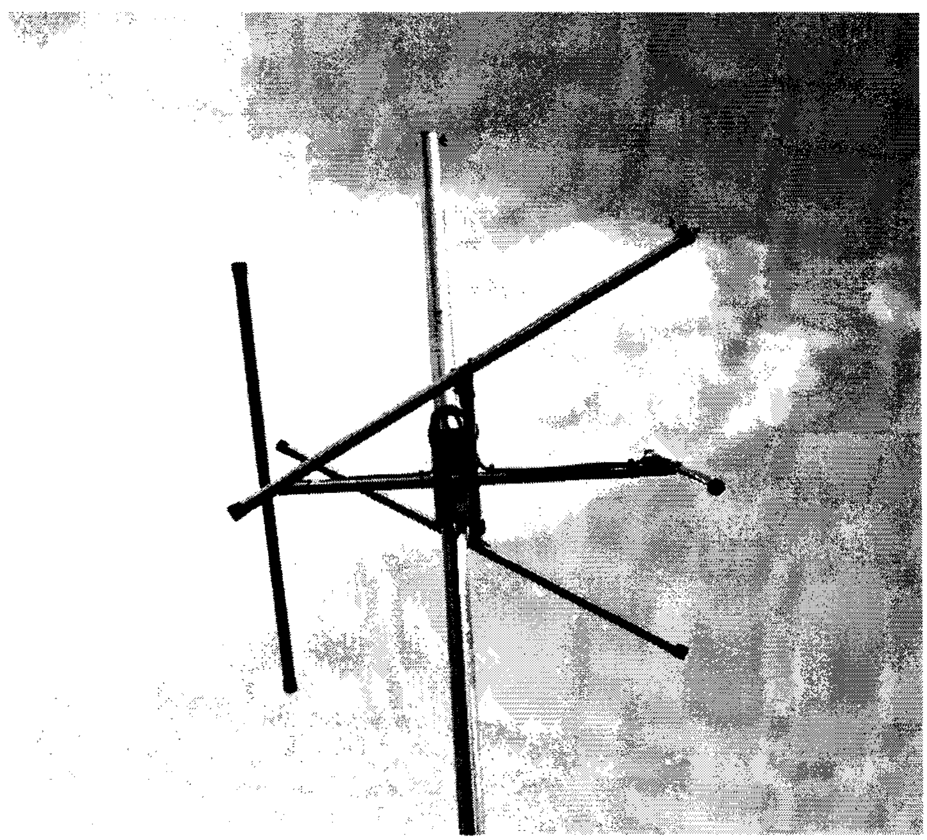
AA2TX@amsat.org

Abstract

The Lindenblad antenna uses four, dipole driven-elements to create a circularly-polarized, omni-directional radiation pattern. This pattern is ideal for accessing LEO satellites and can often eliminate the need for beam antennas and Az/El rotator systems. This makes them especially useful for portable and temporary satellite operation. Unfortunately, constructing these antennas can be difficult because of the need to feed the four, 75-ohm driven elements. Most previous designs have used folded dipoles, balanced lines, BALUN transformers and/or special impedance matching sections in order to provide a good match to 50-ohms.

This paper offers an easier way to construct a Lindenblad antenna by making use of a novel, yet simple, feed mechanism that dramatically simplifies the antenna construction. The four driven dipoles are fed with ordinary, 75-ohm, coaxial cables that are all soldered to a single N-connector with no matching sections or transformers. Yet, it provides an excellent match across the entire 2 meter band.



1 Introduction

A Lindenblad antenna provides circular polarization and an omni directional pattern that has most of its radiation below 30 degrees of elevation. This pattern is ideal for accessing Low Earth Orbit (LEO) satellites. On the 2 meter amateur satellite band, the free-space path loss is relatively low and uplink power is easy to generate making these antennas an excellent alternative to more complicated beam antennas. 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 them ideal for portable and temporary satellite operation as well as providing a good option for permanent or fixed stations as well.

This antenna was invented by Nils Lindenblad of the Radio Corporation of America (RCA) around 1940. 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 $\lambda/3$ diameter. Figure 1 shows a drawing of the antenna concept. At the time, Lindenblad was working on antennas for the then nascent television industry but the start of World War II delayed further TV broadcasting work.

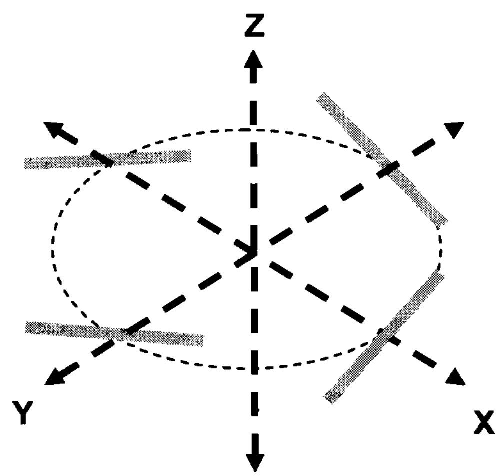


Figure 1. Drawing of Lindenblad antenna concept

After the war, Brown and Woodward, also of RCA, began investigating ways to reduce fading on airplane-to-airport radio links. Airplanes use nominally vertically 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[1] and constructed VHF and UHF prototypes to test. An original Brown and Woodward prototype is shown in Figure 2.

The Brown and Woodward design uses tubing for the dipole elements and for a 100-ohm open-wire line 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.

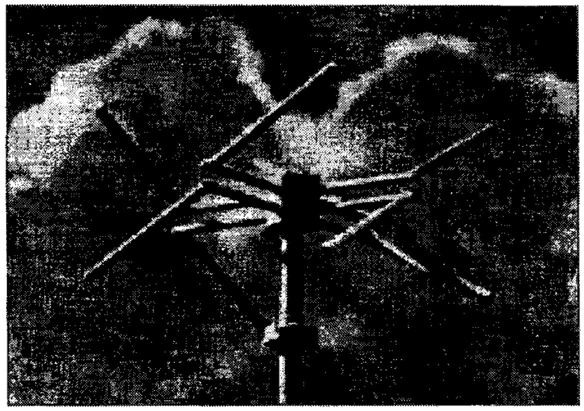


Figure 2. Photo of early prototype Lindenblad[2]

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 need to be fed in-phase 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. For example, typical twin-lead balanced lines cannot be attached to a metal support so this requires special standoff insulators or a non-metallic dipole support structure.

2 EZ-Lindenblad Antenna Design

Design Goals

The goal for this project was to design a Lindenblad antenna for the 2-meter satellite band that would be very easy to build. Specific goals included the following:

1. Use only readily available materials
2. Rugged and weather-resistant structure
3. Can be built in a few hours as a "weekend project" using only hand tools
4. No tuning or adjustments
5. Covers entire 2-meter ham band with less than 1.5:1 SWR

Design Approach

To achieve these goals, the following approach was used:

1. Use ¾" aluminum tubing for dipoles and cross-booms (no folded elements)
2. Use ½" black-PVC insert-T connectors to mount dipoles
3. Use 1.5" x 1.5" aluminum angle stock to mount cross-booms and N-connector
4. Use common RG-59 coax to feed all dipoles (no twin-lead or other balanced lines)
5. Use inexpensive ($.56) ferrite sleeves on the coax to create a simple choke BALUN for the dipole feed

Impedance Matching

The major design issue with Lindenblad antennas is the feeding and impedance matching of the four dipoles. Each dipole presents a 75-ohm balanced load and this needs to be matched to a 50-ohm unbalanced coaxial line feed. The key concept of the EZ approach is to eliminate any extra impedance matching sections or transformers and just solder all four coax feed-lines to a single N-connector.

Since we want to have a 50-ohm load, this means that each of our four dipole feed cables has to present a 200-ohm load at the N-connector. We could easily do this if we used quarter-wave sections of 122-ohm coax to match each 75-ohm dipole to 200-ohms. However, there is no such coax that is readily available.

So, a different way to do this is to use regular, 75-ohm, RG-59 coax but run this line with an intentional impedance mismatch. If we make the standing wave ratio (SWR) on the RG-59 line equal to 200/75, or 2.67:1, then the RG-59 will present a 200 ohm resistive load at our N-connector feed point if we use the right coaxial line length.

How do we make the SWR equal to precisely 2.67:1? Consider that at resonance, the dipoles are each around 75-ohms for a perfect match to 75-ohm coax or a 1.0:1 SWR. If we made the dipoles of length zero, then the SWR would be infinity. Thus, there is some length between resonance and zero where the dipoles will be the correct length to provide any desired SWR. Using an EZNEC[3] model, we can determine the correct dipole length and we find that making the dipoles just a few inches short of resonance provides an impedance of Z = 49 - j55 ohms. This will provide an SWR on the RG-59 coax line equal to 2.67:1 at a 145.9 MHz which was the selected center frequency so as to optimize performance in the satellite sub-band. The only question remaining is; how long should we make the coaxial feed cables? This is easily solved using a *Smith Chart.*

Smith Chart

The Smith Chart was invented by Philip Smith of The Bell Telephone Laboratories in 1939.[4] As a high school student, Philip had been a ham radio operator and used the call sign 1ANB. After graduating from Tufts College (now Tufts University,) he went to work for Bell Labs in the radio research department. As part of his job, he needed to make many impedance calculations and realized that he could create a graphical tool that would allow the solution to be plotted on a chart rather than requiring complex computations by hand. Please see Figure 3 for a view of a Smith Chart.

The Smith Chart allows us to easily calculate the required coaxial line length to provide a 200-ohm load using the 75-ohm, RG-59 coax. The Smith Chart shown is normalized to 1-ohm in the center so we must multiply all impedance values by our coaxial line impedance or 75-ohms. As shown in Figure 3, the shortened dipole impedance (Z = 49 - j55) is plotted at point A on the chart. The desired 200-ohm impedance is plotted at point B on the chart. A constant 2.67:1 SWR curve is drawn between the two impedance points. The length of cable needed is read along the outside curved counterclockwise scale labeled, "*Wavelengths toward load*" from the lines drawn through points A and B. The total length of the line is .25 + .124 =.374 wavelengths. At 145.9 MHz, the wavelength is 80.95-inches and since RG-59 (foam) cable has a velocity factor of .78, we need to make the feed cable lengths; 80.95 x .374 x .78 = 23.6-inches.

There are also several programs available which can also be used to do the Smith Chart calculations. These include *MicroSmith* from ARRL which was used by the author as a cross-check.

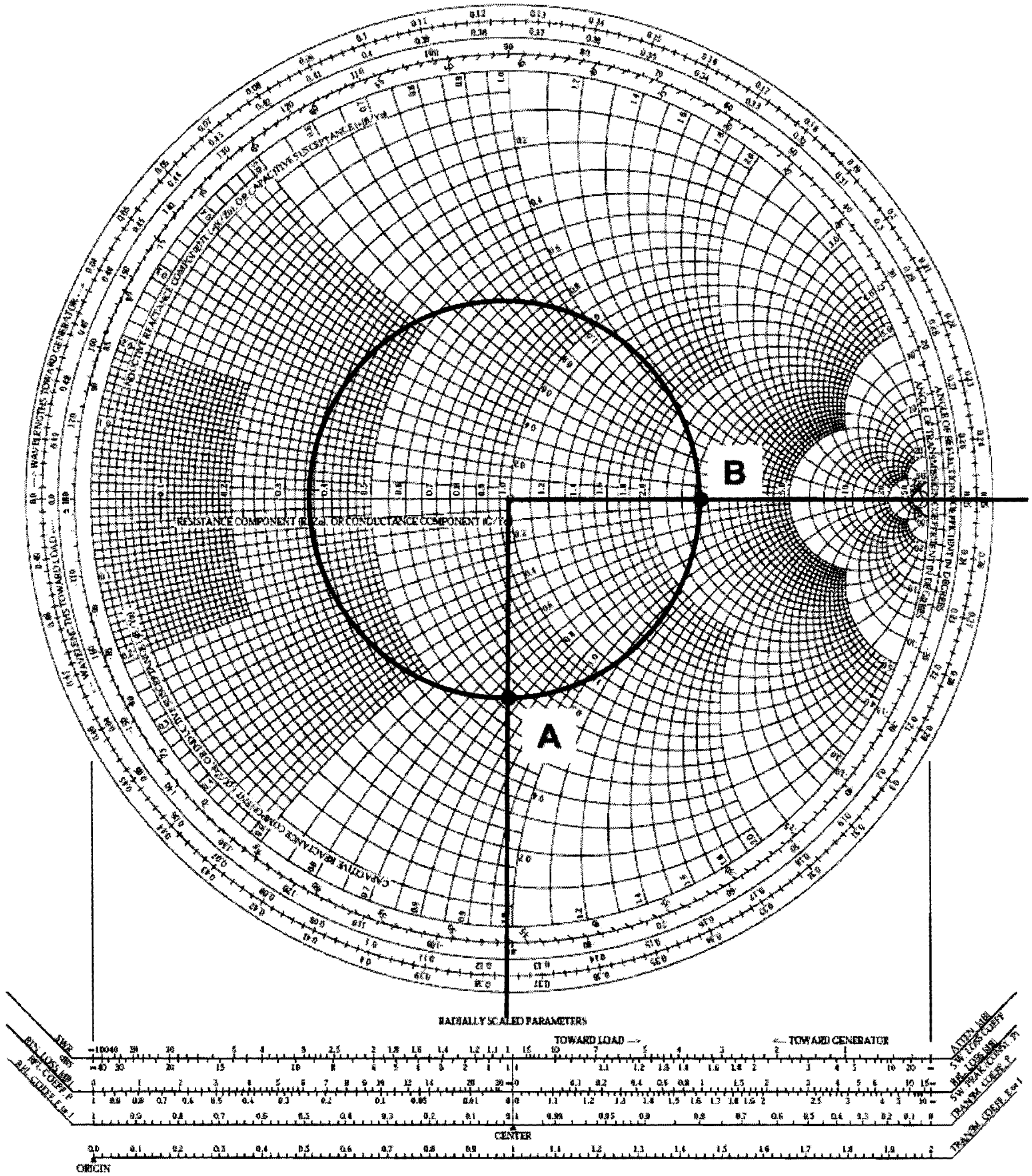


Figure 3. Smith Chart with constant 2.67:1 SWR circle

3 Antenna Construction

This antenna was designed to be easy to construct using only hand tools. Most of the construction and materials are not critical and experienced antenna builders should feel free to substitute their own favorite techniques. The few critical dimensions are noted in the text and include the dipole and coaxial cable lengths.

Parts

All of the parts used in this antenna are readily available. Most of the parts are not critical so feel free to substitute as needed. However, the aluminum tubing used for the dipoles must be ¾" outer diameter and construction will be easier if the tubing is 17-gauge as the inner wall will be just slightly larger than the outer wall of the PVC-insert-T's used to make the dipole assemblies. If heaver wall tubing is used, it will be necessary to file down the PVC insert-T's to make them fit together.

Table 1. Parts list

Quantity	Description
3	6-foot lengths of ¾" OD, 17-gauge, aluminum tubing Note: Available from Texas Towers www.texastowers.com
4	½" x ½" x ½" PVC insert T-connector
1	6" - 12" length of 2" x 2" x 1/16" aluminum angle stock
1	2" length of 2" x 2" x 1/16" aluminum angle stock for mounting connector
12	#8 x ½" aluminum sheet metal screws
~12	3/16" Aluminum rivets (or #8 x ½" aluminum sheet metal screws)
1	Single-hole mount Female N-connector
4	Fair-Rite cable ferrite. Part# 2643540002. Note: Available from Mouser Electronics, www.mouser.com Stock# 623-2643540002 ($.56 each)
1	10-foot length of RG-59 PE foam coax with stranded center conductor
4	High-temperature, (un-insulated) Ring Terminals 22-18 AWG for 8 -10 stud Note: ACE Hardware #3017407
4	High-temperature, (un-insulated) Ring Terminals 12-10 AWG for 8 -10 stud Note: ACE Hardware #3017423
Misc.	Heat shrink tubing for .25" cable, wire ties, cable clamps, electrical tape, *Ox-Gard™ OX-100* grease (for aluminum electrical connections)

Assembly

Start by making a bracket to mount the N-connector. Cut a 5/8" hole in one side of the short piece of angle stock and rivet or screw it to the bottom of the long piece of angle stock. The completed bracket with the connector and cables attached is shown in Figure 4.

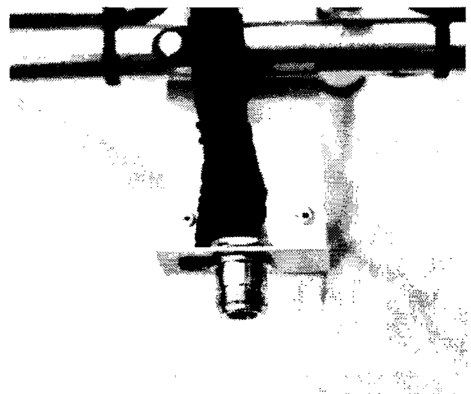


Figure 4. Close-up of N-connector mounting bracket

Next, cut the aluminum tubing to make the cross-booms and dipole rods as shown in the table below.

Table 2. Aluminum tubing cutting guide

Quantity	Length	Description
8	14 -11/16"	Dipole rods
2	23"	Cross-booms

Drill holes for the machine screws at each end the cross-booms but do not insert the screws yet. Attach the cross-booms to the long section of angle stock with rivets or screws. One cross-boom will mount just above the other as shown in Figure 5. Make sure that the centers of the cross-booms are aligned with each other so that the ends of the cross-booms are all 11-1/2" from the center.

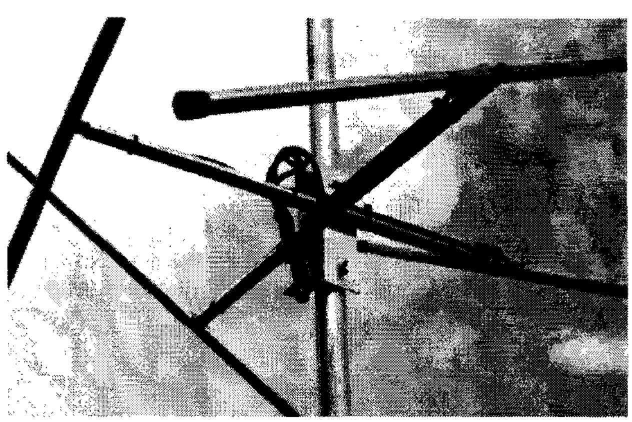


Figure 5. Cross-boom assembly

Make the dipoles by inserting a PVC insert-T into two dipole rods. It should be possible to gently tap in the rods with a hammer but it may be necessary to file down the PVC insert-T a little if the fit is too tight. The dipole length dimension is critical so take care to get this correct as shown in Figure 6.

Drill holes for machine screws in each dipole rod but do not insert the screws yet. The screws will be used to make the electrical connections to the dipoles at the center. The screw holes should be about 3/8" from the end of the tubing.

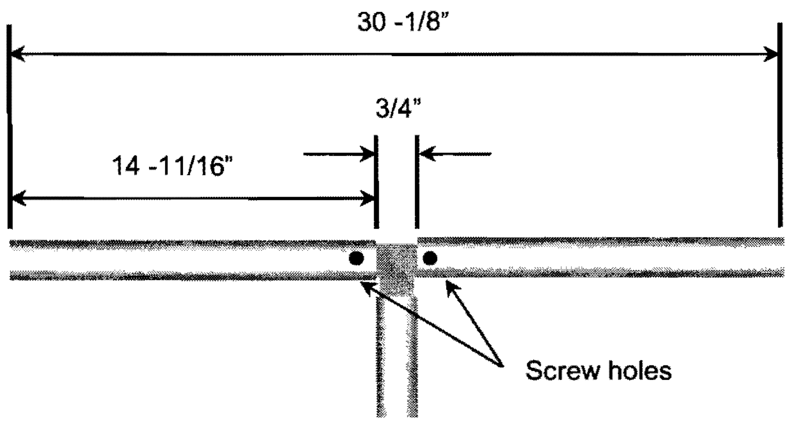


Figure 6. Dipole dimensions

The dipole assemblies are attached by gently tapping the PVC insert-T into the end of each cross-boom with a hammer. The cross-boom assembly dimensions are shown in Figure 7.

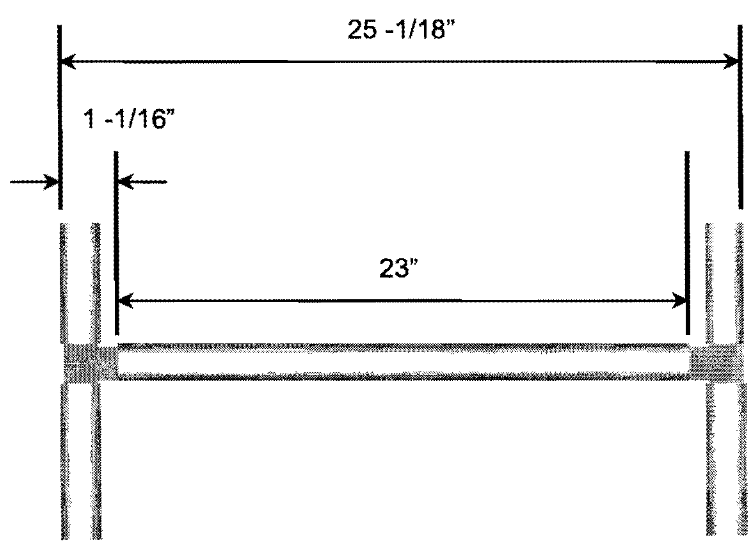


Figure 7. Cross-boom assembly dimensions

Next, temporarily attach the center angle bracket to a support so that each of the cross-booms is perfectly horizontal. Measure this with a protractor. Now, using the protractor, rotate the dipole assemblies to a 30-degree angle with the right hand side of the nearest dipole is up when you are looking towards the center of the antenna. This is for right-hand circular polarization. Drill a small hole through the existing cross-boom holes into the PVC insert-Ts and then use the machine screws to fasten the dipole assemblies into place. They should each be at 30-degrees from horizontal as shown in Figure 8.

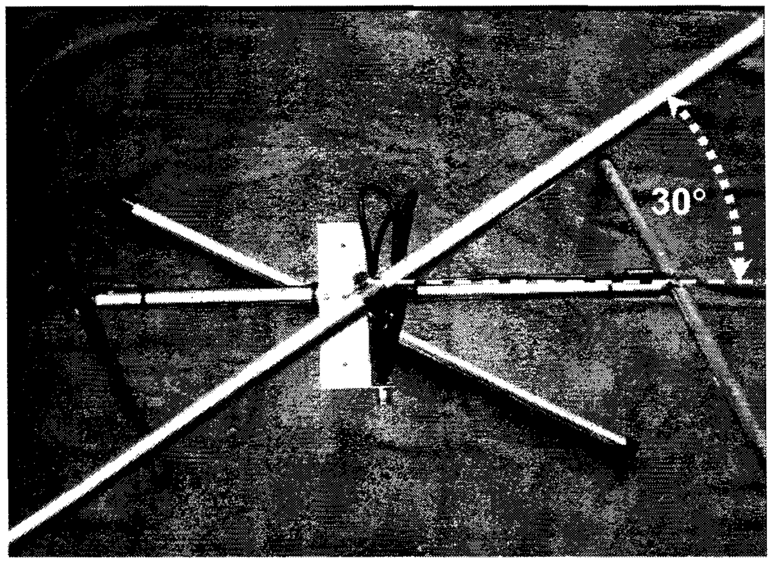


Figure 8. Dipole assembly canted 30-degrees from horizontal.

Next, make the four feed cables by cutting the RG-59 coax as shown in Figure 9. On the dipole connection side, un-wrap the braid and form a wire lead. Apply the ring terminals to the center and braid conductor leads. At the other end of the cable, do not un-wrap the braid but strip off the outer insulation. Slip a 1" piece of shrink wrap over the coax and apply to the dipole side. Next, slip a cable ferrite over the cable and push all the way to the dipole end as far as it will go (*i.e.*, up to the heat-shrink tubing.)

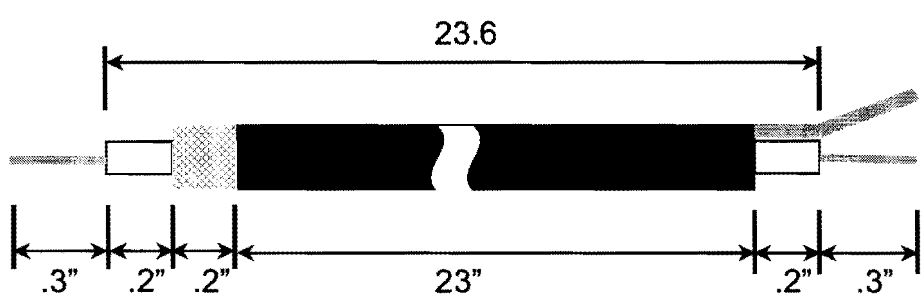


Figure 9. Coaxial feed cables

Prepare each dipole for its feed cable by first cleaning the area around the screw holes with steel wool and then applying *Ox-Gard*™ grease. This is to insure a good electrical connection. The coax center conductor goes to the up side of the dipole and the braid goes to the down side. To make a connection, put a machine screw through the ring terminal and gently screw into the dipole tubing. Do not over-tighten the screws or you will strip the tubing. A photograph of the completed dipole feed connection is shown in Figure 10.

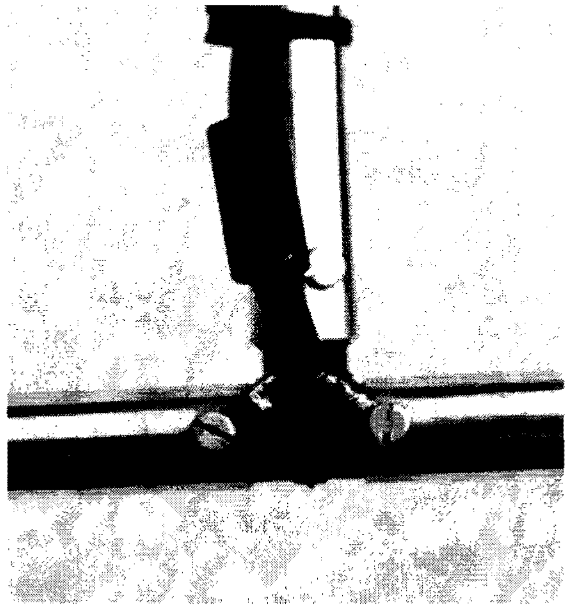


Figure 10. Dipole feed connections

Apply *Ox-Gard*™ grease around the hole for the N-connector. Take a 3" – 4" piece of braid and put the end of it through the hole for the N-Connector. This is to make the ground connection. Secure the N-connector in the mounting hole to clamp the braid.

Use a wire tie or tape to hold the four feed cables together at the connector ends. Make sure to align the cables so that all the ground braids are together and the center conductors all extend out the same amount. Do not twist the center conductors together. Carefully push the four cable center conductors into the center terminal of the N-connector and solder them in place. Wrap the exposed center conductors of the cables and the connector with electrical tape.

Take the piece of braid that is clamped to the N-connector and wrap it around the four exposed ground braids of the coax cables. Solder them all together. This will take a fair amount of heat so use a 100 watt solder gun. Be careful not to overheat and melt the cables though. After this cools, apply electrical tape over all the exposed braid and fix with wire ties. The cables should be secured to the cross-booms with wire ties.

Congratulations, your EZ-Lindenblad antenna is now complete. Although not necessary, the dipoles can be fitted with ¾" plastic end caps and this was done on the author's unit.

The center angle stock section provides a mounting base for attaching the antenna to a mast using whatever mast clamping mechanism is convenient. The author's antenna was intended for portable operation and the angle stock bracket was drilled to accept two #8 stainless steel screws. These screws pass through a portable mast and the antenna is secured with two stainless steel thumbscrews. This allows the antenna to be set up or taken down in less than a minute. The completed antenna with the thumbscrew mounting scheme is shown in Figure 11.

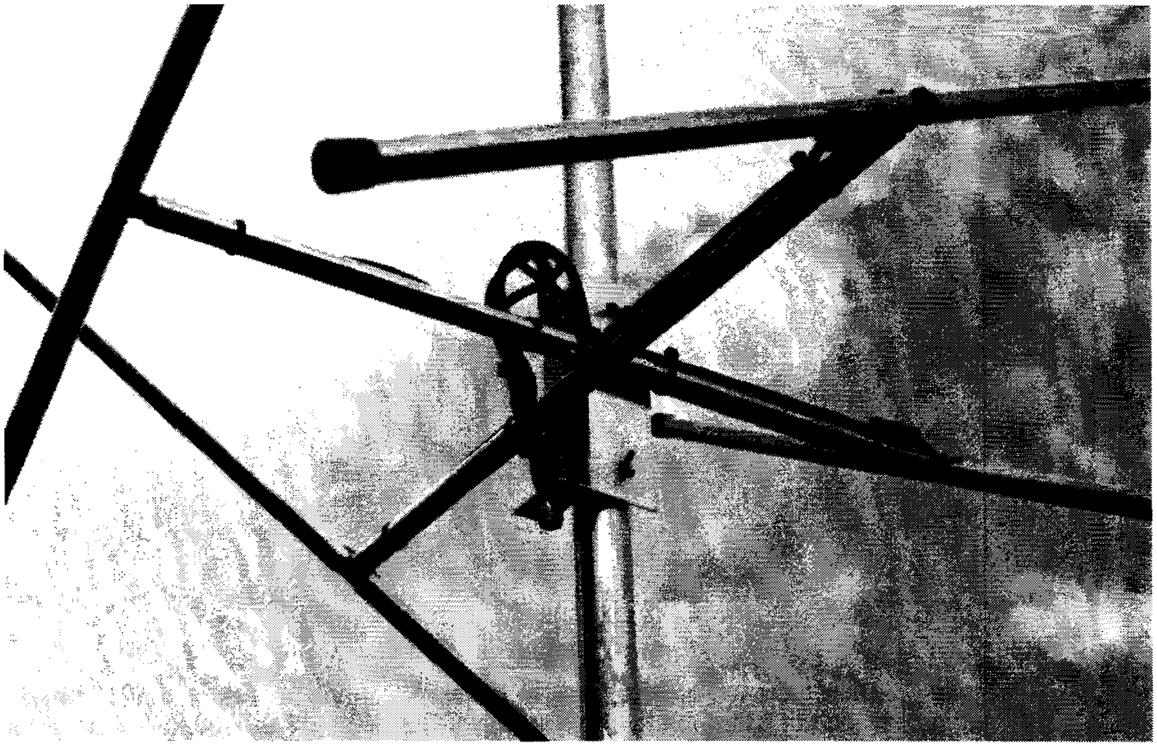


Figure 11. Completed EZ-Lindenblad antenna attached to mast with thumbscrews

4 Radiation Pattern and Gain

The antenna elevation radiation pattern predicted by the EZNEC model is shown in Figure 13. This is the pattern with the antenna is mounted at 6-feet (1 wavelength) above real ground. The maximum gain predicted is 4.8 dBic, right-hand circularly polarized. Note that the pattern will have more lobes and the gain will be somewhat greater if the antenna is mounted higher above ground. The predicted azimuth pattern is almost perfectly circular with less than 0.1 dB variation as would be expected from an omni-directional antenna.

Notice that the elevation pattern favors the lower elevation angles. The -3dB points are shown on the plot and are at about 5-degrees and 25-degrees with the maximum gain at 13.3-degrees. This is an excellent pattern for accessing most LEO satellites as this elevation range is where most of the pass times will occur. It is also where the satellite range provides the best chance for DX contacts.

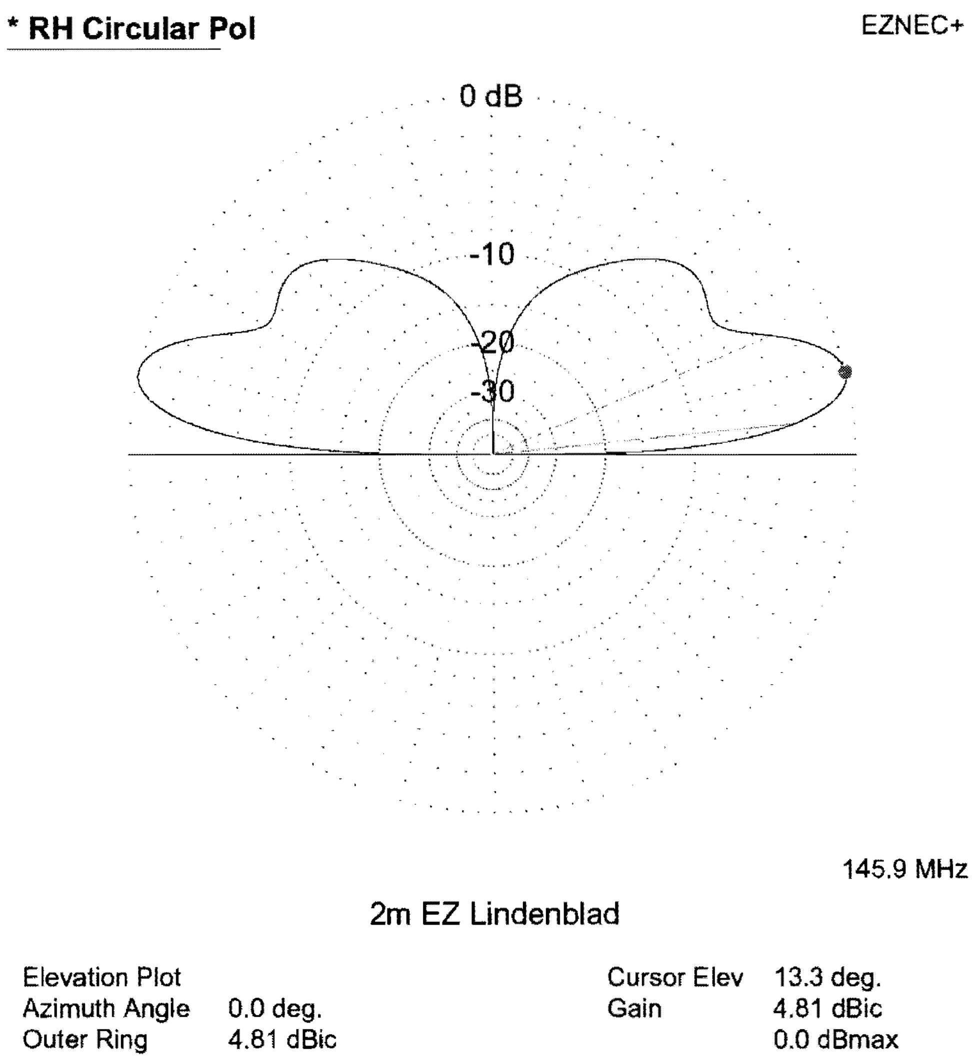


Figure 13. EZ-Lindenblad radiation pattern

5 Testing

This antenna was designed to work as assembled with no adjustments and no testing or test equipment required. However, the prototype was tested in order to verify the antenna design. These tests are not needed when constructing a copy of the antenna.

Impedance Match

The antenna impedance match to 50-ohms was tested using an MFJ-259B SWR meter that has a digital readout of standing wave ratio (SWR) and frequency. The frequency accuracy was verified using an external frequency counter and the 1.0:1 calibration was checked with a Narda precision 50-ohm load.

The antenna was connected to the SWR meter with a 6-foot coax jumper made of Belden 9913F7 which has very low loss. The SWR was measured at 1 MHz intervals over the 144-148 MHz range. The results are shown in the chart of Figure 12.

As can be seen in the chart, the antenna provides a match at the limit of the MFJ meter capability in the satellite sub-band and an excellent match over the entire 2-meter band. The designed center frequency of 145.9 MHz corresponds well with the minimum measured SWR. It is important to note that the MFJ meter is not a precision instrument and that the actual SWR will vary with antenna height and ground quality. However, it is clear that the EZ-Lindenblad antenna would easily provide the 1.5:1 or better match that most modern transmitters require in order to provide maximum power.

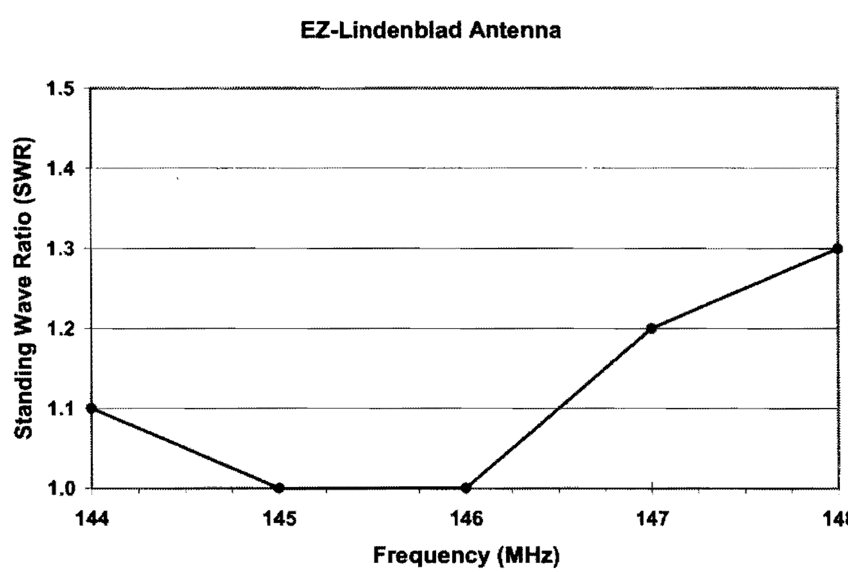


Figure 12. SWR versus frequency chart

Power Handling

This antenna was designed to safely handle any of the currently available VHF ham transceivers. The power handling capability was tested by applying approximately 200 watts continuous for 9-1/2 minutes. The forward power was measured with a Bird™ Wattmeter using a 250 watt slug. At 200 watts forward power, there was no indicated reverse power confirming the low measured SWR. Immediately after the test, the ferrites and cables were checked and there was no noticeable temperature rise.

Circularity

The circularity was checked by using a ¼-wave vertical attached to a short PVC mast as a hand held sense antenna. The sense antenna was connected to a Yaesu FT-817 radio in USB mode with the AGC switched off. The output of the radio was fed into an AC voltmeter with a dB scale.

The antenna under test was set up at a height of 6-feet and was set up approximately 100-feet from the sense antenna location. It was fed an un-modulated carrier signal at 146 MHz using a signal generator.

To verify the test set up, a horizontally polarized reference antenna was tested first. The sense antenna was held at about 6-feet high and was slowly rotated by hand from horizontal to vertical. The reference antenna showed an almost 30 dB difference between the received signal strength at horizontal versus vertical polarization of the sense antenna.

The EZ-Lindenblad was tested next using the same procedure and showed about a 2-3 dB difference between the horizontal and vertical positions of the sense antenna which is good for an omni-directional antenna.

6 Summary

The EZ-Lindenblad antenna was used to make SSB and FM voice contacts via the AO-07, FO-29, SO-50, AO-51 and VO-52 satellites during a test session and on ARRL Field Day 2006. Field day is an excellent test of an antenna as it is probably the busiest time of the year on the satellites and the antenna performed well.

The EZ-Lindenblad uses a novel feed mechanism that makes it easy to construct. Yet, it provides good performance and a good impedance match across the entire 2-meter band. Since it is omni-directional, it does not require an antenna rotator system making it an ideal choice for both portable and fixed station use.

Tony Monteiro, AA2TX, was first licensed in 1973 as WN2RBM and has been a member of AMSAT since 1994. He worked in the communications industry for over 25 years and was a member of the technical staff at Bell Laboratories and a senior manager at several telecommunications companies.

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[1] *Circularly Polarized Omnidirectional Antenna*, by George H. Brown and O. M. Woodward Jr., RCA Review vol. 8, no. 2, June 1947, pp. 259-269.
[2] Ibid. pg 267.
[3] EZNEC+ V4 antenna software by Roy W. Lewallen (W7EL.) Available from: www.eznec.com
[4] Philip H. Smith, Electrical Engineer, an oral history conducted in 1973 by Frank A. Polkinghorn, IEEE History Center, Rutgers University, New Brunswick, NJ, USA available at: www.ieee.org

Analysis of Maximum Elevation Pass Profiles for the AO-51 Satellite

Presented by

Gould Smith, WA4SXM

Abstract

What effect does your location have on the maximum elevation profile for various LEO satellites? This report will look at six months worth of passes for AO-51 and determine whether different locations have an advantage or not.

While writing an article for the AMSAT Journal about the Maximum Elevation Profile for my QTH, I wondered what the profiles looked like for other areas of the country or world and what the differences at different latitudes were. So this analysis was born.

I decided to look at the AO-51 LEO (Low Earth Orbit) satellite.

1 AO-51 Orbit Background

AO-51 is in a polar, sun synchronous orbit with an inclination of 98.15°. This means that as the satellite crosses the equator going south to north it intersects the equator at an angle of 98.15°. This is 8° past vertical, the North Pole being 90° (see Figure 1).

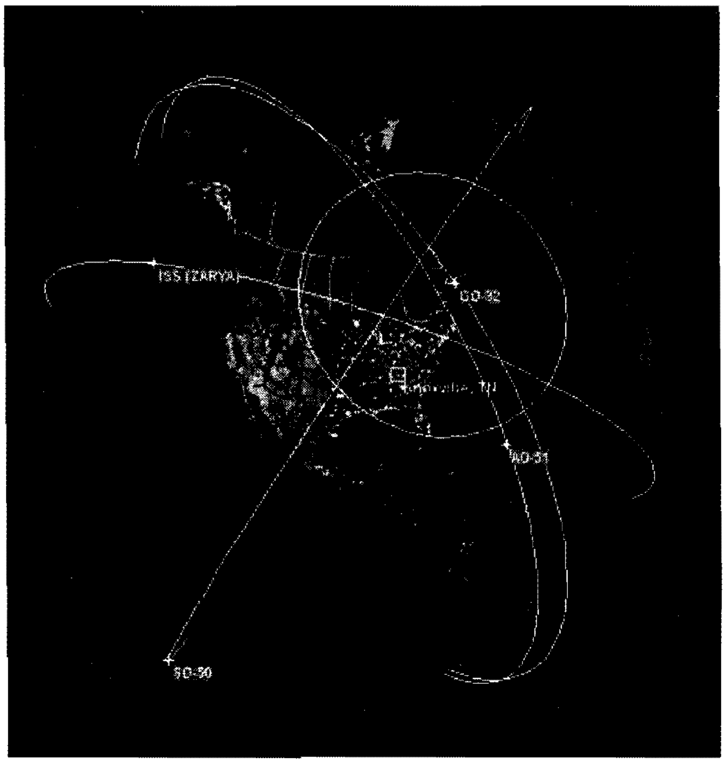
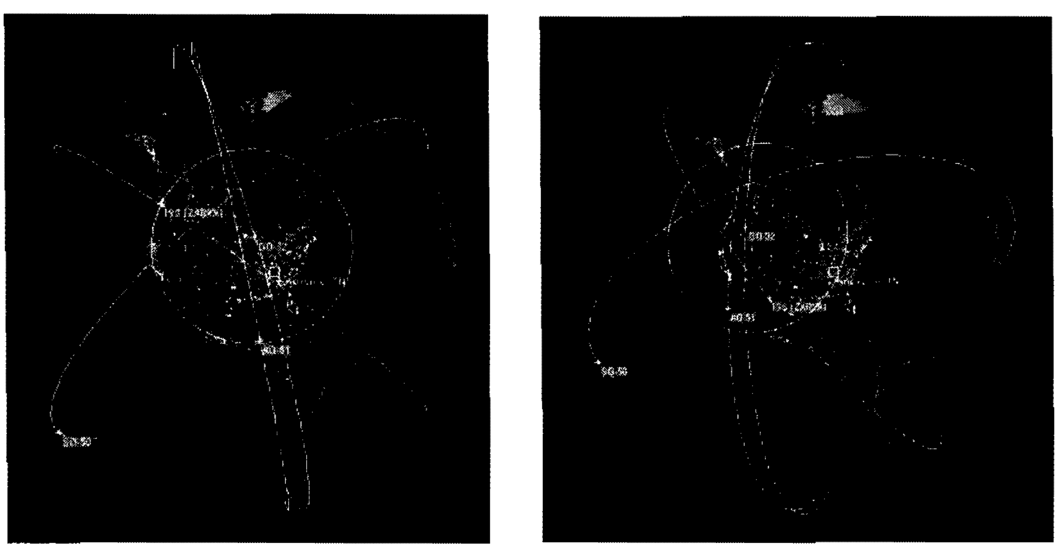


Figure 1. Nova for Windows screenshot of the first evening pass of GO-32 & AO-51

The sub satellite point (SSP) of AO-51 moves about 25° west each pass. At 39 °N latitude this is 1337 miles (2139 km). Mid-latitude locations will get a pass to the east and one to the west, and the second pass will be east, west or close to overhead. The more overhead the pass is (close to 90 °), the lower the first and third passes will be. AO-51 has a footprint of about 3900 miles in diameter; this will give all the mid-latitudes three passes in the morning and three passes in the evening.



Figures 2 & 3. Screenshot of the 2nd and 3rd evening passes of GO-32 & AO-51

Because AO-51 is in a sun synchronous orbit, the morning and evening passes will occur during the same 4 hour window each day. Figure 4 shows the AO-51 operational windows at my QTH, optimal operation times evening (1930 – 0000 local) and morning (0830 – 1300 local). Sun synchronous means that it will appear over the same location at the same 'sun time' each day. So, everyone in the mid latitudes should get about the same pass windows. My question was do they get the same profile of operational passes? The maximum elevation of a pass is a useful measure to determine this.

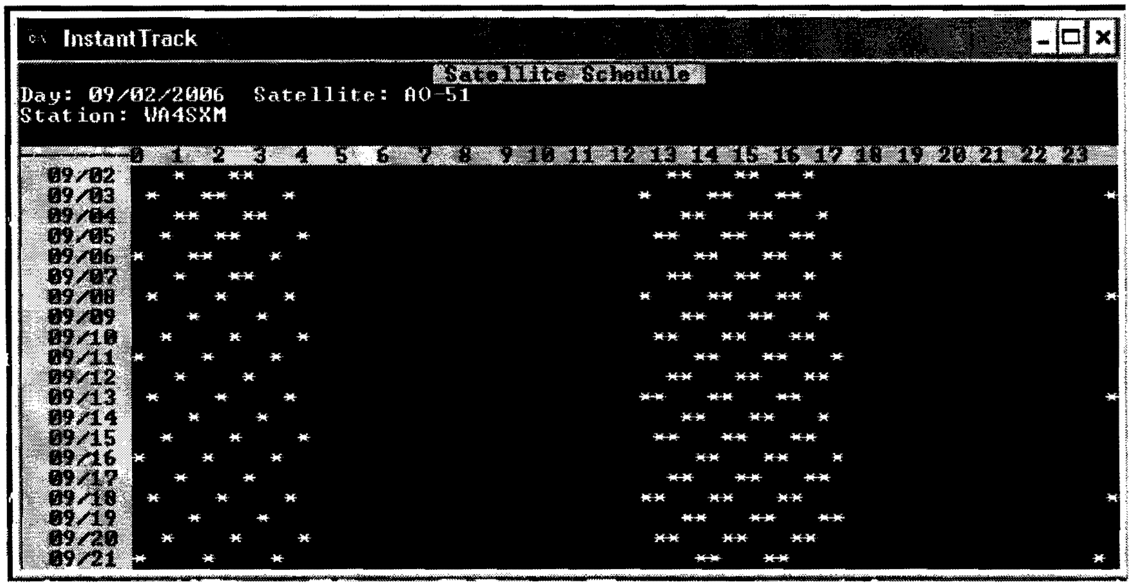
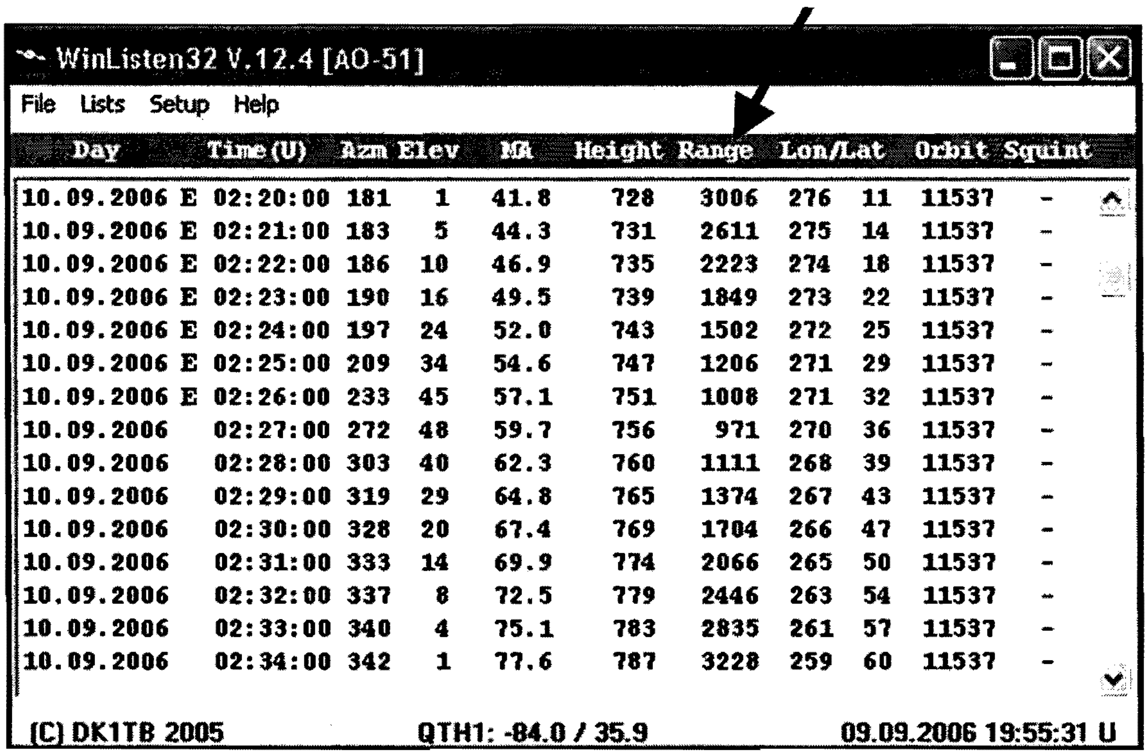


Figure 4. InstantTrack screenshot of the AO-51 passes for 20 days

2 Low Elevation Angles

Low satellite elevation angles make operating difficult for two reasons: 1) distance to the satellite (Range) and 2) obstructions that interfere with the signals. Most operators don't notice how far away AO-51 is from them during most of a pass and especially at the beginning and end of each pass. We tend to think about the 800 km altitude of the satellite and our location as the center of a circular arc, but this is not the case. The arc actually follows an elliptical shape rather than a circle, which produces a much longer distance to the satellite. Due to the increased path loss this extra distance at the beginning and end adds quite a decrease in the signal compared to TCA (Time of Closest Approach). When AO-51 first appears on the horizon it generally is around 3200 km away. The distance at TCA depends upon the maximum elevation of that particular pass.

Look at the printout/display of a standard satellite tracking program and notice how the Range (distance to the satellite from your QTH) changes during a pass. I think you will be quite surprised. Figure 5 shows you the Range to AO-51 for a 48° pass.



WinListen32 V.12.4 [AO-51]

File Lists Setup Help

Day		Time(U)	Azm	Elev	MA	Height	Range	Lon/Lat		Orbit	Squint
10.09.2006	E	02:20:00	181	1	41.8	728	3006	276	11	11537	-
10.09.2006	E	02:21:00	183	5	44.3	731	2611	275	14	11537	-
10.09.2006	E	02:22:00	186	10	46.9	735	2223	274	18	11537	-
10.09.2006	E	02:23:00	190	16	49.5	739	1849	273	22	11537	-
10.09.2006	E	02:24:00	197	24	52.0	743	1502	272	25	11537	-
10.09.2006	E	02:25:00	209	34	54.6	747	1206	271	29	11537	-
10.09.2006	E	02:26:00	233	45	57.1	751	1008	271	32	11537	-
10.09.2006		02:27:00	272	48	59.7	756	971	270	36	11537	-
10.09.2006		02:28:00	303	40	62.3	760	1111	268	39	11537	-
10.09.2006		02:29:00	319	29	64.8	765	1374	267	43	11537	-
10.09.2006		02:30:00	328	20	67.4	769	1704	266	47	11537	-
10.09.2006		02:31:00	333	14	69.9	774	2066	265	50	11537	-
10.09.2006		02:32:00	337	8	72.5	779	2446	263	54	11537	-
10.09.2006		02:33:00	340	4	75.1	783	2835	261	57	11537	-
10.09.2006		02:34:00	342	1	77.6	787	3228	259	60	11537	-

(C) DK1TB 2005 QTH1: -84.0 / 35.9 09.09.2006 19:55:31 U

Figure 5. WinListen display of a 48° pass of AO-51

Another important thing to notice in Figure 5 is how little time the satellite spends at TCA and how quickly the distance moves back to 1000 km plus. Two minutes after TCA the satellite is already 400 km further away.

So how much does the path loss increase with distance during a pass?

3 LEO Path Loss

Table 1 shows that the 435 MHz downlink signal from AO-51 is 9dB weaker at 3200 km than at 1154 km (1/8 of the signal strength). The TCA for a 44° pass is 11 dB stronger than when the satellite first appears. Well it turn outs that the lower the maximum elevation of the pass, the further the satellite is from you during the entire pass; therefore more path loss and a weaker signal to work with. Looking at it the opposite way, the higher the maximum elevation, the stronger the signal will be at TCA. For an 80° pass this is a 12 dB increase (or 16 times stronger signal than at AOS). So, you are most likely to hear the satellite at mid pass with a poor antenna, and less likely to hear it before or after.

Table 1. AO-51 435 MHz Path Loss

Range (km)	dB Loss	Part of the Pass
3200	155	AOS, LOS
2300	152	TCA 11° pass
1400	148	TCA 26° pass
1154	146	TCA 33° pass
1000	145	TCA 44° pass
800	143	TCA 79° pass
3200	155	AOS, LOS

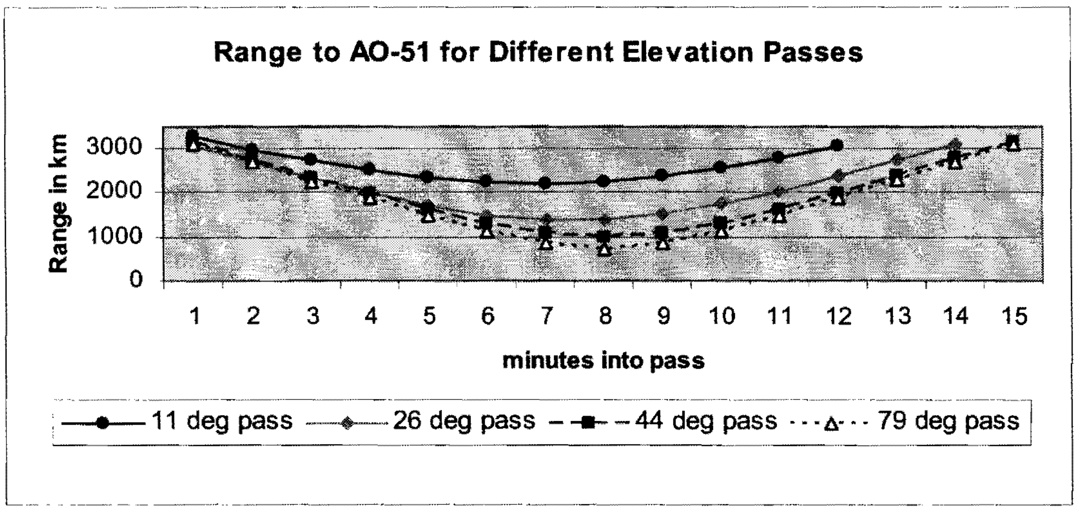


Figure 6, Distances to AO-51 at selected Maximum Elevations

Figure 6 shows how the range changes with different maximum elevations. The higher the maximum elevation gets the shorter the range at TCA. Passes with a maximum elevation of 44° or more don't offer much more advantage as far as path loss, but they do have a longer pass time and more time spent with the satellite closer to your QTH. For you number crunchers, the average range for the passes in Figure 6 are shown below.

11 ° average range 2609 km   26 ° average range 2111 km

44 ° average range 1962 km   79 ° average range 1834 km

4 Maximum Elevation (MaxEL)

The maximum elevation of each pass is a great predictor of operational success. The higher the pass the fewer the obstructions and the shorter the distance to the satellite, thus a better pass with which to operate. The more high passes at your location, the better the total LEO operational experience. So, what is the MaxEl profile?

5 AO-51 Profile

For my QTH at 36ºN I used the ITPASS program (part of the *Instant*Track suite) to generate a data file for 1080 passes which works out to about six months worth of data. Imported the text data into Excel and did a pivot table on the maximum elevations (MaxEl) for the 1080 passes to get the counts for each MaxEl. Figure 7 shows the results of this data.

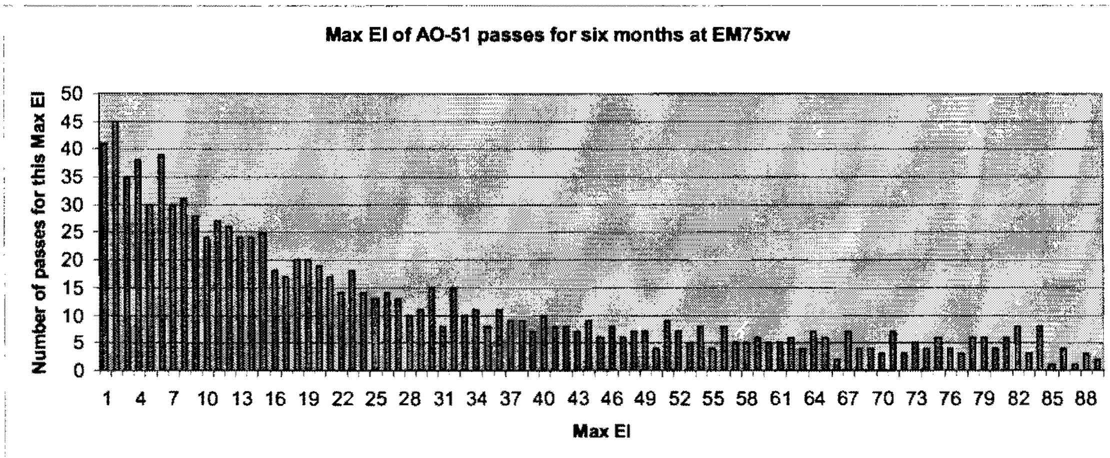


Figure 7.AO-51 MaxEl Profile at WA4SXM QTH

Obviously the low elevation passes occur most frequently, but practical experience has shown that I get at least four very good passes (of the six) per day. How does this data breakdown? I created a pie chart breaking the MaxEls into standard decimal groups of ten. Figure 8 shows the results.

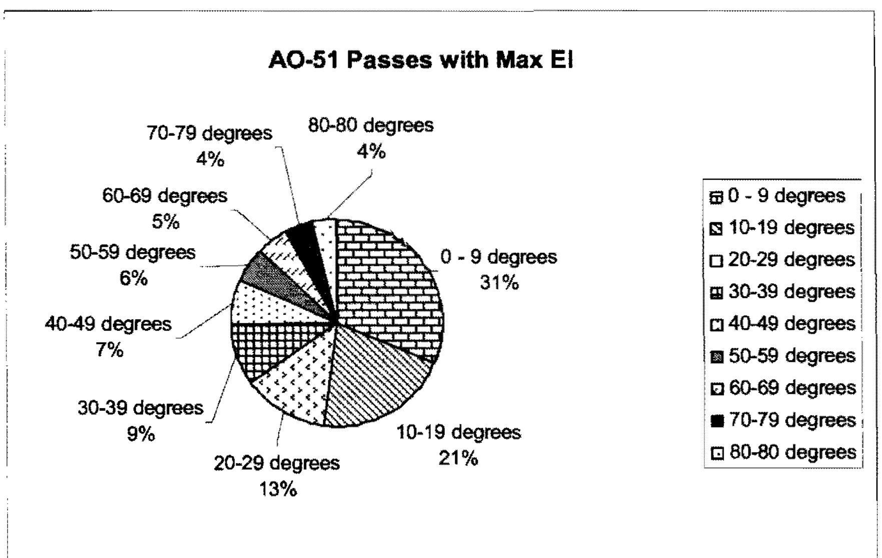


Figure 8.

65% of the passes are ≤ 30 º. 74% ≤ 40 º and 81% ≤ 50 º

One in three passes is less than 10 º, which corresponds with what I have observed.

Practically speaking passes above 5 ° are usable for me, especially for the digital modes which give me a little more quantitative feedback. So, re-addressing the breakdown for a more practical range, I take 0 ° - 5 ° as a special category, since these are very marginal passes. The results are shown in Figure 9. The graph shows that 81% of all AO-51 passes are useable at my QTH, which is better than my anecdotal observation of 4 out of 6 passes. I need to take more advantage of this.

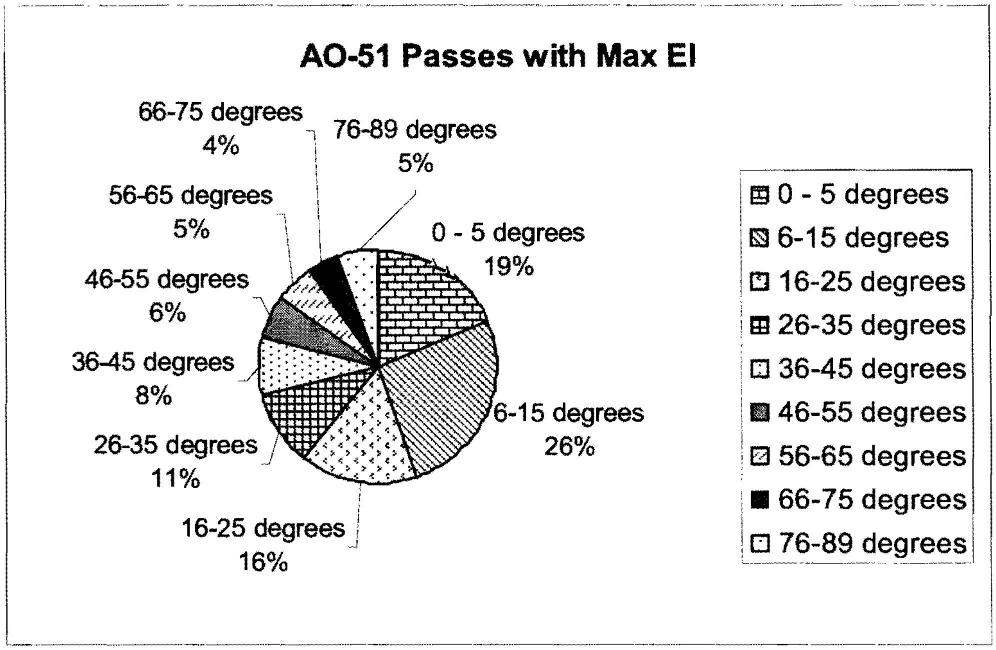


Figure 9. AO-51 MaxEls Breakdown at WA4SXM QTH

6 Shorter Term Pass Patterns

Now that we have looked at the pass breakdown over a long period, let's look at some shorter term patterns. This is probably elementary for the orbital mechanics people, but it is new territory for me.

Looking at Figure 10 you see that the 70 ° - 80 ° passes come in pairs about every 5 days or 30 passes. Often there are two pairs of 30 ° passes preceding them. Sometimes there are six 40 ° to 60 ° passes in between the 80 ° passes, sometimes four 40 ° to 50 ° passes between the 80 ° passes.

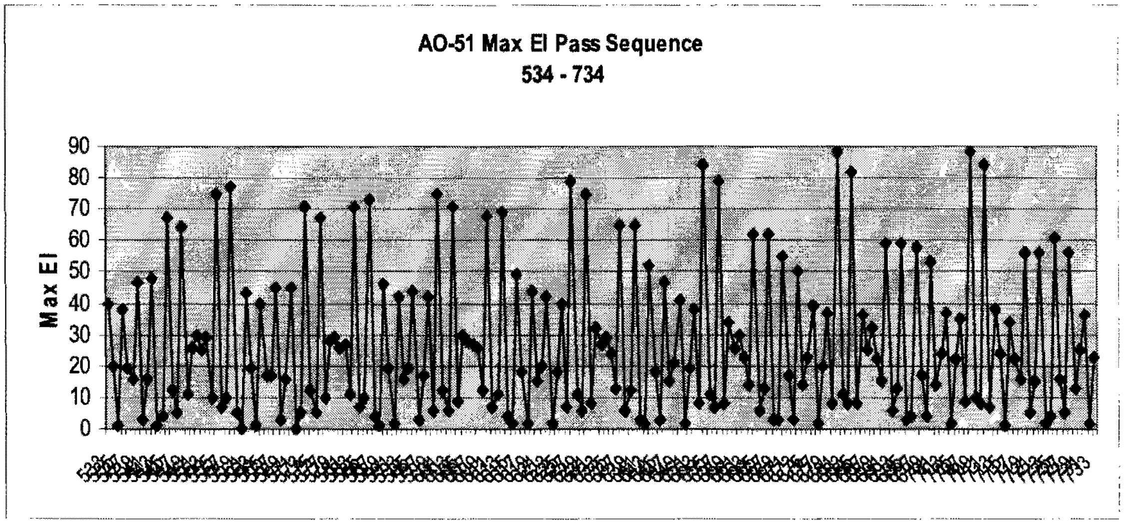


Figure 10. Typical AO-51 pass sequence at EM75xw showing 200 passes

Figure 11 shows a smaller and different part of the sequence, although it looks quite similar, the patterns begin to emerge.

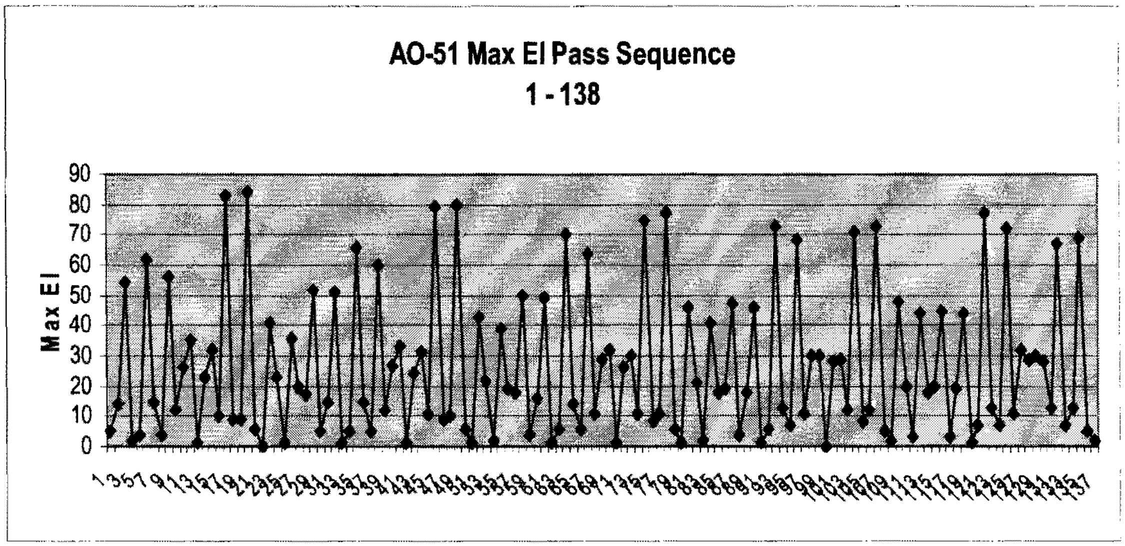


Figure 11. Another section of the AO-51 pass sequence showing only 138 passes

In Figure 11 it becomes obvious that there are a number of low, low high sequences. Upon closer inspection there are also a number of other pairs, *i.e.*, 30°s, 40°s, 50°s, 60°s and 80°s. Moving on to a very small sequence of only 24 consecutive pass and breaking them down into am and pm passes it becomes obvious in Figure 12 that the morning passes are almost duplicated by the evening passes. This duplication follows all three of the passes, not just the high maximum elevation part. I had noticed before that the highest elevation pass during the morning was often the same high elevation that evening, but hadn't paid attention that all three were duplicated in the evening pass.

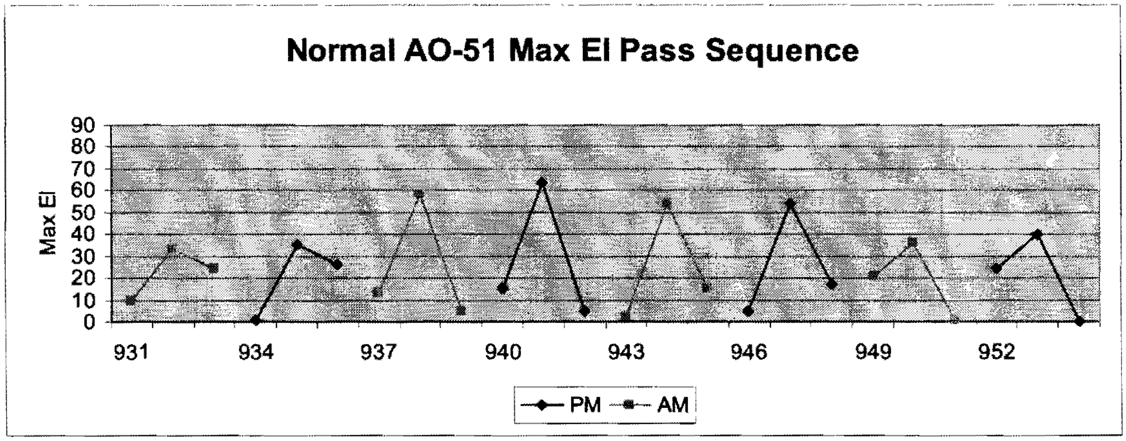


Figure 12. A smaller area of the AO-51 sequence

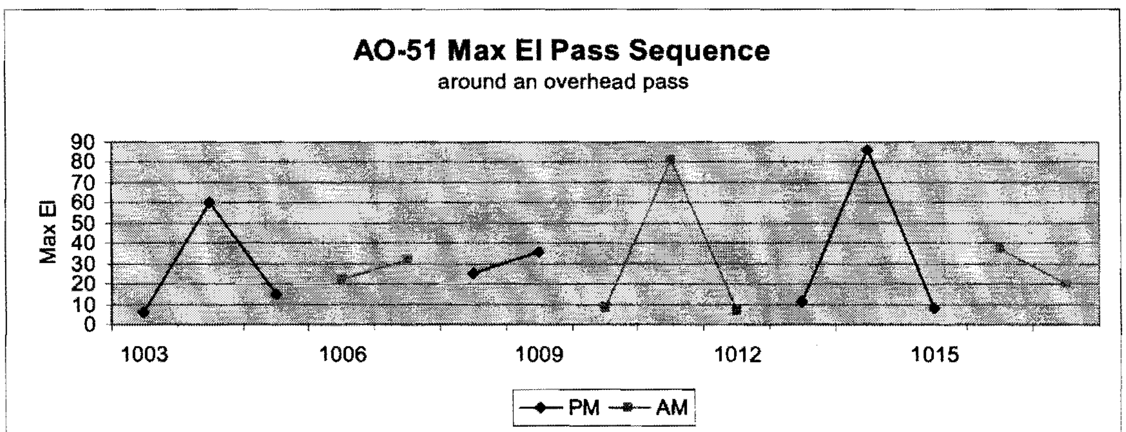


Figure 13. Another small sequence of am and pm AO-51 passes

7 AO-51 Profile at Other Sites

The next question that peaked my interest was "How consistent were these results for people at other QTHs" ?

- Because the satellite moves 1337 miles to the west each pass, does this cause different MaxEls for the stations over time?
- Because the earth is wider at the equator, how does this affect their MaxEl profile?
- Since this is a polar orbiting satellite, how many more passes do the northern states get?

I selected some representative locations to compile their AO-51 MaxEl data and compare with my data. To keep it interesting I selected some QTHs for some AMSAT volunteers in addition to cities. I added these locations/call signs to the IT Station Elements list and once again called upon ITPASS. I decided to check data for one month first; if it were representative, then I would have less data to contend with.

A representative ITPASS command string to collect data is:

itpass -s "Keith W5IU" -n 180 AO-51 >AO51W5IU.txt

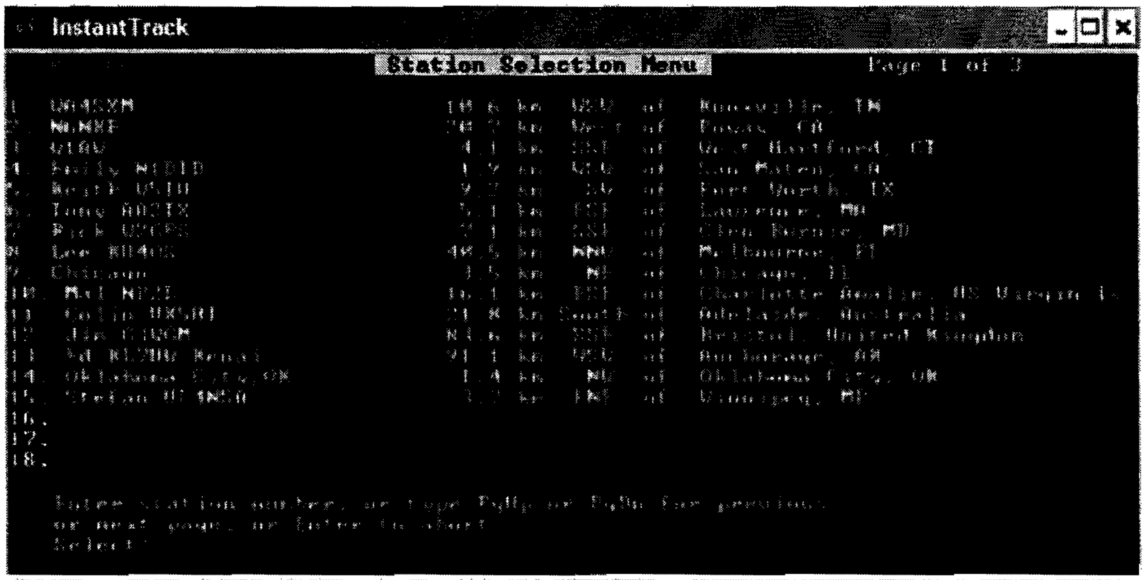


Figure 14. Selected observers in IT Station Elements list

Figure 15. North America observer locations

I chose the KU4OS, WA4SXM, Chicago and VE4NSA sequence first because they line up at about a 98° angle to the equator, the same as AO-51 inclination. I expected them to have very similar MaxEl profiles, and sure enough they did. Next I started mapping the MaxEl profiles of some of the other stations like W5IU, W2GPS, W1DID, Tony up in Massachusetts and Mal down in the Virgin Islands. To my surprise these graphs lay right on top of one another. In fact, my QTH saw the most movement from the norm, I tended to go higher and lower for most of the sequence.

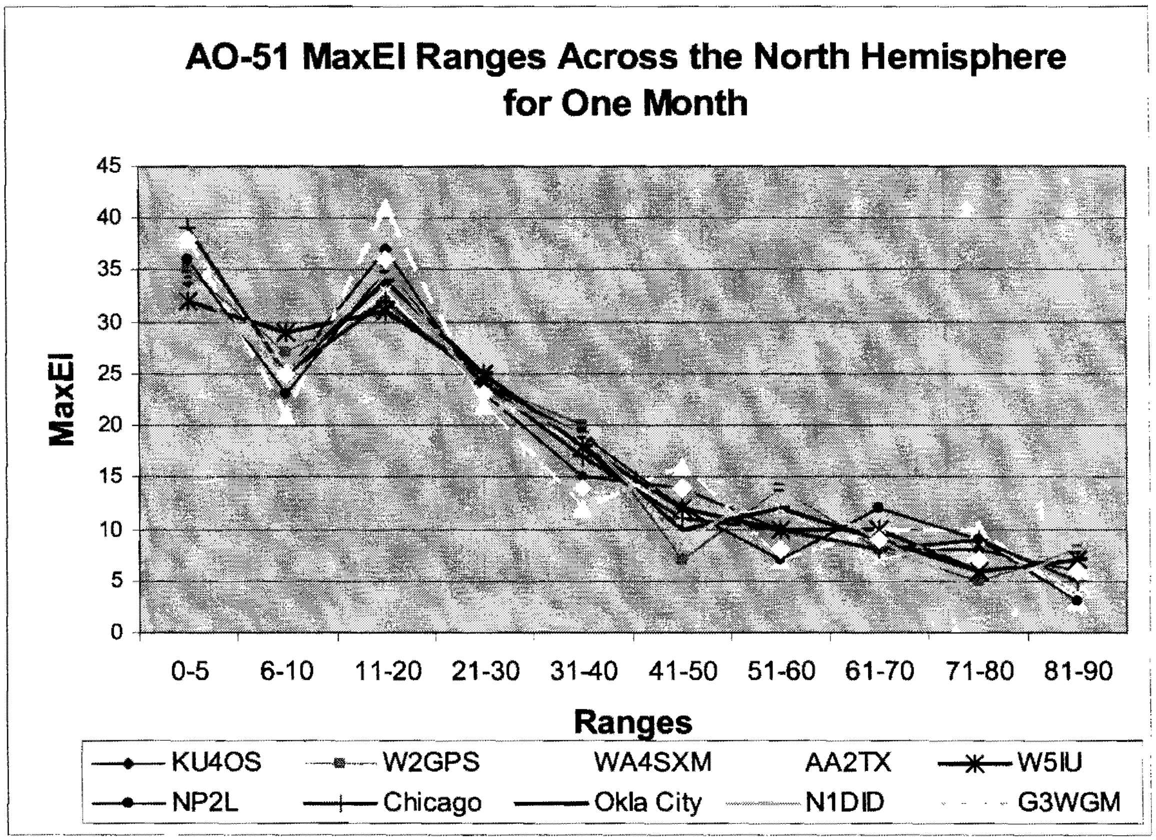


Figure 16. MaxEl pass profiles for various US stations

If you looked closely at the legend, you probably noticed that I also looked at Jim Heck on the southern coast of England, and his pattern fit right in. The initial values for the 0 to 5 degree passes occupy the highest number of passes, and only cover six MaxEL angles. The dip at the second value is because it only covers five MaxEl values, where all the others cover ten values.

I had some lengthy discussions with myself about whether to do 180 passes for everyone, or to cover the same number of days. For everyone except Mal, Stefan and Tony this wasn't a problem because they were the same. 180 passes for most of the test sites covered a period from the first evening pass on 3 September 2006 to the last morning pass on 4 October 2006 – one month.

Mal, NP2L in the Virgin Islands had fewer passes per day and it took until the first morning pass on 11 October 2006 to get his 180 passes – one extra week.

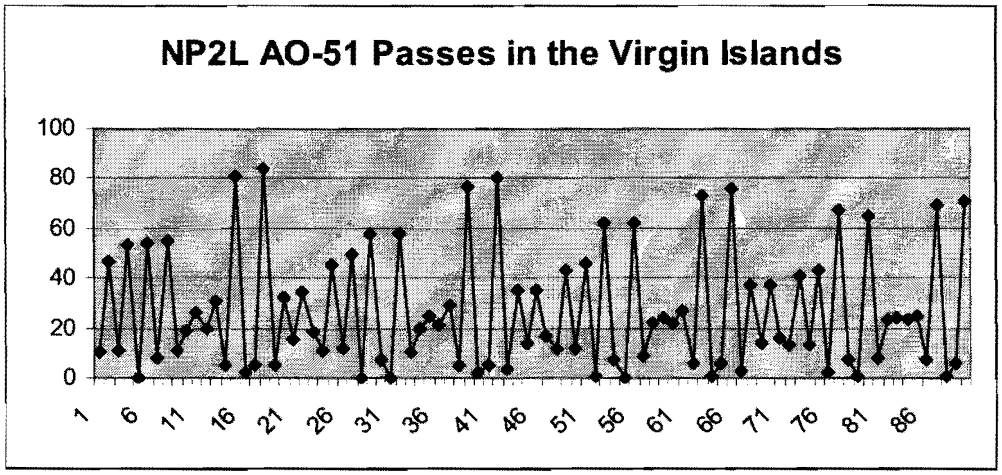


Figure 17. Virgin Island pass profile for AO-5

The pass profile looks familiar, but what is different are the morning and evening pass counts. In Figure 18 you can see that most of the time there are only 2 passes in the morning and 2 in the evening. If there are three passes, they are 0 – 2 degrees MaxEl.So, there are essentially only 4 passes per day. If you have a high MaxEl pass, like 80°, then there is essentially only 1 pass for the evening and morning session.

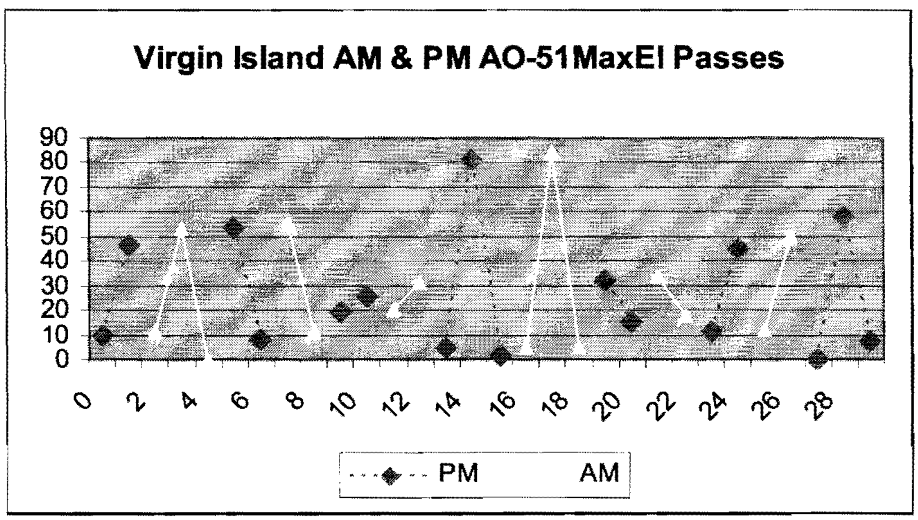


Figure 18. AM and PM AO-51 passes for the Virgin Islands

Moving north to Massachusetts, the time for Tony to get 180 passes was from first evening pass on 3 September 2006 to first morning pass on 1 October 2006 – 3 days less. Chicago was similar to Tony, same start time, but their 180 passes went through the first evening pass on 1 Oct 2006. This was 4 more passes than Tony, but 2+ days less than those of us further south.

Things start changing a little quicker when we move to Stefan in southern Manitoba. Tony has latitude of about 42.7 °N while Stefan is at 49.9 °N. To get 180 passes of AO-51 Stefan only had to go to the first evening pass on 27 September 2006- a week earlier than those of us to the south.

Now we move to Ed in Kenai Peninsula at latitude of 60.7 °N. To get 180 passes of AO-51, it only took Ed until the first evening pass on 20 September 2006 – 13 days earlier than us in the lower 48. Obviously the number of AO-51 passes per day changes a great deal. Figure 19 shows the MaxEl for the pass sequences in Alaska. The major difference in the pattern is that there are not morning and evening sessions. The sessions start about 1600 UTC go continually until about 0900 UTC – 11 consecutive passes. Then seven hours without any passes, then the sequence begins again.

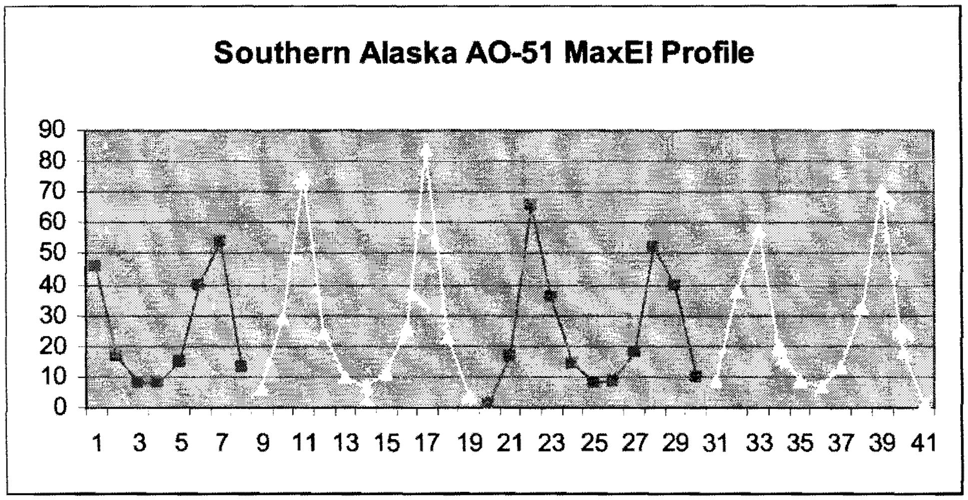


Figure 19. AO-51 MaxEl pass profile for Kenai

There is also a large change in the proportioning of the MaxEl of the passes in southern Alaska. Figure 20 shows some of the original QTHs as well as some new ones. AO-51 MaxEls passes for Colin, VK5HI in Adelaide on the central, southern coast of Australia blend right into the standard graph. You can see Stefan, VE4NSA's pass profile begin to rise from the melee.

Ed up in Alaska however shows a dramatic change in the number of passes with a MaxEl in the 6° - 30° range. The scale changes in Figure 20 to data for a month rather than a fixed number of passes. The Kenai sees fewer very low elevation passes and quite a few more mid range passes and fewer high MaxEl passes. In addition to the profile change, Ed gets 11 passes of AO-51 a day in which to operate.

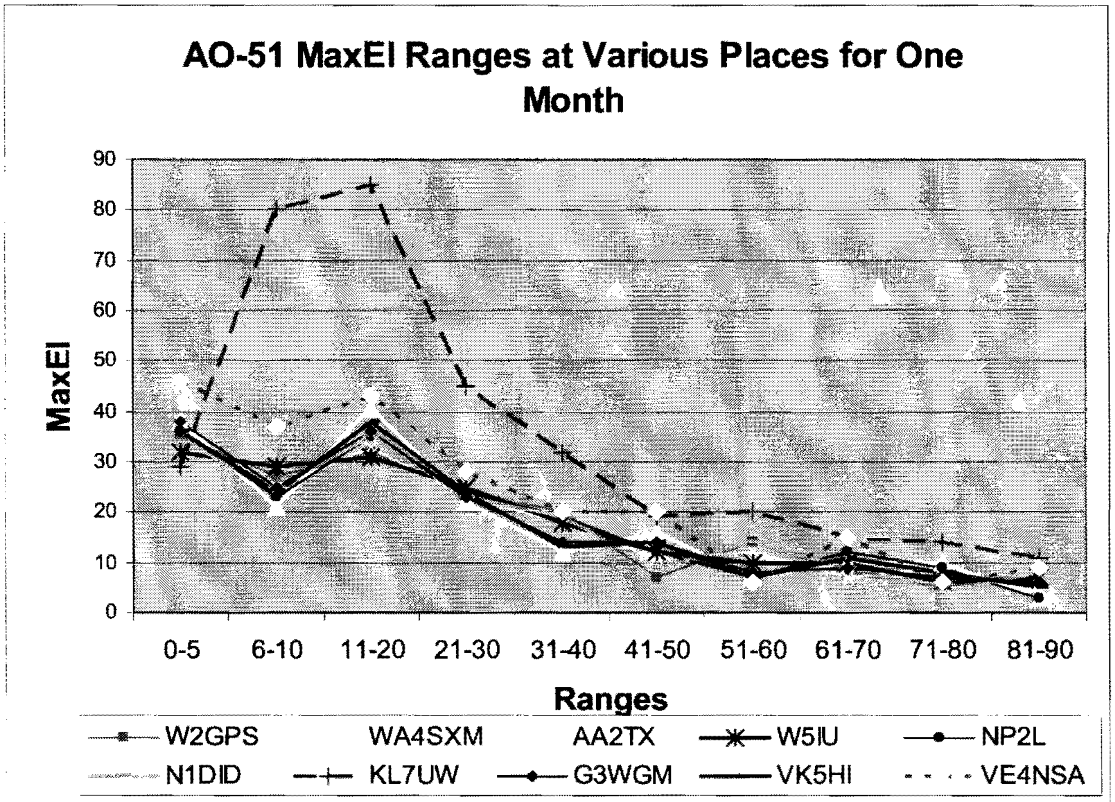


Figure 20. AO-51 MaxEl profiles from around the world

8 Summary

- Each AO-51 pass moves 3900 miles west at the mid latitudes
- The Range to the satellite is quite different than the altitude of the satellite
- AO-51 will give ground stations a 9-12dB signal strength change during a pass
- High MaxEl passes last longer and get the satellite closest to your QTH
- Range to AO-51 can change 2400km during a pass
- 81% of AO-51 passes have a MaxEl >5° (at mid latitudes)
- Evening and morning passes are very similar
- Everyone in the mid latitudes get the same AO-51 pass profile

References

http://www.terabeam.com/support/calculations/lat-long.php#calc lat/long distance measurements

WinGrid by Stacey Mills, W4SM, footprint diameter calculations

A Parasitic Lindenblad Antenna for 70cm

Presented by

Anthony Monteiro, AA2TX

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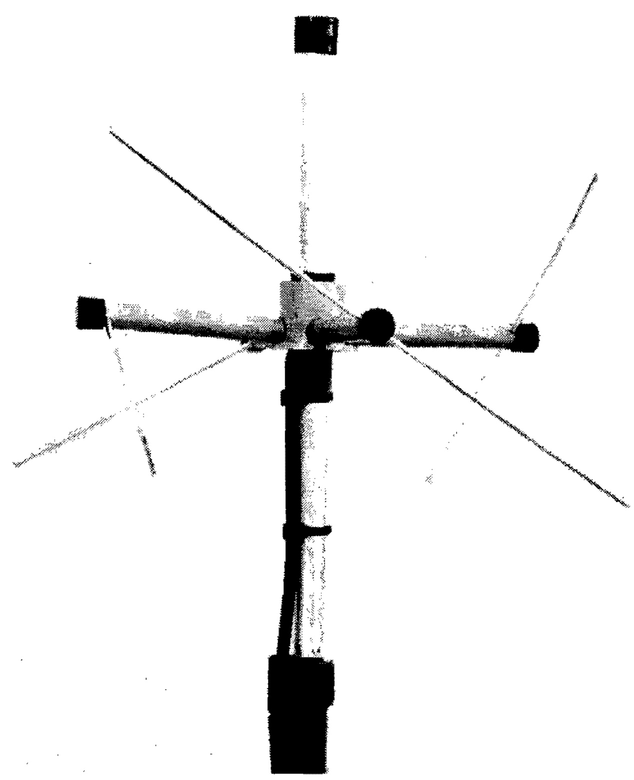
Abstract

A traditional Lindenblad antenna uses four, dipole, driven-elements to create a circularly-polarized, omni-directional radiation pattern. This pattern is ideal for accessing LEO satellites and can often eliminate the need for beam antennas and Az/El rotator systems. This makes them especially useful for portable and temporary satellite operation. Unfortunately, constructing these antennas can be difficult because of the need to feed the four, 75-ohm driven dipoles. Most previous designs have used folded-dipoles, balanced lines, BALUN transformers and/or special impedance matching sections in order to provide a good match to 50-ohms. On the 70cm band, higher precision is needed than for VHF and this can make the construction especially challenging.

This paper introduces a novel and considerably simpler way to construct a Lindenblad style antenna. It uses a single dipole, driven-element along with a passive, parasitic, circular-polarizer. The single driven element is designed to provide a 50-ohm load and the circular polarizer is very easy to build. While technically not a "Lindenblad," the antenna radiation pattern is nearly identical.



1 Introduction

A Lindenblad antenna provides circular polarization and an omni directional pattern that has most of its radiation 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 them ideal for portable and temporary satellite operation as well as providing a good option for permanent or fixed stations as well.

This antenna was invented by Nils Lindenblad of the Radio Corporation of America (RCA) around 1940. 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 $\lambda/3$ diameter. Figure 1 shows a drawing of the antenna concept. At the time, Lindenblad was working on antennas for the then nascent television industry but the start of World War II delayed further TV broadcasting work.

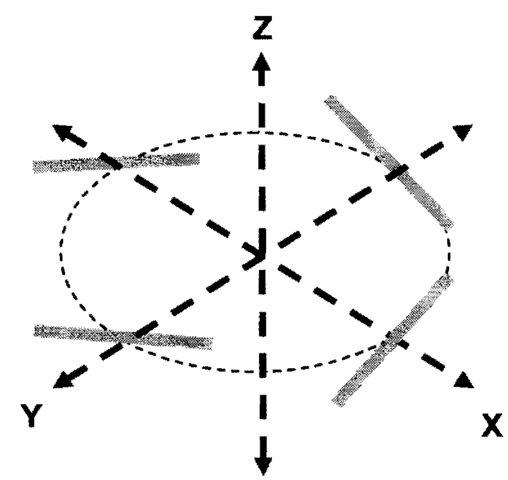


Figure 1. Drawing of Lindenblad antenna concept

After the war, Brown and Woodward, also of RCA, began investigating ways to reduce fading on airplane-to-airport radio links. Airplanes use nominally vertically 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[1] and constructed VHF and UHF prototypes. An original Brown and Woodward prototype is shown in the photograph of Figure 2.

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 the author to duplicate.

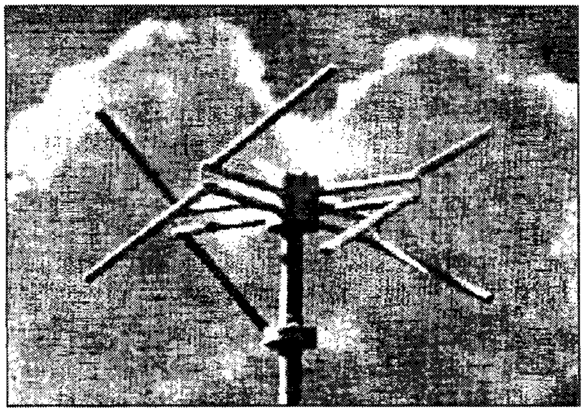


Figure 2. Photograph of early prototype Lindenblad[2]

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.

2 A Parasitic Lindenblad Antenna

The idea of a *Parasitic* Lindenblad is to use a single, dipole, driven element along with a passive, parasitic, circular polarizer to create the radiation pattern. This eliminates all the feed lines except the one for the driven dipole and helps make the construction significantly simpler.

Parasitic Elements

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 1920s3. 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 design was patented and assigned to the Radio Corporation of America (RCA) and by the late 1930s, 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, in the Parasitic Lindenblad, all of the antenna elements are in different planes as the purpose of the parasitic elements is to convert linear polarization to circular polarization.

Passive Circular Polarizer

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 at a spacing of 0.15 wavelengths. 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 basically 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 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 horizontal and vertical fields from the combination of the parasitic and driven 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 right-hand circular polarization.

Impedance Matching

At resonance, an ordinary dipole provides a load impedance of about 75 ohms. Due to the mutual electro-magnetic coupling to the parasitic elements however, the impedance of the driven dipole in the Parasitic Lindenblad would be about 32-ohms at resonance. This 32-ohm load would not provide a good match to 50-ohm coaxial cable.

To keep construction simple, it is desirable to provide a good match without requiring additional components or folded elements. This can be done by taking advantage of the stray capacitance at the dipole feed point. This stray capacitance is about 4pF and appears in parallel with the dipole feed. By making the driven dipole a little bit longer than the resonant length, we can introduce a small amount of inductive reactance. Using this inductive reactance and the stray capacitance, we can make an L-match impedance matching network and tune it to provide a good match to 50-ohms. The driven element need only be lengthened by ¾ of an inch to accomplish this so it does not affect the radiation pattern.

The vertical dipole driven element 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. This would negatively affect the radiation pattern and cause an impedance mismatch. Fortunately, it is very easy to make a choke BALUN by slipping a pair of inexpensive ($.56 each) ferrite cable sleeves over the outside of the coaxial cable. The coaxial cable runs down vertically from the center of the dipole and the sleeves are just aligned with the bottom of the dipole element which stops any cable radiation below the dipole.

3 Antenna Construction

This antenna was designed to be easy to construct using only hand tools. Most of the construction and materials are not critical and experienced antenna builders should feel free to substitute their own favorite techniques. The few critical dimensions are noted in the text.

Overview

The polarizer structure is made from UV-resistant (gray) PVC components that are cemented together. These are shown in Figure 3 and consist of four plastic rain-gutter ferrules and a 1" x ¾" PVC electrical conduit adapter. The polarizer structure is used to support the four parasitic elements which are made from 8-gauge aluminum ground wire.

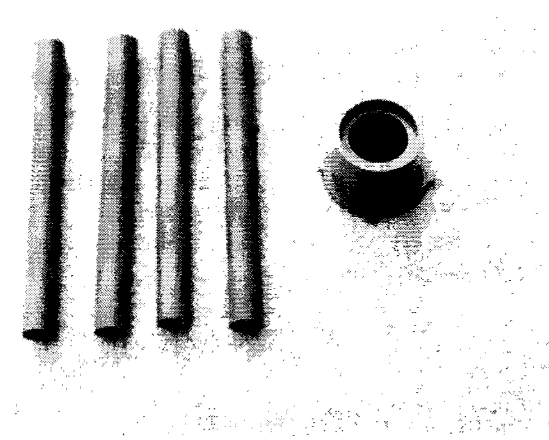


Figure 3. Standard PVC components used to make polarizer structure

The dipole driven element is made from two pieces of ¾" OD aluminum tubing that are connected with a PVC insert connector. The dipole is mounted to a threaded 12" x 1/2" PVC riser using an insert-to-threaded adapter. These PVC components are of the type used for lawn irrigation systems. The coaxial feed line is attached directly to the driven dipole using aluminum sheet metal screws.

Parts

The hardware components used in this antenna were readily found in a local *ACE Hardware* store and most of the parts are not critical so feel free to substitute as needed. However, the aluminum tubing used for the driven dipole must be ¾" outer diameter and construction will be easier if the tubing is 17-gauge as the inner wall will be just slightly smaller than the outer wall of a PVC-insert-connector. If heaver wall tubing is used, it will be necessary to file down the PVC insert-connector to make them fit together.

Table 1. Parts list

Quantity	Description
2	6-1/16" length of ¾" OD, 17-gauge, aluminum tubing Note: Available from Texas Towers www.texastowers.com
4	11.75" lengths of #8-AWG aluminum ground wire (or 1/8" OD tubing)
1	½" x ½" gray PVC insert connector
1	½" to ½" gray PVC insert-to-threaded adapter
1	12" x ½" threaded gray PVC riser
4	5" x ½" gray PVC ferrule for spacing rain gutter nails
1	1" to ¾" PVC electrical conduit adapter
2	#6 x 3/8" aluminum sheet metal screw
2	#8 x ½" aluminum sheet metal screws
2	Fair-Rite cable ferrite. Part# 2643540002. Note: Available from Mouser Electronics, www.mouser.com Stock# 623-2643540002
1	3-foot to 10-foot length of Times Microwave LMR-240 coaxial cable
1	Male N-connector for LMR-240 coaxial cable
1	¾" Black plastic end cap
4	½" Black plastic end cap
Misc.	Heat shrink tubing for 3/4" cable, Regular bodied gray PVC solvent cement for Carlon™ conduit,, *Marine Goop™* outdoor waterproof contact adhesive, *Ox-Gard™ OX-100* grease for aluminum electrical connections, black wire ties

The LMR-240 coaxial cable was selected because of its low-loss, low cost and wide availability but any 50-ohm small diameter cable may be used. The cable ferrites have a 0.25" inner diameter so the cable needs to be smaller than this to fit.

Assembly

Start by making the parasitic element assemblies, see Figure 4. 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 ground wire through the hole in the ferrule and center the wire 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 the Goop™ is dry.

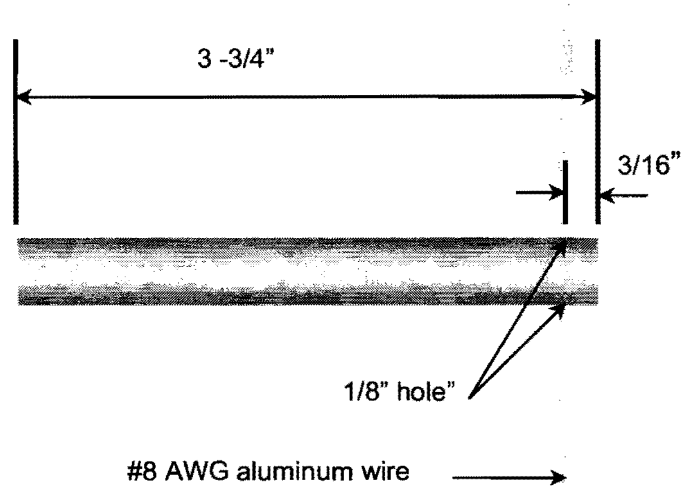


Figure 4. Parasitic element assembly

Next make the driven dipole assembly. Please see Figure 5. Gently tap the PVC insert connector into the two pieces of aluminum tubing with a mallet or hammer until they are spaced ¼" in the center. The overall dipole length should be 12-3/8". Then, drill a hole for a #6 screw, 3/8" from end of the tubing at the center insulator. Directly across the insulator, also spaced 3/8" from the end, drill a hole for a #8 screw.

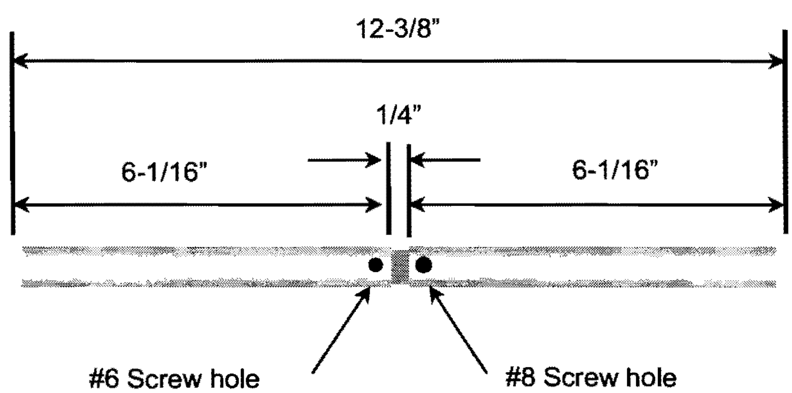


Figure 5. Driven dipole assembly

Clean the holes in the dipole with steel wool and apply *Ox-Gard™* grease. Carefully thread the machine screws in the holes but do not tighten them. Strip the insulation from one end of the coax and un-braid the shield making a pair of wires. Leave about ¼" insulation on the center conductor. Wrap the center conductor around the #6 screw and the shield around the #8 screw and tighten as shown in Figure 6. Attach the coaxial cable with wire ties to hold it in place.

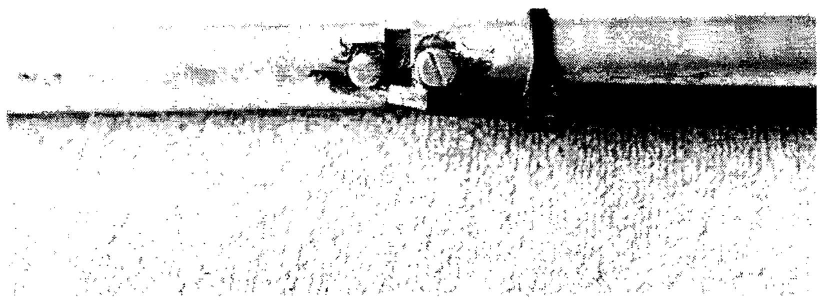


Figure 6. Coax cable attached to dipole

Slip the heat-shrink tubing over the dipole connections and heat until it makes a tight fit as shown in Figure 7.

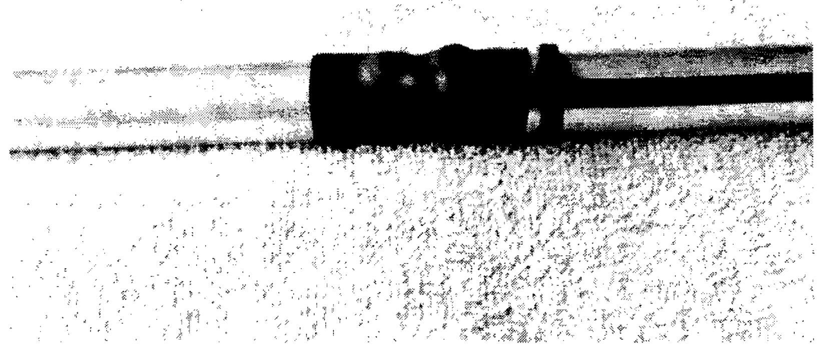


Figure 7. Dipole with heat-shrink tubing applied

Push the insert end of the insert-to-threaded PVC adapter into the end of the aluminum tubing with the coaxial cable. Drill a hole for a #6 screw and secure the tubing to the insert adapter. Thread the 12" riser onto the threaded end of the adapter. This provides an insulated section to use for fastening the antenna to a mast. Slip the cable ferrites over the open end of the coaxial cable and align them with the bottom of the driven dipole as shown in Figure 8. Fasten the ferrites and cable with wire ties.

Attach the N-connector to the open and of the cable. The cable length does not matter and should selected for convenience. On the author's unit, 10-feet of cable were used because the antenna was to be mounted on a 10-foot portable mast.

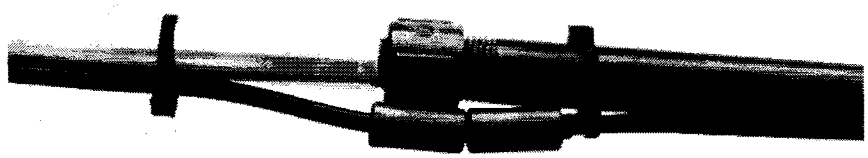


Figure 8. Ferrites aligned with bottom of driven dipole

To make the parasitic element hub, drill four, ½" holes in the conduit adapter, spaced equally around the adapter with the holes flush with the top of the flange (i.e. the ¾" conduit end.) The four parasitic element assemblies will fit into these holes but do not attach them yet.

Using a file or a *Dremel™* tool, create a small channel for the #6 screw at the dipole center. The parasitic element hub needs to fit over the driven dipole so that the ½" holes are centered on the PVC insulator. Create the channel so that the hub fits flat over the center part of the dipole.

After this is done, drill a hole through the top part of the hub and through the aluminum tubing for a #8 machine screw. Screw in the #8 screw to hold the hub in place.

Temporarily attach the 12" PVC riser to a vertical support so that it is perfectly straight. For each parasitic assembly, apply the gray PVC solvent cement around the outside of the ferrule on the end away from the aluminum wire. Carefully insert the ferrule into the ½" hole in the hub about 1/8" and quickly set the angle of the wire to 30-degrees from horizontal by rotating the ferrule. Looking towards the hub, the left hand side of the wire should be up. The aluminum wire should be 3-9/16" from the outer wall of the dipole. This is 4-1/16" from the exact center of the antenna. Allow the PVC cement to dry on all of the parasitic assemblies.

When dry, push the plastic end-caps onto the ferrules and the top of the dipole. This completes the construction of the antenna. The completed antenna is shown in Figure 9.

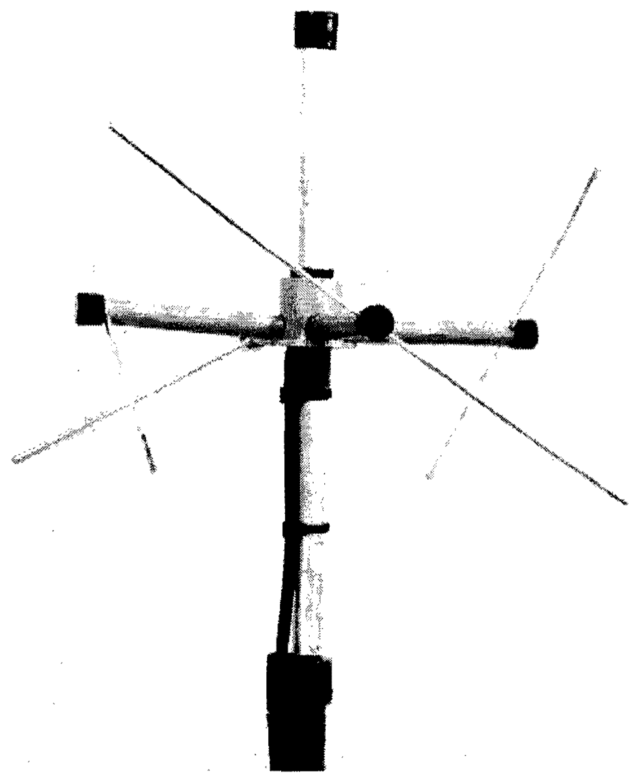


Figure 9. The completed Parasitic Lindenblad antenna

The PVC riser is used to attach the antenna to a mast. A pair of U-bolts can be used for this in the traditional manner. Since the author's antenna was intended for portable use, a quick connect scheme was used instead. A ½" to 1" PVC conduit adapter was cemented to the end of the 12" riser after cutting off the threaded section. This fits into the top of a portable mast. A hole was drilled through the mast and the PVC adapter near the top of the portable mast and was fitted with a 2" long, #8 stainless steel screw. A #8 stainless thumbscrew is used to secure the antenna to the mast. This arrangement, shown in Figure 10, allows the antenna to be put up and taken down in less than 5 minutes.

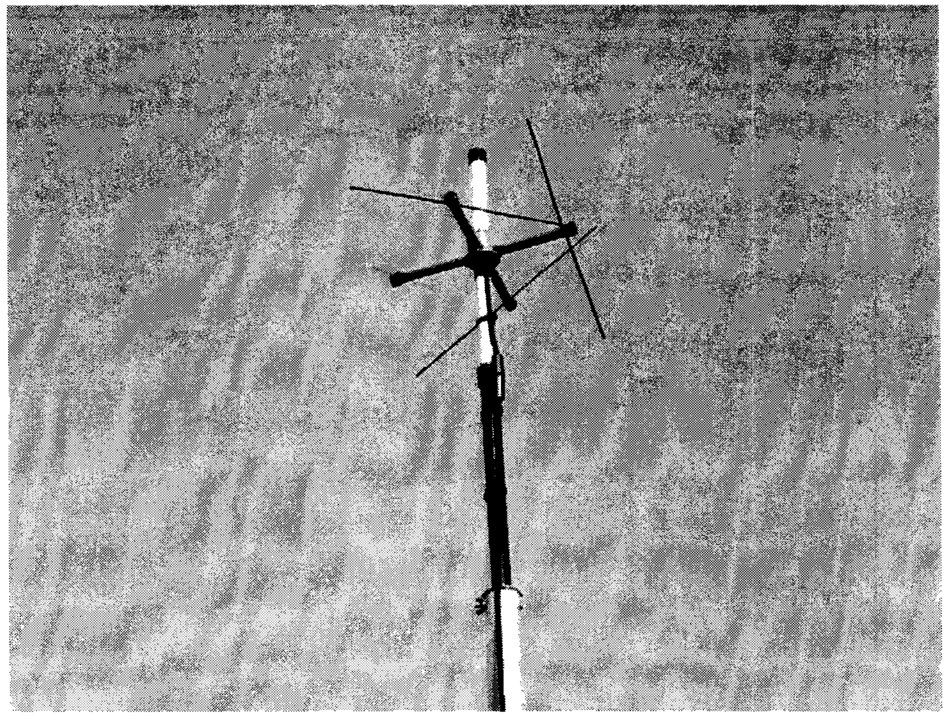


Figure 10. Antenna attached to the portable mast

4 Radiation Pattern and Gain

The antenna elevation pattern predicted by an EZNEC[4] model is shown in Figure 11. This is the right-hand circularly polarized gain with the antenna is mounted at 10-feet above real ground. The Primary plot in black is the pattern of the Parasitic Lindenblad antenna. The plot in gray 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.

The maximum gain predicted by the model is 7.47 dBic at an angle of 3-degrees elevation. Note that the 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.

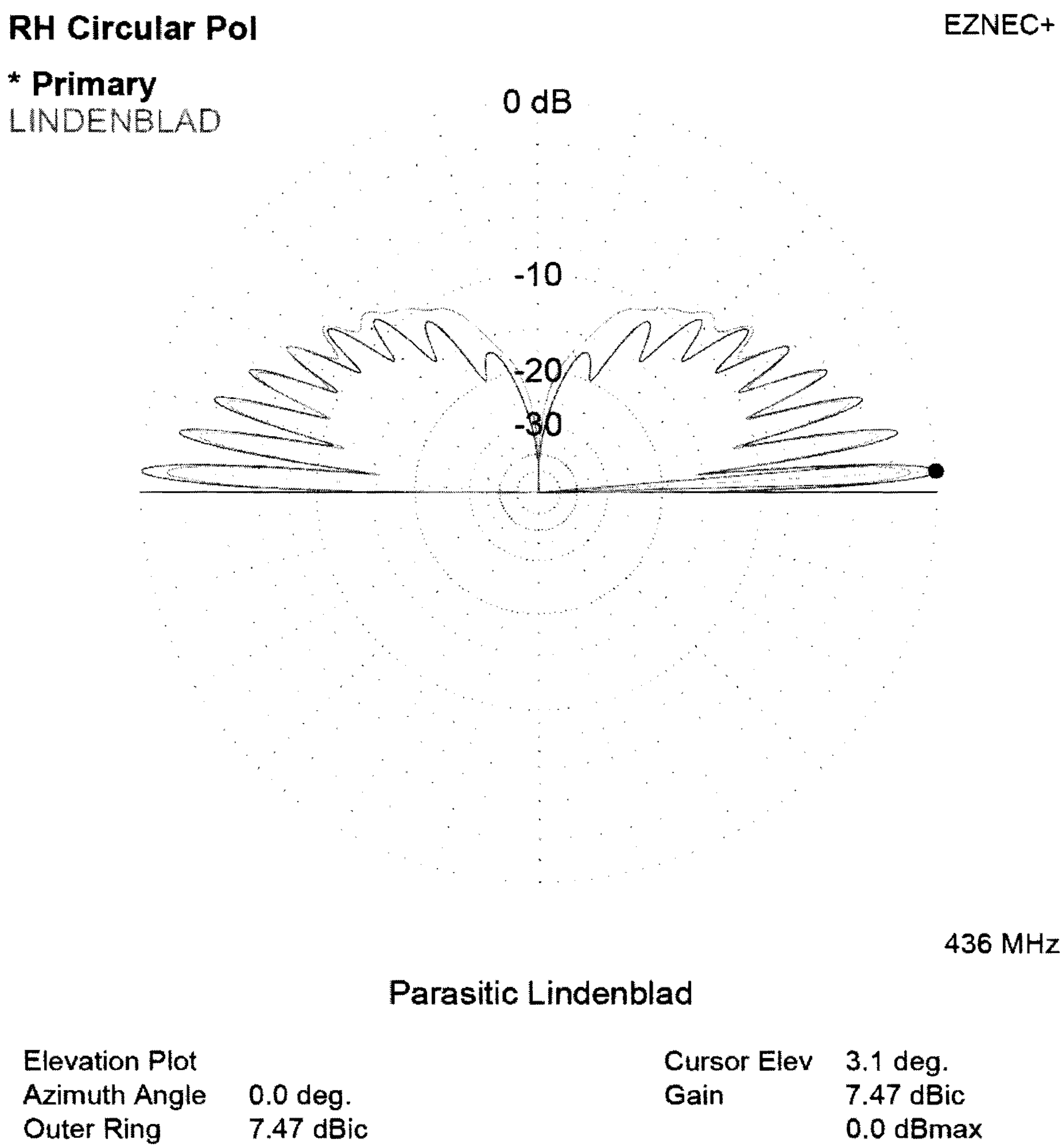


Figure 11. Antenna elevation pattern

5 Testing

This antenna was designed to work as assembled with no adjustments and no testing or test equipment required. However, the prototype was tested in order to verify the antenna design. These tests are not needed when constructing a copy of the antenna.

Impedance Match

The impedance match to 50-ohms was checked using an AEA-Technology 140-525 Analyzer. This device plots a graph of the standing wave ratio versus frequency and has an LCD digital readout. The antenna was directly connected to the analyzer through its 10-foot feed cable. The SWR was measured over a 20 MHz range centered at 436 MHz and the results are shown in the chart of Figure 12.

As can be seen in the chart, the antenna provides an excellent match over the satellite sub-band from 435-437 MHz and the SWR is very low over the entire measured 426-446 MHz range. The low SWR allows this antenna to be used as a general purpose antenna for 70cm including FM and repeater use. It is important to note that the actual SWR will vary with antenna height and ground quality but, it will easily provide the 1.5:1 or better match that most modern transmitters require in order to provide maximum power.

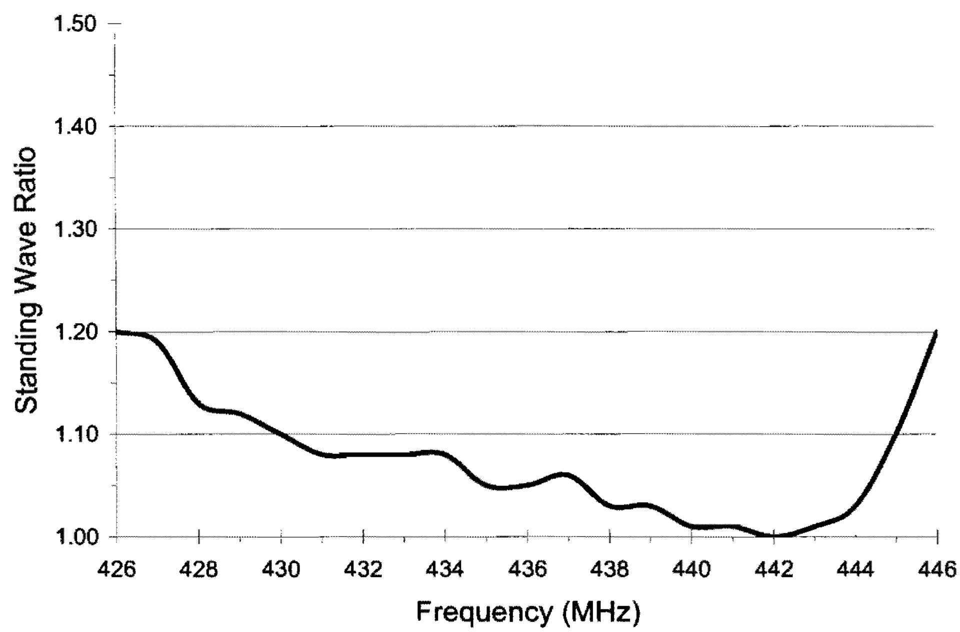


Figure 12. SWR versus frequency

Power Handling

This antenna was designed to handle the power from any of the currently available ham radio transceivers. A test was run with a Yaesu FT-847 radio operating on 436 MHz at its maximum output of 50 watts. It was connected through approximately 100-feet of coaxial cable to the Parasitic Lindenblad antenna prototype. The power at the antenna input connector was measured using a Bird™ Thruline Wattmeter and showed about 30 watts forward power. The reflected power was much less than the first mark on the meter scale confirming the low measured SWR. The FT-847 was operated key-down to provide a continuous carrier for 9-1/2 minutes. There were no observed ill effects on the antenna although the power from the FT-847 dropped a few watts by the end of the test.

An overload test was also run using about 100 watts at the antenna via a high-power amplifier. After about 5 minutes of key-down, continuous operation, there were no observed ill effects to the antenna although the ferrites were noticeably warm.

Circularity

The circularity was checked by using a phased array sense antenna that could be selected for either horizontal or vertical polarization. The sense antenna was connected to a Yaesu FT-817 radio in USB mode with the AGC switched off. The output of the FT-817 was fed to an AC voltmeter calibrated in dB. The antenna under test was set up at a height of 10-feet and approximately 100-feet from the sense antenna location. An un-modulated carrier signal at 436 MHz was fed to the antenna under test using a signal generator.

A horizontally polarized reference antenna was tested first. The sense antenna was switched from horizontal to vertical. The reference antenna showed about 15 dB difference between horizontal versus vertical polarization. The Parasitic Lindenblad antenna was tested next using the same procedure and showed no measurable difference between the horizontal and vertical polarization of the sense antenna indicating very good circularity.

6 Summary

This paper has presented a design for a Parasitic Lindenblad antenna. This antenna has only a single, dipole, driven element and uses a passive, parasitic, circular polarizer to create the same radiation pattern as a Lindenblad antenna. This approach makes construction of the antenna significantly simpler.

The Parasitic Lindenblad antenna was used to make SSB and FM voice contacts via the AO-07, FO-29, SO-50, AO-51 and VO-52 satellites during a test session and on ARRL Field Day 2006. Field day is an excellent test of an antenna as it is probably the busiest time of the year on the satellites and the antenna performed well.

The Parasitic Lindenblad is omni-directional and does not require an antenna rotator system making it an ideal choice for both portable and fixed station use on LEO satellites.

Tony Monteiro, AA2TX, was first licensed in 1973 as WN2RBM and has been a member of AMSAT since 1994. He worked in the communications industry for over 25 years and was a member of the technical staff at Bell Laboratories and a senior manager at several telecommunications companies.

[1] *Circularly Polarized Omnidirectional Antenna*, by George H. Brown and O. M. Woodward Jr., RCA Review vol. 8, no. 2, June 1947, pp. 259-269.
[2] Ibid. pg 267.
[3] *Directive Short Wave Antenna, 1924,* IEEE History Center, Rutgers University, New Brunswick, NJ, USA available at: www.ieee.org
[4] EZNEC+ V4 antenna software by Roy W. Lewallen (W7EL.) Available from: www.eznec.com

Old Dogs Can Teach Themselves New Tricks

Presented by

Nick Pugh, K5QXJ

K5QXJ@AMSAT.ORG

Abstract

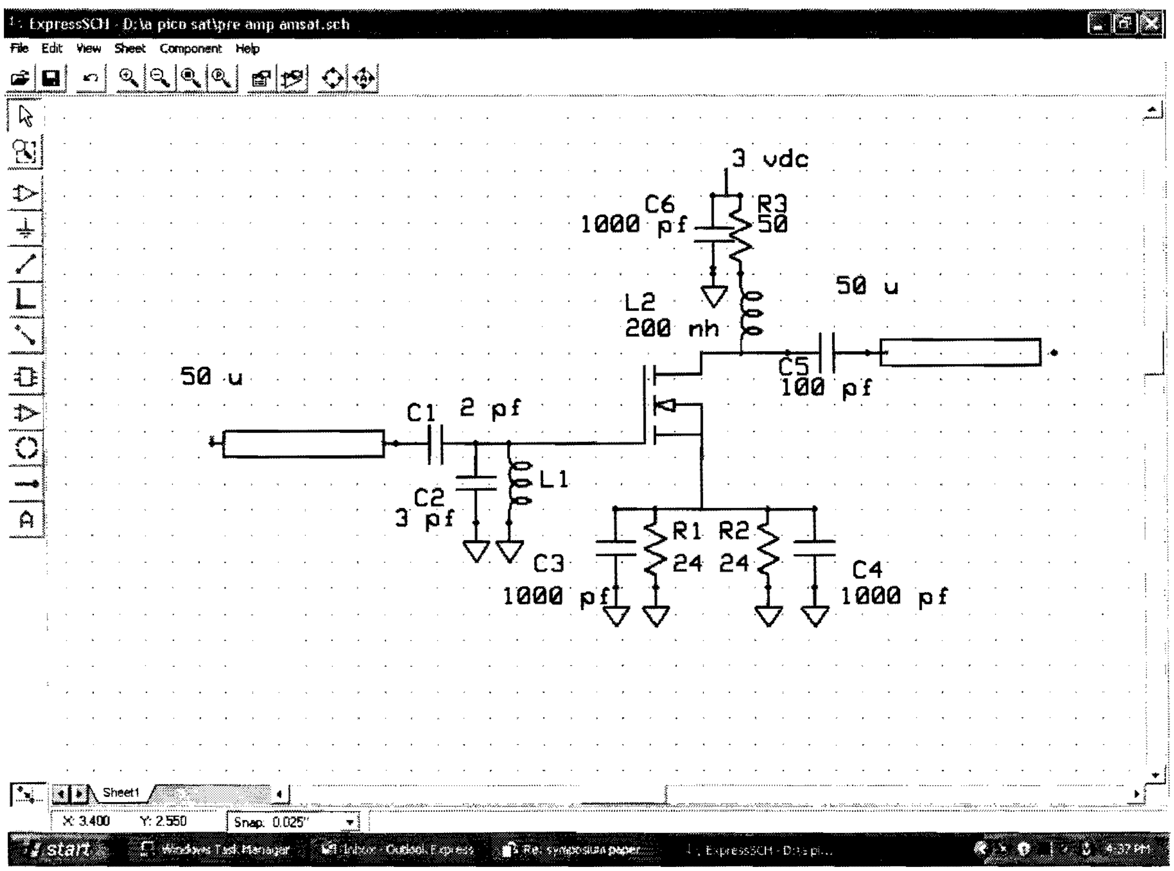
This presentation is a demonstration of two freeware programs to accomplish schematic capture and printed circuit board layout. The use of this software allows amateurs, with very limited experience to design and purchase printed circuit board for less than $55.

The demonstration will show the layout of a UHF preamp using surface mount components that allow printed circuits to be ordered with two day delivery. This presentation includes a cursory tutorial on surface mount devices and the tools needed to populate a PCB. The over reaching theme of this presentation is," as components get smaller and as aging amateur eye sight diminishes", there are very inexpensive and intuitive tools that allow amateurs to produce complex designs.

1 Draw a Schematic

The first step in any design is to draw a schematic. In years past we would simply pick up a pencil and paper and hand draw a schematic. The next step would be to layout the PCB with tape on Mylar. Today there are newer methods to get this job done. The designer has many choices and the cost of these tools range from free to several 10's of thousand dollars. Hams usually choose free but with free you lose some nice features. I recommend two software packages that can be downloaded at www.expresspcb.com. There are several other free software packages available however the author has used the package above and finds it adequate and very intuitive with a gentle learning curve.

The next step is to open the program "ExpressSCH.exe" and draw the schematic. This is a very intuitive program and within a reasonable time you will be able to produce a schematic. Below is a simple schematic of a UHF preamp. This pre amp is part of the CAPE cube satellite, which should fly this year.

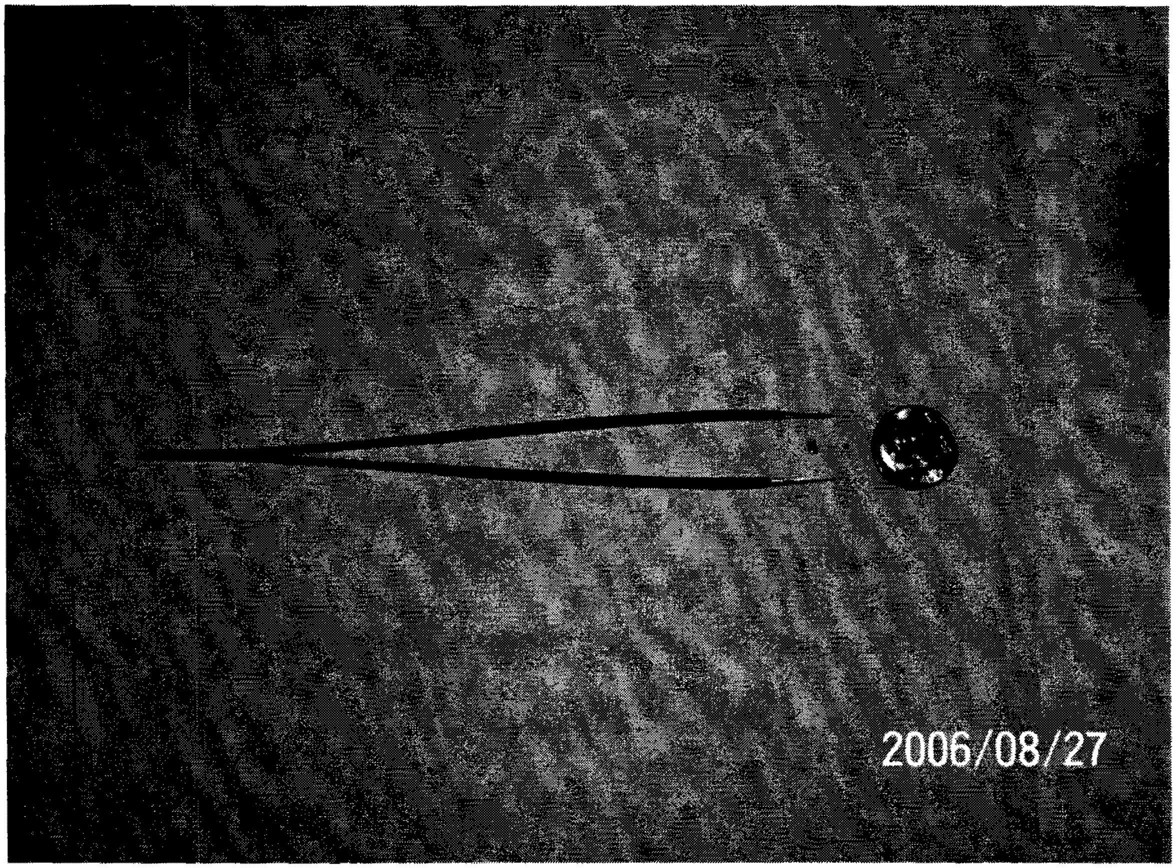


The above schematic took the author less than 10 minuets to produce. This is a document that can be printed or electronically shared with others in its native freeware or as a bit map.

2 Select Components

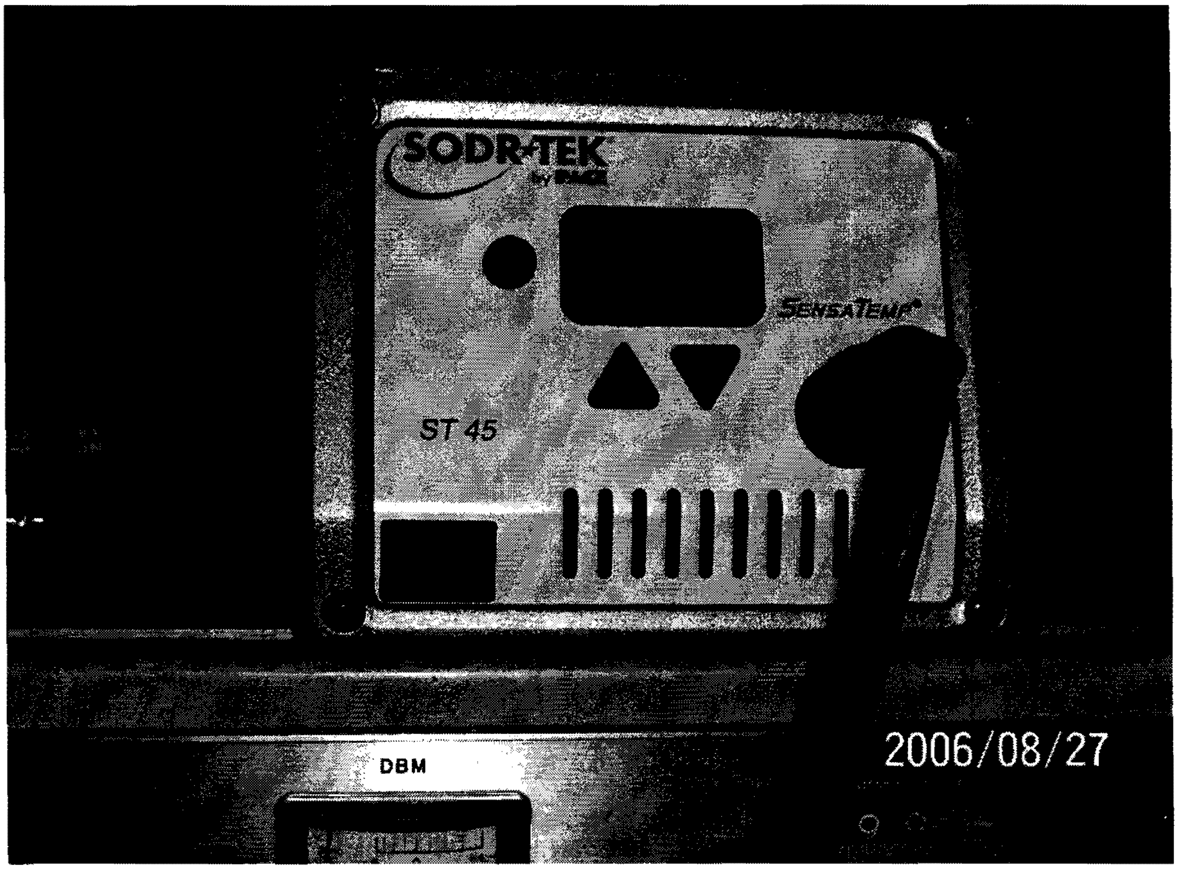
The next step is to pick the components that will go into the design. The design becomes interesting for those who cut our teeth on tubes. The new technology uses surface mounted device. These devices come in various sizes however, for this presentation we will examine only two sizes.

The object in the middle is a dime. The spec on the left is a 1000 pf capacitor and has a size designation of "0603" The slightly larger object on the right is a 10 uf capacitor and it's size designation is "1206". The good news is that these devices are available at Digikey and other supply house. They can be delivered overnight. The cost for the 1000pf cap is $.03 in quantities of 10 and the cost of the 10 uf cap is $0.30 in quantities of 10. The devices are extremely small. If you drop them on the floor they are probably lost, so buy in quantities of 100 and take advantages of the 30% or better discounts. The big advantage of surface mount devices is when used in UHF design, is that a device marked 3pf has very little parasitic resistance and inductance. The disadvantage is that they are small and are not easily handle by hand. There are tools to pick up and place these components on printed circuit boards.

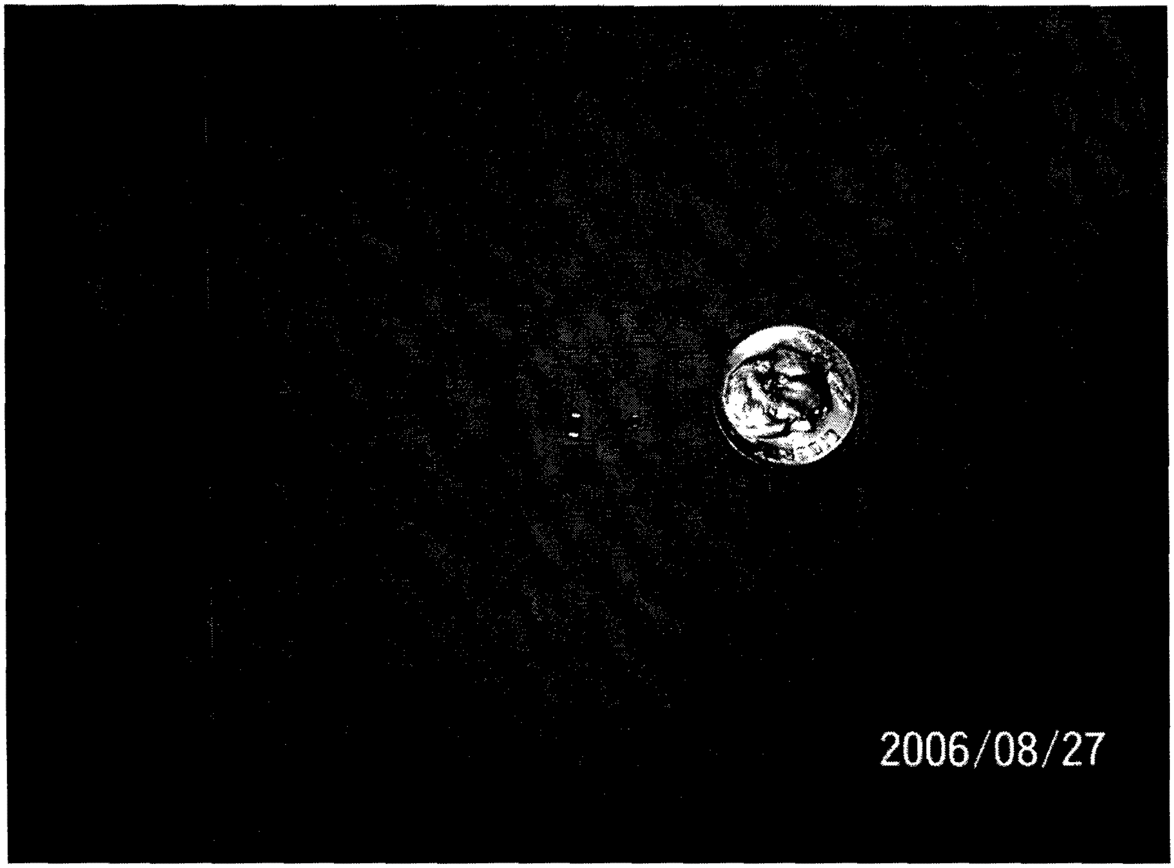


The tweezers in the picture are designed to handle these device and they are costly approximately $20.

Once these devices are placed on the PCB, it takes a special a soldering iron to solder these devices. There are several soldering irons on the market. Below is picture of one the author uses and finds satisfactory. I do not recommend look-alike devices that show up on Ebay for about $20. The unit pictured below costs about $120. The same manufacturer makes an analog unit for $20 less dollars that is faster than the digital model.



These units come with interchangeable tips. The author recommends that 1/32 inch tip is the smallest tip used. A larger tip that has a chisel shape is useful for mounting larger parts.

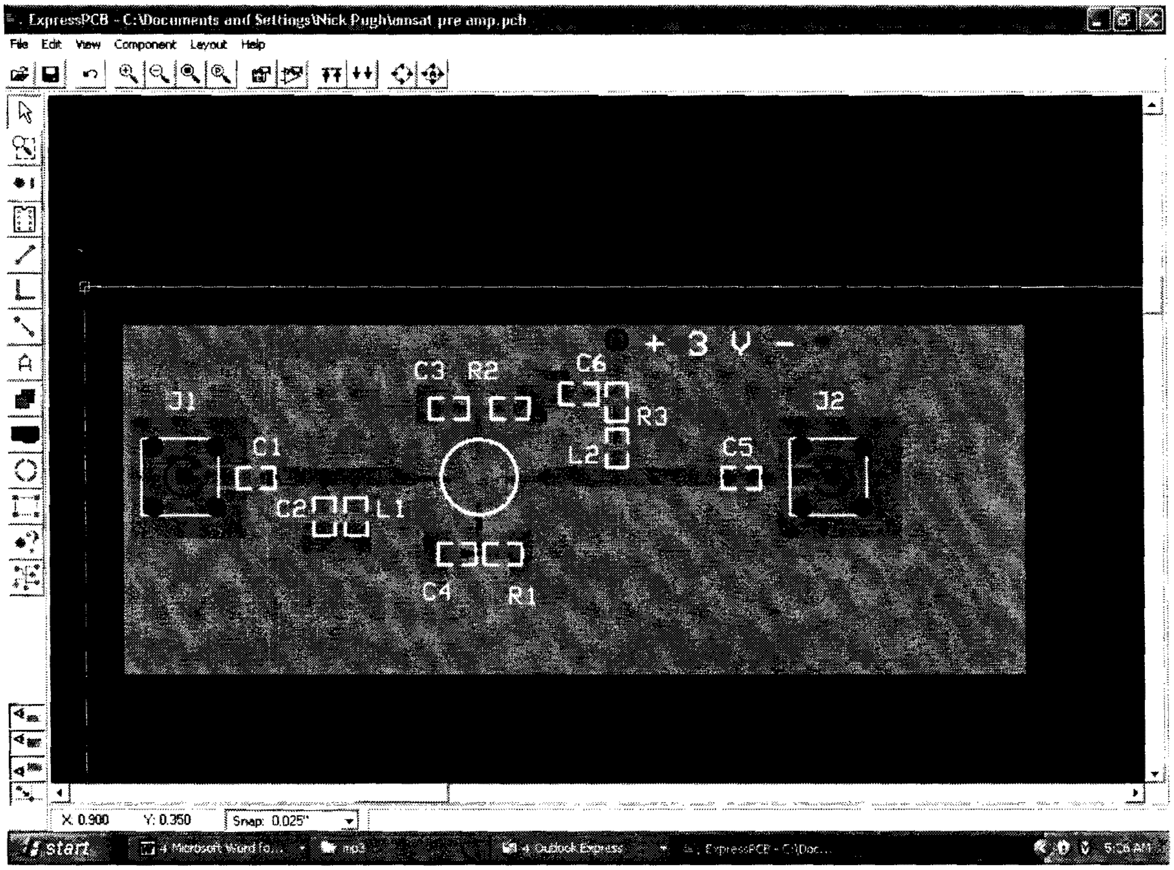


Notice in the picture that the tip is about the same size of the 0603 component. It takes some practice to get proficient in soldering these components. The professionals usually mount the components under a microscope, but as hobbyists, the device shown below leaves a lot to be desired but is adequate.

In addition, other items that are useful is a flux pencil and solder wick. All of these items are available at Digikey.

3 Lay Out the PCB

The second to last step is to take the schematic and lay out the PCB. This is accomplished with the freeware "Expresspcb.exe". This program is intuitive and works similar to ExpressSCH.exe. There are several free programs available however, the author has used this program and finds it adequate. It is easy to use and share with others in either the native freeware or via bit map format.



4 Push the Button

The last step is to push the order button embedded in the software and ding your credit card for approximately $55. You will receive two PCB's delivered via UPS in two days.

5 Conclusion

For those inclined to do circuit design even at microwave frequencies, it doesn't take long to acquire the necessary skills. You can deliver very clever designs and share them with our community at very reasonable prices.

History and Traditions of the AMSAT HF Nets

Presented by

Keith D. Pugh, W5IU

Abstract

This paper presents the history of how the AMSAT News Service relayed information across the country and around the world from the early days until the present. Emphasis is on the HF Nets - the bands, the people, the information. The question is raised: Do we still need them today?

About the Author

Keith Pugh has been an active Amateur Radio Operator since August, 1953, and has been active in AMSAT since 1982 starting with AO-08. During the early days of AO-40 he held the position of AMSAT VP of Operations. He holds an Amateur Extra class license and is a retired Radar and Navigation Systems Engineer from Lockheed Martin Aeronautics Company. He has been active on all of the AMSAT HF Nets since 1982 and currently is the Lead NCS on the AMSAT 20 Meter Net.

1 Yesterday

Since the early days of Amateur Radio Satellites, AMSAT has operated a series of HF Nets to disseminate timely news and data necessary for operation on the satellites. In the true spirit of Amateur Radio, these nets were originally organized to relay the information across the country and the world. In the early days, the Internet did not exist and weekly nets operating on various HF Bands were the most effective means available to spread the news and data. The HF Nets also served as places for interested amateurs to learn about Amateur Radio Satellites and for experienced satellite operators to share experiences, Hints and Kinks, etc., with the newcomers to the ranks. In the early days, a lot of time was consumed doing a voice relay of the current Keplerian Data.

Nets operated on several of the HF bands: 75, 20, 15, 17, and 10 meters. Typically the information flow started on the East Coast 75 Meter Regional Net and was relayed to the Mid America and West Coast nets in turn. This was done in a three hour time slot on Tuesday evenings starting at 2100 Eastern Time. The Mid America Net came on at 2100 Central Time and was followed by the West Coast Net at 2000 Pacific Time. The same basic information was used on the 20, 15, and 17 meter nets that met on Sunday afternoons and the 10 meter net on Saturday. Late breaking items were added as they came up. Over the years the 15, 17, and 10 meter nets were greatly affected by changes in the Sun Spot Cycle and did not operate in the "poor years." Eventually these three nets were dropped altogether.

A similar series of nets operated in the United Kingdom for many years. Additional nets existed in other parts of the world. When propagation permitted, Information was relayed between the North America and United Kingdom nets, usually during the 20 Meter Net.

No discussion of AMSAT HF Net history would be complete without mentioning at least some of their "voices" over the years. In North America the ones that come to mind are: Vern (Rip) Riportella, WA2LQQ; Jim McKim, W0CY; Wray Dudley, W8GQW; John Browning, W6SP; Bill Tynan, W3XO; Ron Long, W8GUS; Byron Lindsey, W4BIW; and John Shew, N4QQ. In the United Kingdom they are: Ron Broadbent, G3AAJ; Pat Gowen, G3IOR; and Richard Limebear, G3RWL. Most of the information flow between the North America and United Kingdom nets went between Pat, G3IOR, and Rip, WA2LQQ. Unfortunately, many of these "voices" are now silent.

Many fond memories of these days exist, but a return to these nets as they existed in the past is not necessary.

2 Today

The HF nets are now reduced to the 20 meter net on Sunday. Operation of this net follows:

20 Meter International Net – This net meets at 1800 UTC, Sunday afternoons, on 14.282 MHz. Co-hosts for the net are typically Keith Pugh, W5IU, and Larry Brown, W7LB. When travel and work interrupt the routine, Don Anastasia, AA6W, usually fills in. Occasionally, other "regulars" help out. The first hour, know as the "Pre-net Warmup" is informal discussion of Amateur Radio Satellites, requests for information, and check-ins. At 1900 UTC, the weekly AMSAT News Service (ANS) Bulletins for the week are read by Keith Pugh, W5IU, with his beam antenna pointed east from Fort Worth, TX. At 1930 UTC the second reading of the ANS Bulletins is done by Larry Brown, W7LB, on an Inverted V from Tucson, AZ. Larry's coverage is primarily the West Coast and the Mid-West. Variations on this routine occur due to absences. Sometimes W5IU does a second reading with his beam pointed west. Sometimes W7LB does the only reading from Tucson and sometimes AA6W does the second reading with his beam from the Bay Area pointed east. On rare occasions, AA6W does the only reading from the Bay Area pointed east. As time permits, status of the currently active satellites is given and any additional time is used for Q&A.

3 Tomorrow

The function of disseminating the ANS Bulletins, Keplarian Data, etc. is now done more efficiently by the Internet; however, there are still operators out there that prefer to receive their information via radio or have not yet joined the computer generation. Introduction of operators to satellites is many times done better via the nets than by the cold printed word. Discussion of the relative merits of equipment, Hints & Kinks, and general Q&A is many times better accomplished by "on the air contact" via the nets. For these reasons, the nets continue to have a place.

As a minimum, the current HF nets should be maintained. As more Net Control Stations can be recruited to "share the wealth" the 75 Meter Regional Nets should be re-activated. This author has established a goal of getting the Mid America Net back on the air in the winter of 2006-2007 with the help of the Lockheed Martin Amateur Radio Club. Additional relief could also be used on the 20 Meter Net.

4 Summary

Let's keep the HF Nets healthy and restore at least the 20 Meter and 75 Meter Nets to their original function. Expand the use of local VHF and UHF nets where possible. Look over your capabilities and consider helping out with the AMSAT Nets in the future.

Keith Pugh, W5IU

AMSAT Area Coordinator

Design of Eagle Modules

Presented by

Dick Jansson, WD4FAB

Abstract

The experience gained in working with the AO-40 electronic modules has governed the creation of the mechanical features of the modules for the Eagle spacecraft. This design has been created independently of the actual spaceframe design as any spaceframe will be made to accept these modules.

Module mechanical design for a satellite is dictated by a number of parameters, such as manufacturability, accessibility of the electronics, the removal of dissipated heat, functional volume for the electronic components, and electrical connections to the spacecraft suitable for the function of the module.

About the Author

Dick Jansson, 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 (using punched cards and run on an IBM 7090) thermal analysis 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.

1 Introduction

Electronic modules for Eagle are designed to house individual electronic functions for the spacecraft. These functions consist of the command equipment, receivers, transmitters, and computers. The computer functions provide for the spacecraft "housekeeping" and is thus called In-flight Housekeeping Unit, or IHU.

Other spacecraft functions are composed of the power management electronics, navigation electronics, the communications experiment transmitters and receivers, and any external, space-related experiments (or "this space for rent": TSFR).

All of these electronic functions must be properly housed so as to provide any needed electronic field isolation as well as providing the proper controls of the thermal environment for these electronics.

This paper describes the design and application of the electronic modules for the AMSAT-NA Eagle spacecraft. It further describes how the users should apply this module design to achieve their specific electronic functions in this satellite. All drawings referenced in this paper are available on the Eaglepedia Web site: http://www.amsat.org/amsat-new/eagle/EaglePedia/index.php/Main_Page .

2 Design Origination

Early P3 satellites, P3A, P3B [AO-10], and P3C [AO-13], employed a modular design concept in which the modules were specifically tailored to fit particular locations in the satellite spaceframe. There was not a general organization of the module sizes and configurations. This situation was changed for the P3D (AO-40) spacecraft.

The P3D spaceframe did not restrict the sizes of electronic modules to specific locations. Consequently, a unitized module plan was generated in which the depth of the modules was set for a printed circuit board, PCB, size of 200mm, with the module length set for three values of PCB, in 75mm increments, at of 130mm, 195mm, and 270mm. The height of the modules was either 38mm or 25mm. The modules were also designed to permit them to be vertically stacked in increments of either 25mm or 38mm, see Figure 1.

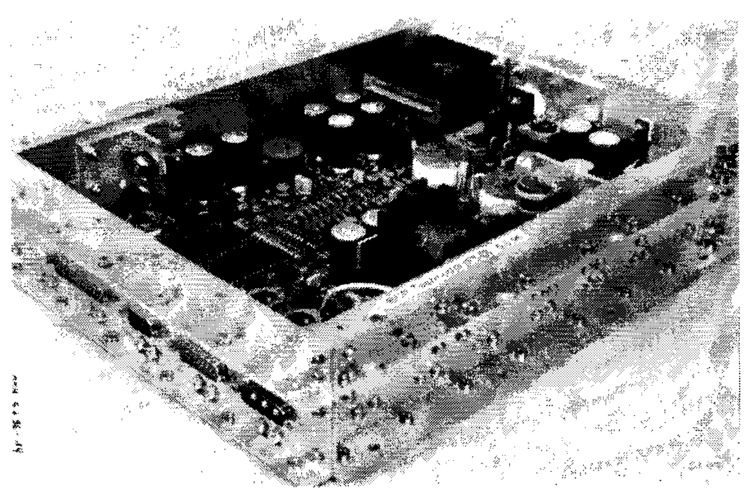


Fig.1 Stacked module frames for P3D battery charging regulator, BCR

All P3D modules were mounted on fiberglass (generally) channels which were riveted to internal spaceframe panels. These channels provided thermal isolation of the modules from the spaceframe. Screw mounting points for these modules were provided in increments of 75mm, thus allowing a variety of modules to be mounted on pairs of these channels.

Modular construction consisted of four extruded aluminum channels for the sides with top and bottom cover plates of thin sheet aluminum. Small molded plastic blocks were attached to the side channels, protruding into the inner space and providing the attachment points for the edges of the, PCB.

The thin sheet aluminum covers for the P3D modules were made of AlClad aluminum, consisting of a 0.5mm thick core of 2024-T4 laminated on the surfaces with high purity polished aluminum. This material was selected to further provide for the thermal isolation of the modules, a subject that is important for the spacecraft but will not be further discussed herein.

3 Design Details

With the experience of the P3D project behind, Eagle designers examined that experience to incorporate desirable features and to change the less than desirable features. It was decided that it would be very helpful if the Eagle mounted modules would provide a complete top and side access for the PCB. Further, the attachment method for the high-power heat sink modules was cumbersome and heavy. One other factor was that the edge mounting of PCBs did not provide for a means to suppress center vibration modes for these boards.

To overcome these "problems", the Eagle module design 1) incorporates a flat panel baseplate in which numerous spacer mounting points are provided for the whole area of the PCB removing the vibration issue; 2) a single four-sided formed cover is made to allow the PCB accessibility; 3) high-power modules will use shorter screws through the heat sink to the mounting surface, requiring these screws to be installed prior to the attachment of the module cover.

A series of three different sizes of modules have been designed for Eagle, incrementing one dimension by 75mm. The smallest module, drawing E05 20, has a PCB size of 125x180mm, see Figure 2. Two larger modules have been designed, the E05 10 with a PCB of 200x180mm, and the E05 30 with a PCB size of 275x180mm. This size range was created based upon the prior experience of the AO-40 satellite. Since the time of the AO-40 fabrication, the space occupied by electronic circuits has greatly diminished and it is felt that only the smallest of these modules will be needed for the Eagle mission.

For later discussion in this paper will be the special provisions in these modules for the heat sinking of power semiconductors used in high-power transmitter, RF, electronics.

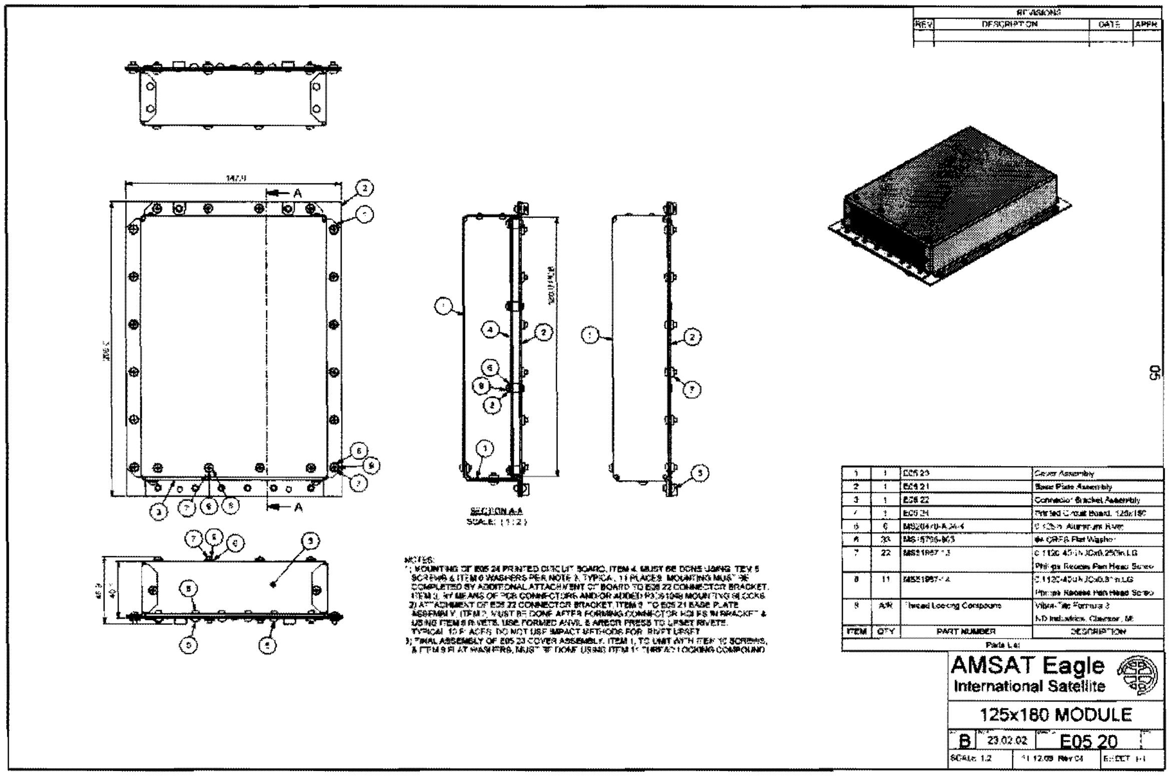


Fig. 2 – The E05 20 Module Assembly Drawing

This module design consists of just four parts held together with machine screws and rivets. A flat aluminum Baseplate, E05 21, Figure 3, provides multiple mounting points for the PCB, E05 24, Figure 4, which is spaced parallel to the baseplate by 4.8mm. On the "front" face of the module is riveted a right-angle, formed aluminum Connector Bracket, E05 22, Figure 5, on which are mounted all provisions for the necessary electrical connections to the PCB. Covering this assembly is a four-sided formed thin-wall aluminum Cover assembly, E05 23, Figure 6. The complete assembly of a prototype module is shown in Figure 7. This paper will discuss the pertinent details of all of these parts, however, it is noted at the beginning that the Cover is made from AlClad, a high-strength core covered on each side with highly polished pure aluminum. This surface is a thermally sensitive surface which in the flight preparation must be protected even from the finger prints of the users. This reference will be discussed later.

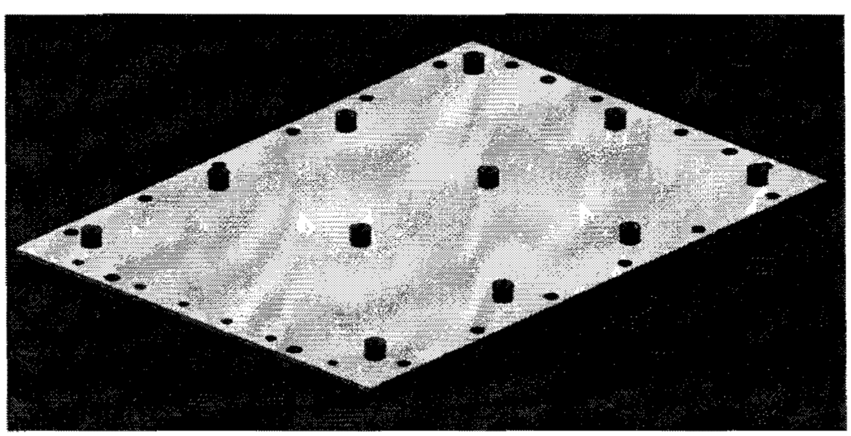


Fig. 3 – The E05 21 Baseplate Assembly

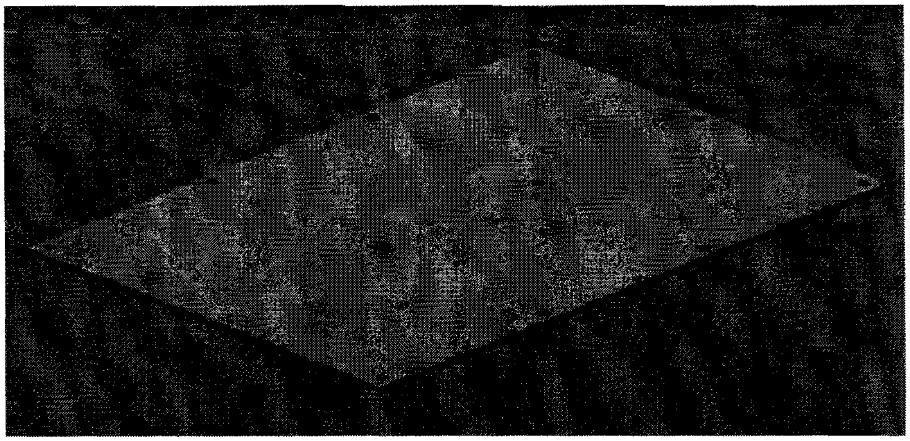


Fig . 4– The E05 24 PCB.

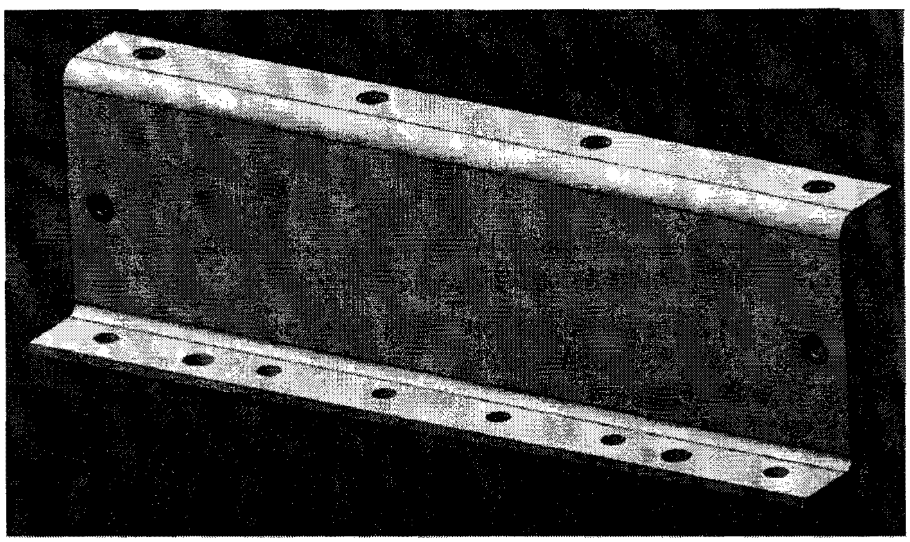


Fig. 5 – The E05 22 Connector Bracket Assembly, without connectors

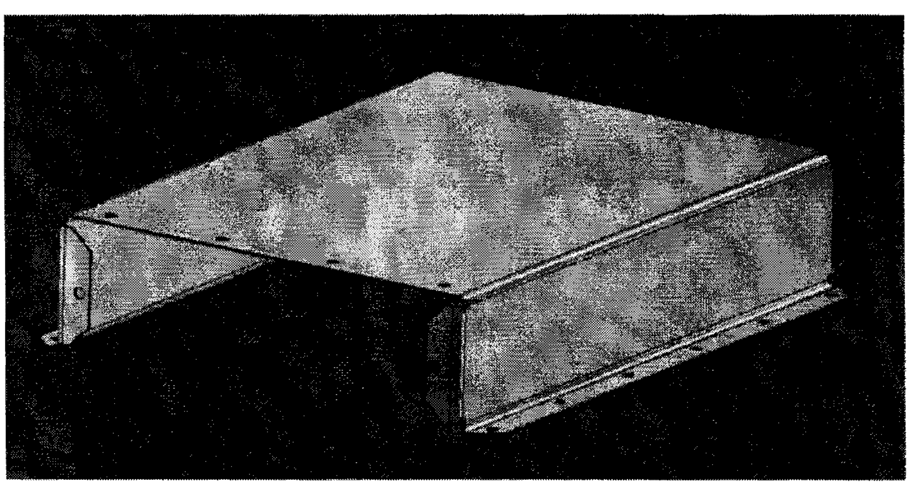


Fig.6 – The E05 23 Cover Assembly

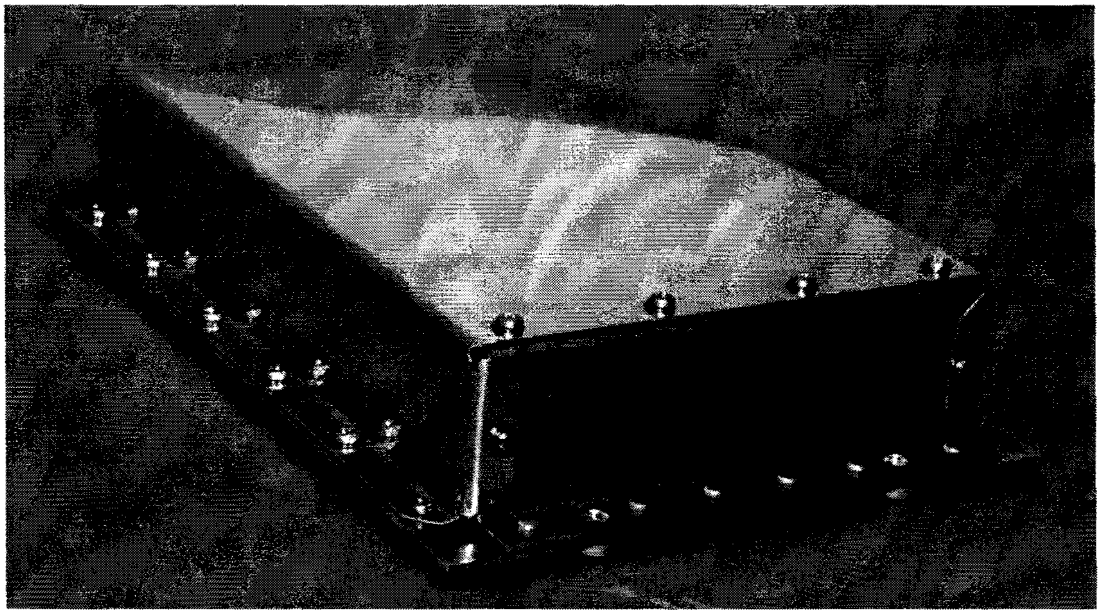


Fig. 7 – E05 20 Module Assembly

4 Mechanical Design

The PCB is mounted on spacers 4.8mm above the module baseplate floor. PCB top & bottom surfaces should be free of components and exposed traces approximately 4mm around mounting screw locations. The dimensioned outside extents of the PCB are the maximum allowed as there is only an 0.5mm gap between the PCB and the E05 23 Module Cover.

If possible, the PCB should use all available mounting screw locations. This encourages a higher natural frequency of the PCB under vibration, which generally reduces deflections and soldered connection stresses. The spacers provide approximately 3.5mm to components and leads below the PCB, accounting for both desired gap and expected deflections of both the Module Baseplate and PCB. This quantity of PCB mounting screws is sufficient to avoid a need to totally foam encapsulate PCB assemblies, as was done for AO-40 and earlier satellites.

Assuming approximately 1.6mm thick PCBs, the module provides approximately 30mm maximum for components and leads above the PCB, accounting for both desired gap and expected deflections of both the Module Cover and PCB.

5 Connector Design

A major issue in the use of the module in a satellite is that of the wiring to and from the module. Wiring in AO-40 was done using point-to-point wiring methods, resulting in a very sizeable wiring bundle in the spacecraft. This also forced the need to use extensive data base computer operations to insure the accuracy of these wiring connections. In countering the connector mounting space and wiring issues is the fact that in Eagle the major module wiring will be done using the CAN communications bus principle. This is afforded by the use of a standard "CAN-DO" module mounted on the inner wall of part of the E05 22 Connector Bracket, see Figures 8 and 9.

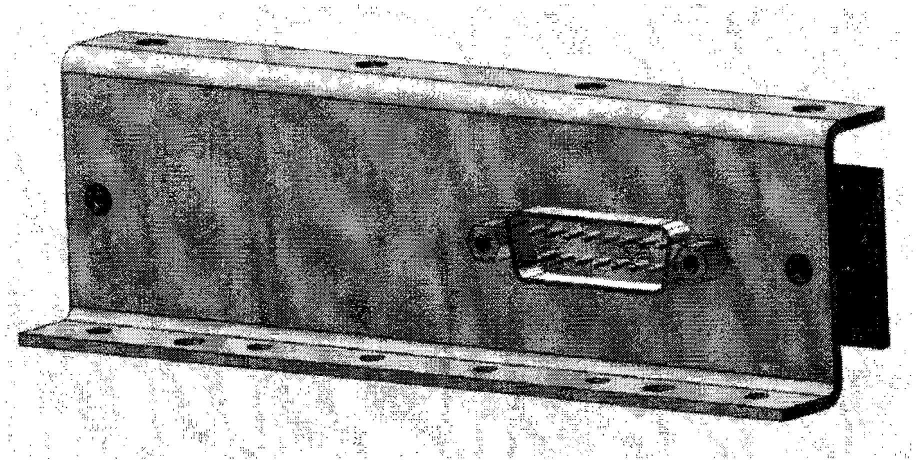


Fig. 8 – E05 22 Connector Bracket with CAN-DO module showing the DA15 connector

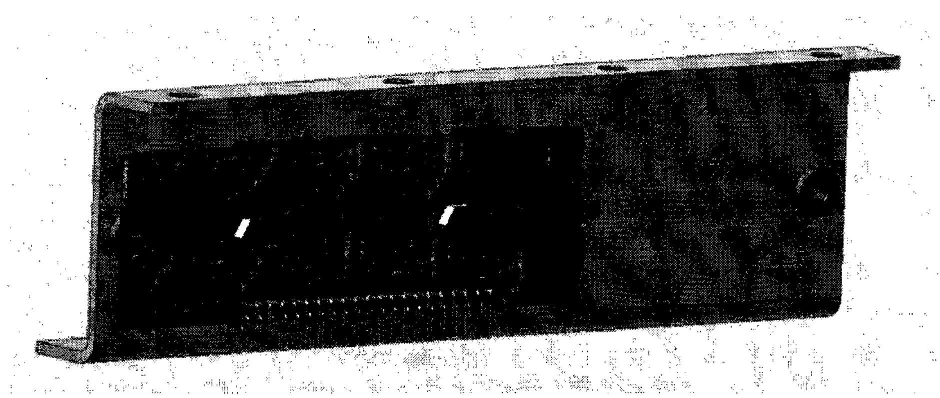


Fig. 9 – E05 22 Connector Bracket showing CAN-DO module mounted on inside

Some of the details of the CAN-DO module are worthwhile in discussing. It is noted in Figure 9 that there is a 40 pin PCB plug-in connector along the bottom edge of this subassembly. In the illustrated version, this module would be soldered into the top of module PCB along this connector. A CAN-DO module can be obtained in which these 40 pins point upward and would plug into the bottom of the PCB. Such a step would necessitate that the main PCB be shortened to permit this arrangement. The advantage of such a CAN-DO mounting is that it would provide space above the CAN-DO module for other small connectors to be mounted near the top of the E05 22 bracket. In addition, each of these CAN-DO to PCB arrangements can also be provided with the moving of the CAN-DO to the opposite side of the Connector Bracket

Space is available to the right side of the CAN-DO PCB, as viewed in Figure 9, for additional connectors. Note that this is wide enough to accommodate up to two additional DA15-pin connectors if the second is stacked vertically upon the other. Multiple RF connectors can also be accommodated in this area. If the "pins-up" configuration of the CAN-DO mounting is selected, a space of just 10mm is also available above this assembly in the top area of the Connector Bracket.

6 Thermal Design

Electronic modules to be employed in the Eagle satellite service are designed principally to use radiative heat transfer methods to dissipate the internally generated heat from their circuit power dissipation. Modular low power dissipation designs are to be highly encouraged. In the overall thermal design of the Eagle satellite, conditions will be established to maintain workable operating temperatures for all modules, even in the face of some of the extreme thermal conditions of space operation. The most severe situation is found at the time of solar eclipses which occasionally be encountered for durations up to two to three hours, depending upon orbital conditions. Under these conditions, the spaceframe will very quickly cool to temperatures of -100°C or lower. Critical command system modules must be maintained to temperatures, no lower than -20°C, so as to retain their functionality. With proper designs these module temperatures can be held to no lower than 0°C. Past orbital telemetry documentation has confirmed analytical predictions for earlier satellites of similar design.

This system thermal approach employs low power dissipation in these critical modules, coupled with the design steps of thermally isolating these modules from the spaceframe, thus limiting their cool-down under eclipse conditions. Modules are mounted to the spaceframe on insulating fiberglass-epoxy molded channels. In assessing these conditions even the wiring conduction to the modules are closely examined, and the module Covers are held to as low of a thermal emittance as possible to minimize their heat transfer losses. Polished, pure aluminum is the second, to gold, lowest of thermal emittance materials available, and this is fortunately available in the form of the AlClad surfaced aluminum sheet material used to form these Covers. Even such an innocuous thing as the oils from a human finger print can defeat this low emittance property on these Covers.

Externally, the temperature of a module is controlled by the coating on the module. As an example, presume that the spaceframe is operating at Tsf = 0°C and the module case is Tm = 20°C. Under these conditions, the following chart shows the relationship between the emittance of the module and its power dissipation.

Table 1

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

Achieving variations in the emittance of the module exterior is provided through the use of thermal control tapes and paint. In the case of the highest emittance, v = 0.91, the overall coating of space-rated black paint is to be used. Such modular treatment must commence even prior to the assembly of the module. The lesser emittance coatings will often be achieved through the use of tapes. In nearly all cases, the E05 23 Cover will be black painted on its interior to enhance internal radiative heat transfer in the module.

Modules of greater dissipation, and even some of the lower overall power dissipation, will need to employ the thermal dissipation provisions afforded by the heat sink design module. This module is shown in drawings E05 15, E05 25 and Fig. 10. The E05 15 module has a PCB size of 200x180mm and it use is not encouraged if the circuit functions can be handled through the use of the smaller E05 25 module with its 125x180mm PCB size. The heat sink arrangements in these modules are identical, with a working surface of 50x170mm.

Heat sink modules have defined locations for their mounting in the Eagle spaceframe to insure their proper attachment to the spaceframe. The process of mounting of these modules will require access to the interior of the module to have access to the bolting holes to properly clamp the heat sink to the thermal dissipating elements of the spaceframe. Once mounted the module cover can then be carefully attached to the module.

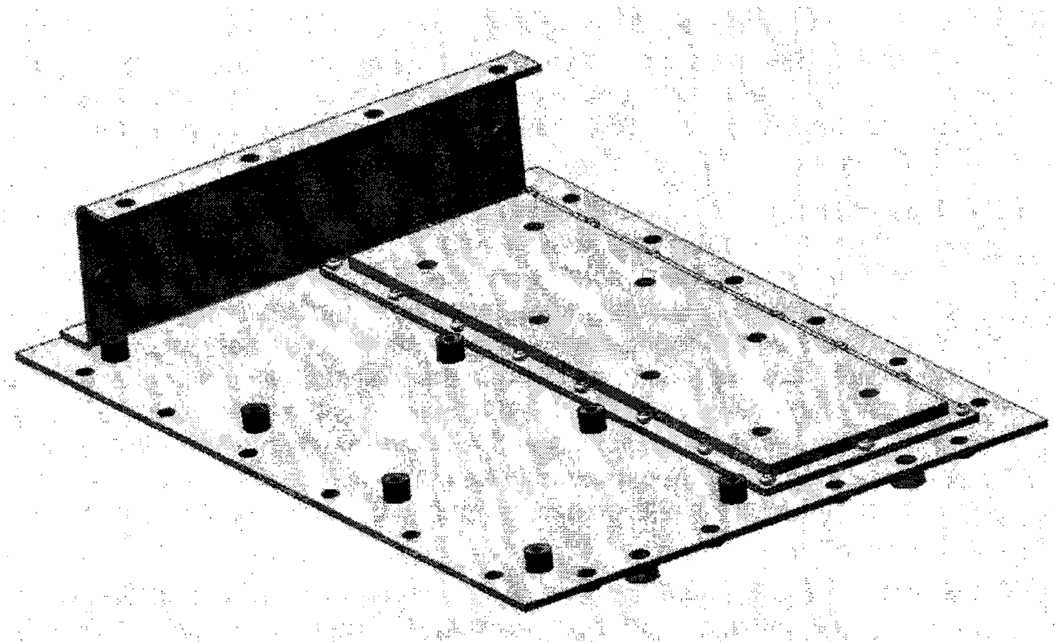


Fig. 10 – E05 25 Heat Sink Module without PCB and Cover, showing Heat Sink riveted to Baseplate

While the numbers of Table 1 provide some guidelines, it is clear that all modules will need to have some level of thermal engineering overview to insure that the internal arrangements of components would allow such dissipations to be safely handled. Any circuit containing any device with a specific heat sink tab, such as TO-220-like devices must be properly mounted to the module structure to insure that the device will function properly in the Eagle mission. The only useable structural members of the E05 20 module would be the E05 21 Baseplate or the E05 22 Bracket. Attachment of devices to the E05 23 Cover is neither feasible nor permissible. In dealing with such heat-tab devices it is also advisable that the tab be mounted to the module structure rather than to the PCB, which practice would require the use of a thermally inefficient copper thermal strap to link the tab to the module structure.

Internally to the module it is also advisable to provide broad coverage of the Power and Ground planes in multi-layer PCB designs. Such steps will enhance thermal conduction across the PCB to provide a level of heat distribution across the PCB to assist the overall dissipation of the circuit powers.

7 Prototypes

Considering the advanced state of the Eagle module design, it was seen appropriate to bring several modules into the hardware stage to evaluate the fabrication process and to iron out any manufacturing wrinkles in the design. The following section will discuss this fabrication processes and the plans for full-scale manufacturing of flight-quantities modules.

Figures 7 and 11 illustrate one of the first of the E05 20 module assemblies created using flight-capable tooling and methods. The process of fabricating this module held no surprises as the process went about as expected. The fabrication steps that were actually used were, in some regards, different from that which had been planned, thus proving that the design is adaptable for several methods for the construction. The final assembly steps were, however, exactly as had been anticipated. The design points describing this module can be quickly discerned by the photographic illustration of the unit.

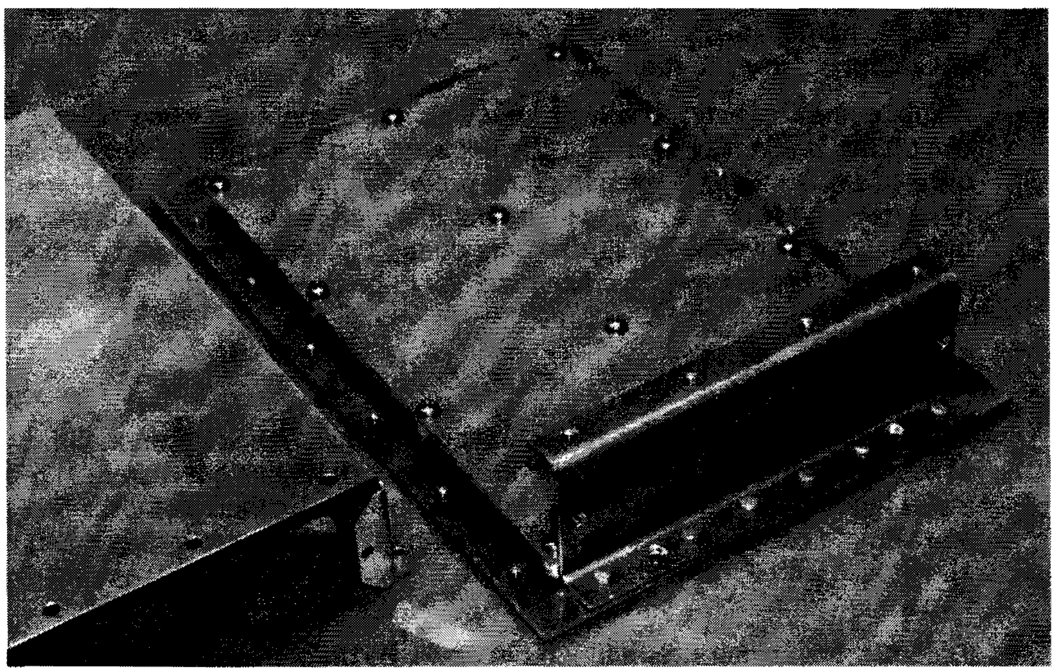


Fig. 11 – E05 20 Module with Cover removed

It should be noted that in general the E05 22 Bracket can not be riveted to the E05 21 Baseplate until following the punching and/or machining of the major connector holes in the Bracket. This reference is expressly made for the DA-15 CAN-DO connector and any other D series connector placements for each module. This restriction is made as the punch tools that are normally used for such connectors would be rather awkward to use on the assembled Bracket-Baseplate combination. This situation makes the modular assembly process a bit unconventional as a user-ready supply of modules will not be "off the shelf" and each unit will need to be adapted for its function prior its delivery to the electronic assemblers. Fortunately, such restrictions would not be necessary for the smaller sized connector holes that may be needed in the Bracket.

To date, several E05 20 prototypes have been fabricated and will be circulated for comments and general information. One E05 10 Module has been constructed and an E05 15 Heat Sink Module is still awaiting the machining of the heat sink.

8 Lessons Learned

The prototyping effort of the E05 20 Module was not done without learning many things, even though the process went very much as planned, in general. One area that showed itself clearly was that of the tolerances of the bending radii on both the Bracket and the Cover. These issues were addressed with a small design change.

A second problem cropped up in the fabrication of the E05 23 Cover units. Owing to the sensitivity of the thermal characteristics of the pure aluminum surfaces on the AlClad material, it is seen necessary to protect these surfaces with some form of a protective film material during the fabrication steps. Without knowledge of the availability for such protective film material, a covering of the prototype Cover units was done using consumer-commercial shelf plastic sheet. The adhesive used in this material, is quite tenacious and not easy to remove.

A subsequent investigation was done with 3M Corporation whose representative divulged the availability of suitable Protective Films that have PSA materials that will permit a clean, no-residue release of the protective film. Usable quantities of this material have been procured. It is also seen that this material would be useful to protect other thermally sensitive on the spaceframe during their fabrication and assembly. These added uses of the protective film have yet to be investigated.

9 Fabrication Plan

Module designs for Eagle have been very much independent upon the spaceframe in which they will fly. In fact the spaceframe concepts have been created to accommodate these module designs. That independence allows the module fabrication to parallel any spaceframe construction thus providing the ability to promote the housing of system electronics with a freedom and promote the more thorough testing and evaluation of the system electronics.

Accordingly, all materials either have or will be ordered and handled as if for flight. Once a fabrication tooling and process is established, it will be easier to do all of a module type in succession; therefore we are planning on two spacecraft plus spares. Under this scenario some guessing will have to happen however such guessing is not too hard to perform. Some uncertainty as to what the satellite can or may accommodate but system functions are well known and it is estimated that an Eagle satellite will accommodate twelve or thirteen modules, four of which will need to have power semiconductor heat sinks. There is the need for engineering model prototyping of each module for a satellite mission, allowing the assembly of a "Flat-Sat" assembly of modules to test an electrically fully functional mission. Fulfilling AMSAT's long-range mission calls for the placing two Eagle spacecraft in orbit. When all of these situations are added the total fabrication of modules can be shown to be in the range of fifty to sixty modules, with 25% of these having the heat sink module functions (the heat sink Baseplate). These numbers provide some solid goals for the funding, material procurement, tooling, labor, and facility requirements for these quantities of modules.

10 Conclusion

It is our intent to proceed, after appropriate peer review of prototypes, through step 4 of this plan, prior to having necessarily all details of spacecraft accommodation. This module design is intended to be less platform dependent, and allows us to support the board-level testing of electronics on an earlier schedule. Such a plan will significantly reduce the lead time needed to bring a satellite to full fruition and into orbit.

Another SUNSAT

Presented by

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President Southern Africa AMSAT

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1 Introduction

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. From this modest beginning grew SunSpace (Pty) Ltd, today a successfully company involved in the space communications field.

Soon, South African will get another voice in the sky when the second satellite, named **Sumbandila** is launched in December. The naming of the satellite in itself 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 or freely translated into English: *"Pathfinder".*

Sumbandila is a very appropriate name for a satellite that is paving the way for a number of satellites planned for launch over the next few years.

Sumbandila Sat is sponsored by the Department of Science and Technology and is being built at SunSpace in cooperation with the University of Stellenbosch. The amateur payload will offer similar activities than that of SUNSAT but implemented in a new innovative way.

2 Sumbandila 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 including:

- SA AMSAT – 2m/70cm amateur radio transponder and digitalker
- Stellenbosch University
  - Software defined radio (SDR) experiment
  - Architectural radiation experiment for commercial off the shelf devices (ARECOTS)
- Nelson Mandela Metropolitan University
  - Forced vibrating string experiment
- University of KwaZulu- Natal
  - Very low frequency (VLF) radio experiment

The Amateur Radio Payload will be operating in conjunction with the University of Stellenbosch Software Defined Receiver project as it will share the VHF receiver and UHF transmitter used by the SDR project.

SA AMSAT has 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.

The technical team comprising of Andrew Roos ZS6AAA and Hannes Coetzee ZS6BZP have faced a real challenge to complete two prototypes of the controller in time for evaluation and integration in the main unit by end July. The launch of the satellite is scheduled for early December.

Sumbandila is expected to be followed by two or more satellite projects and with more time available a more sophisticated amateur payload is envisaged.

The mission of the project 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. There are several additional benefits that will accrue from the project including: technology demonstrator of new generation satellite avionics for future satellites, international and regional benefit through imaging and data provision and a platform for international interaction through joint missions and constellations.

3 Unusual Launch

Discussions have been concluded with the Russian State Rocket Centre in Makayev to launch Sumbandila Sat into orbit on a Shtil launch vehicle from a submarine. 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 is scheduled for the December 2006/January 2007 time frame and will place Sumbandila Sat into a 500 km circular orbit with local pass time around 10 am and 10 pm CAT (Central African Time= UTC plus 2 hours).

4 An Educational Challenge

Like SUNSAT, the Sumbandila Project presents several educational opportunities at various levels from learners at school to Post Graduate students at University.

The satellite development kit provides for three main areas of training. Students will be exposed to hands-on system level building of complete satellites in their own country with satellite engineering laboratory infrastructure established. The training is intertwined with a specific satellite mission including AIT Laboratory Establishment and Training, In-orbit commissioning and training and In-orbit operational training. The third component is specialised satellite engineering training including detail design of components and sub systems.

A steady stream of 18 students, 19 Master Degree students and 3 PhD students plus a post doctorate position is fully funded. In addition, between 5 and 8 internships have been created for the building of a satellite knowledge base and capacity in Industry.

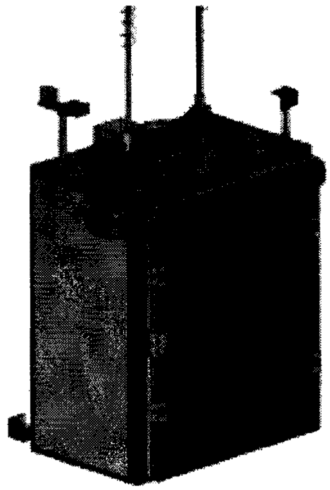
Another outflow of Sumbandila Sat and the constellation of satellites planned for the future is that it offers scientist at other institutions the opportunity to develop scientific experiments which will be included in the programme. The next satellite in the series offers 2 kg of payload capacity. It is expected that SA AMSAT will have further opportunities for amateur radio payloads in the constellation of satellites planned.

Another important component is the expansion of the SUNSTEP programme. SUNSTEP is a joint venture by sponsors and the University of Stellenbosch to reach out to learners and increase their Science, Electronics and Technology knowledge. During the past 9 years, 164 850 learners and 5039 teachers have been touched. Learners generally love the fun, dynamic "hands and minds-on" approach followed and as a result many have realised that the ability to study towards engineering is in fact within their reach. Once in orbit, Sumbandila Sat will provide increased scope for the SUNSTEP programme and expansion to all provinces of South Africa. The Amateur Radio payload will be used extensively in youth programmes with the objective of bringing the youth into amateur radio.

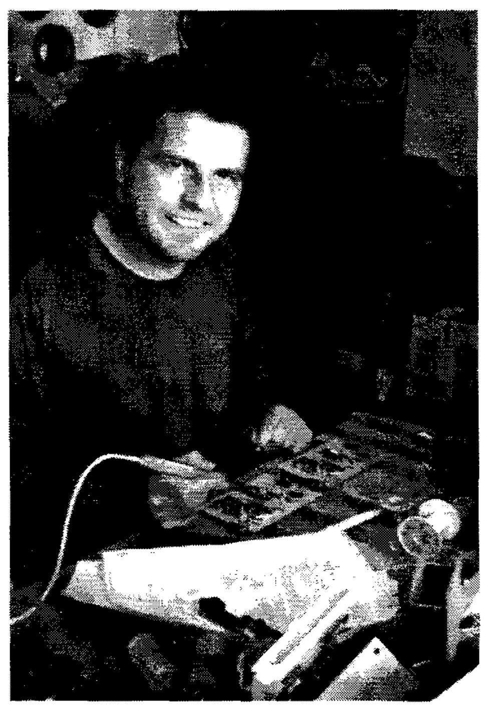
5 Why an Entry-level Satellite?

Amateur Radio is at the crossroad. It is confronted with an aging population coupled with a relatively slow intake of new younger enthusiast. The South African Radio League has embarked on a programme to attract young people into Amateur Radio and an easy to use satellite will go a long way to fire their imagination.
In the words of the late Bill Orr, W6SAI, about the launch of OSCAR 1:

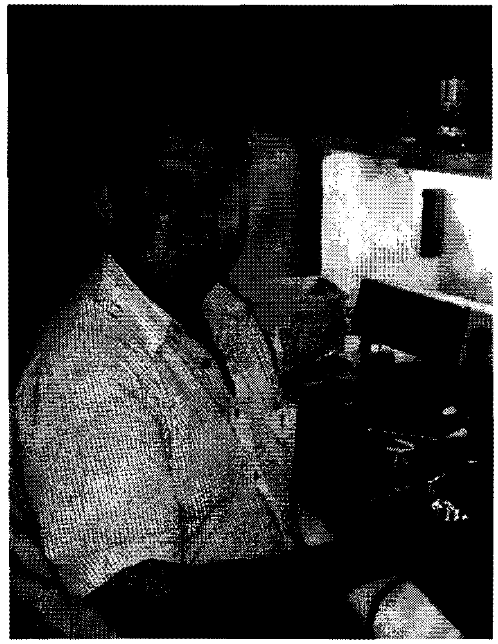
> *"The spirit of adventure lies buried in very man's soul. Strike the spark and ignite the soul and the impossible is accomplished".*



Artist impression of the Sumbandila Sat



Hannes Coetzee, ZS6BPZ, working on the proto type controller. He built two proto type controllers, one for the University of Stellenbosch, and one for SA AMSAT to do software testing in Pretoria. This allowed work to be carried out in parallel.



Andrews Roos was responsible for the design of the controller and the writing and debugging of the software.

KiwiSAT
A Communications Satellite for New Zealand

Presented by

Ian Ashley, ZL1AOX; Fred Kennedy, ZL1BYP

Abstract

KiwiSAT is a MicroSAT class satellite designed and built by AMSAT-ZL (New Zealand). This paper reviews progress in its construction.

About the Authors

Ian Ashley, ZL1AOX has had an interest in satellites since the 1970's. He has been involved in the Commanding of AMSAT satellites since Phase 3A, the Digital Communications Experiment with the University of Surrey and PCsat 1 and 2 for the US Naval Academy.

Ian is now retired from a career in commercial aviation.

Fred Kennedy, ZL1BYP: A retired Royal Navy Engineer Commander who moved with his wife to New Zealand in 1992. Fred "cut his teeth" by copying pictures from the "Nimbus" satellites back in 1965 using homebrewed "fax drums with electro-sensitive chart paper and gramophone needles". He became interested in AMSAT satellites whilst in New Zealand on loan from the Royal Navy to the Royal NZ Navy in 1986 and set his sights on Fuji Oscar 12. He recalls being beaten into the mailbox by Ian ZL1AOX – by one orbit!!

Fred produced a number of machined items which flew in AO-40 and on the strength of that picked up the short straw to lead the "KiwiSAT Project".

He has held the calls G3PJA, ZB1RF and 9V1RN as well as the current ZL1BYP. One daughter lives in the UK, and the second married into the USN and lives in Pascagoula. She survived (just) "Katrina".

KiwiSAT

A Communications Satellite for New Zealand

Introduction:

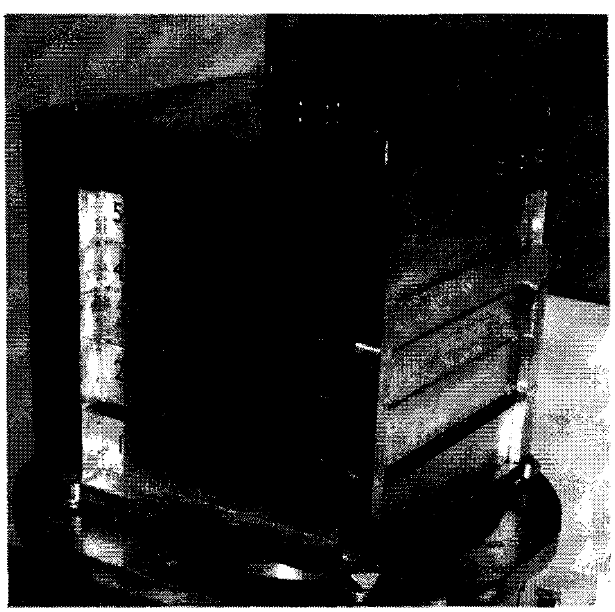
The first idea for an Amateur Satellite came from the 1999 NZART conference at which Lyle Johnson KK7P was present.

AMSAT-ZL took on the challenge. The first design considered was for a CubeSAT (100 mm cube), but this was discarded and it was decided to proceed with a MicroSAT sized satellite based on the AMSAT-NA MicroSAT's.

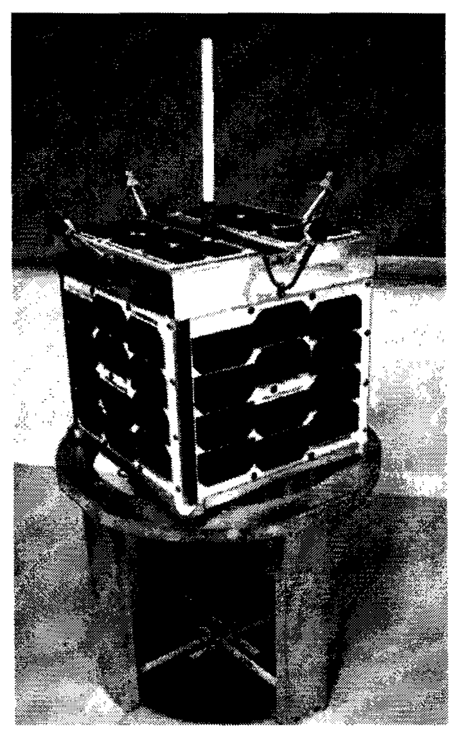
This paper is a progress report on progress to date.

Spacecraft Frame:

- A stack of five fabricated aluminum trays each 244 mm x 244 mm plus an 'attic'
- The height of each tray varies from 25 – 45 mm making a total of 244 mm also.
- Nominal useful internal area in each tray is approximately 210 mm x 200 mm
- RF cables plus a wiring harness carry power, inter-module data, telemetry, and control signals.
- Four rods running the height of the spacecraft bolt the assembly together.
- Satellite's surface area to be covered by solar cells
- All unused surface area (including "attic") is covered with thermal absorbing or reflective tape.



KiwiSAT Frame (Engineering mockup)



Final Design Model

KiwiSAT Modules:

From the top down –

Attic: Antennas and sensors, Science package - ADAC, CMOS Camera & antenna harness

Tray 5: Receivers on 70 cm and 23 cm and sensors. (+ GPS)

Tray 4: IHU (Integrated Housekeeping Unit – Flight Command Computer) with integrated 1200 and 9600 baud modems

Tray 3: Battery tray contains NiMH battery 12 volt at 4.0 Ah and magnetorque coil.

Tray 2: Battery Charge Regulator (BCR)

Tray 1: 2 m transmitters + secondary sun sensor and release power switches

Tray 5: 70 cm (U Band) receivers and 23 cm receive converter

KiwiSAT Linear Transponder – UHF receiver designed by Terry Osborne ZL2BAC will be used as the primary operational mode as part of the Main Transponder.

- 30 kHz bandwidth will handle up to 10 simultaneous SSB QSO's
- HP MMICS used ~25 dB gain, unconditionally stable
- Ring Mixer
- Toko Helical Filters
- NDK IF filter – very good specs
- AGC from Analog Devices VGA. 45 dB gain reduction possible

U Band receiver:

435.260 to 435.230 MHZ

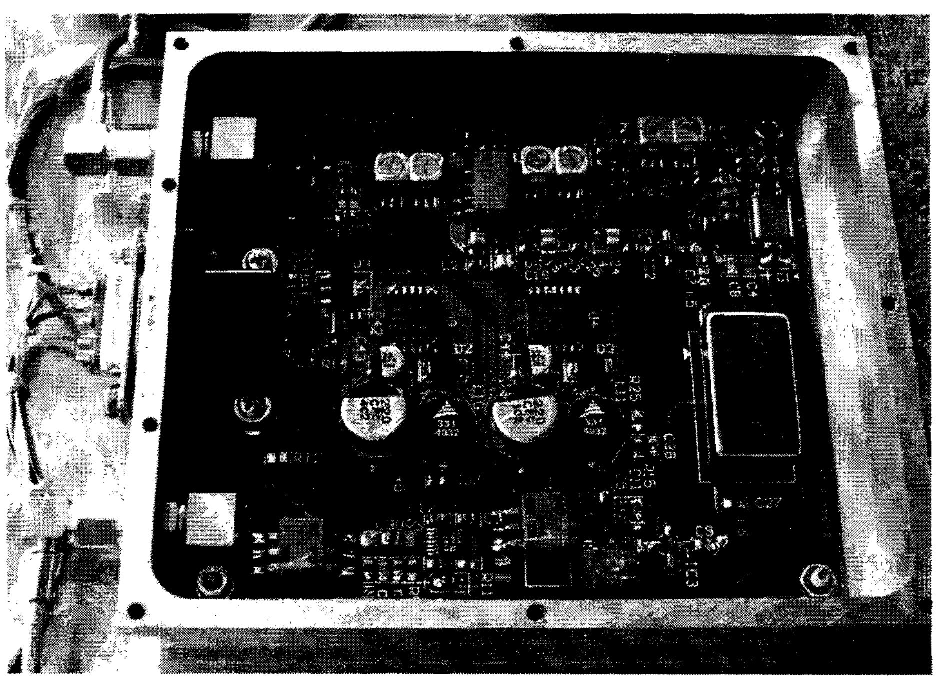
The 23 cm receive converter is still under construction.

Uplink frequency:

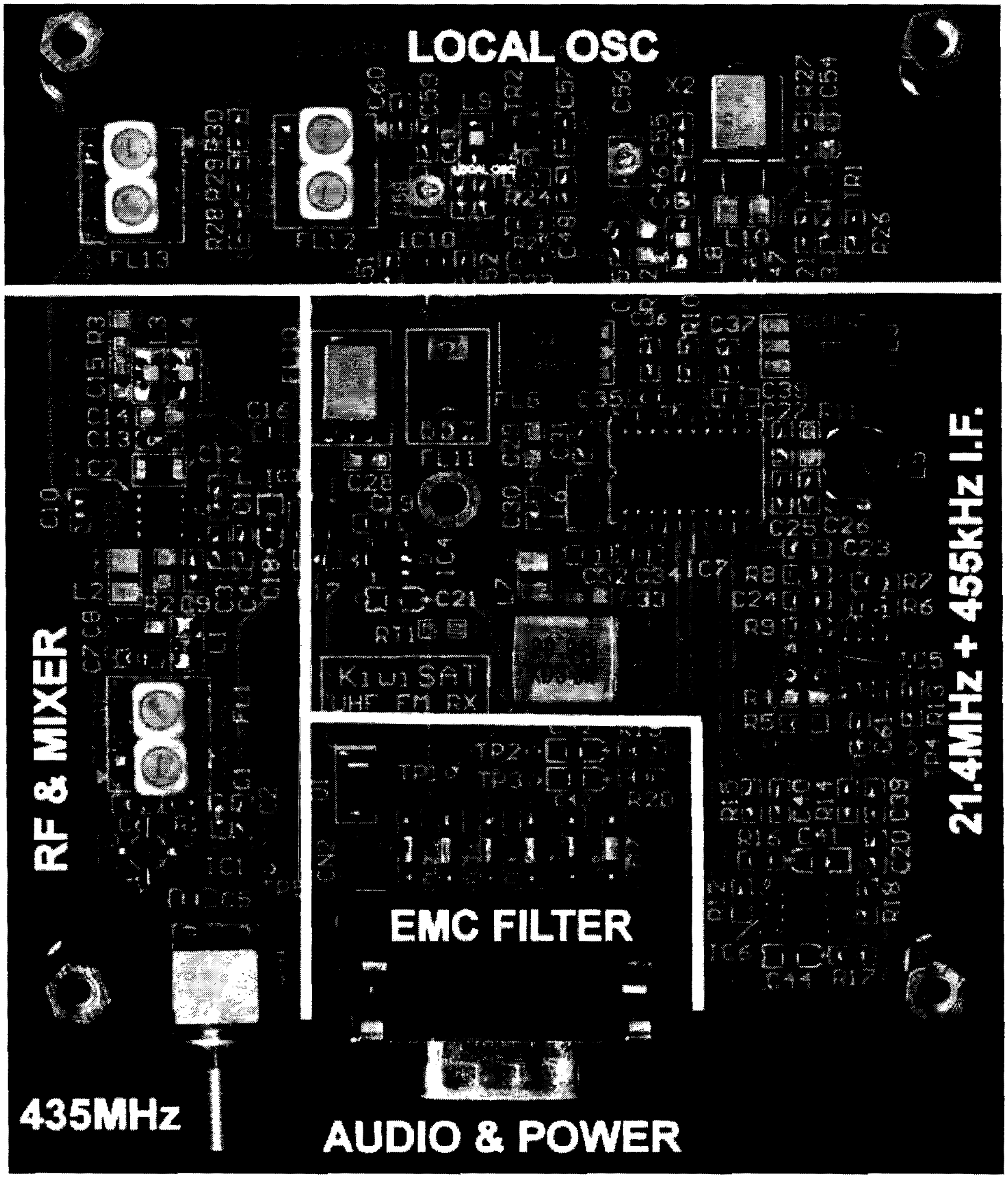
1268.880 MHz to

1268.850 MHz

U Band Linear receiver



In the same tray is the FM UHF receiver, designed by Mark Atherton ZL3JVX.



This unit, when combined with the 2 metre FM transmitter, will provide a similar service as AO-51 or AO-27.

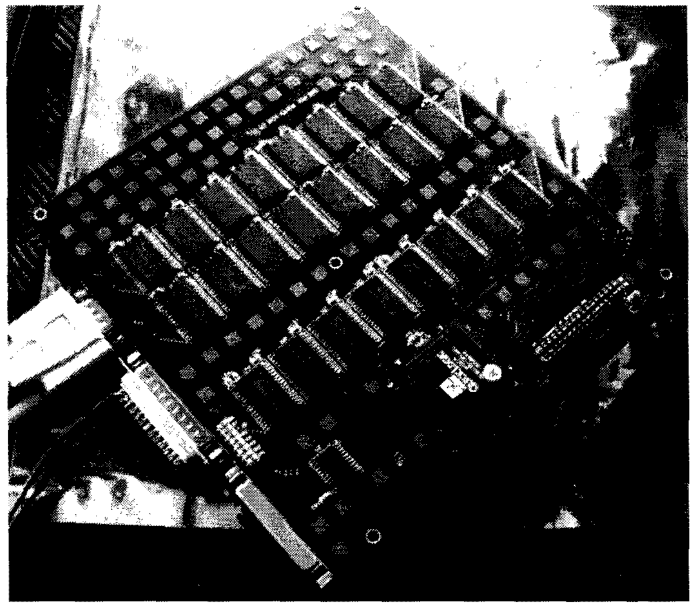
Uplink Frequency 435.245 MHz

Tray 4: IHU Integrated Housekeeping Unit

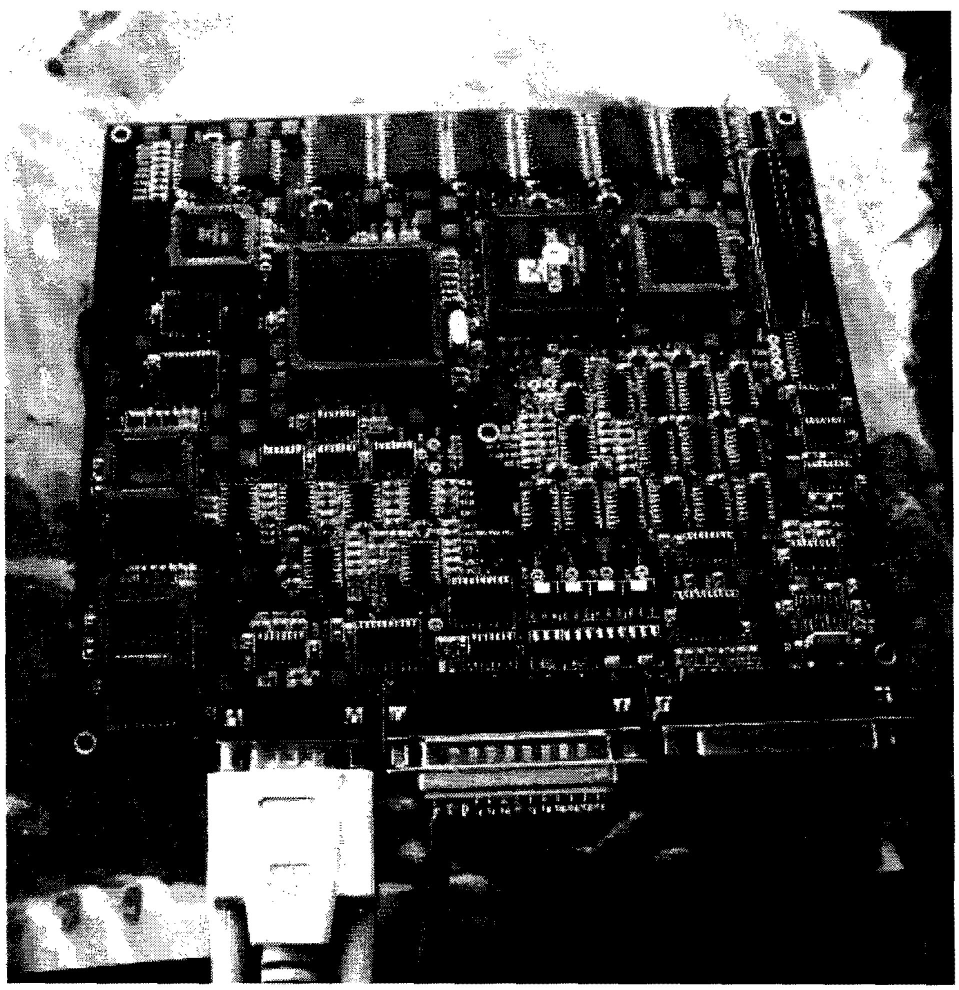
The circuit for this unit was designed by Lyle Johnson KK7P for AMSAT-ZL. It was designed to be as close as possible to the older V53 design and to make the porting of the SCOS operating system as easy as possible.

The processor is an Intel 80C188EB-25 running at 7.373 MHz with a 12 Megabyte RAM disk.

Layout and design of the PCB was undertaken by a group in Wellington led by Terry Osborne ZL2BAC



RAM Disk 12 Megabyte



Prototype IHU under test.

Flight version will not have sockets for IC's.

General Specification of IHU (Integrated Housekeeping Unit)

Radio Mod/Demodulators: 1 x 1200 bps standard AFSK AX25 packet radio modem, (Chip MX614), 1 x 9600 bps FSK AX25 packet radio modem.

Memory: 1M byte E-Prom, 12M bytes RAM with 1M byte of EDAC protection.

CPU Microprocessor: INTEL 80C188EB

Operating System: SCOS. (TBC)

Crystal Frequency: 14.7458 MHz.

Serial Ports: 1 x RS232 (for initial programming), 1 x SPI (for Telemetry/data and forward control of spacecraft modules.

Parallel I/O Ports: 24 digital I/O ports. **Connectors:** 2 x DB25 connector

Operating Temperature: -10 degrees C to +60 degrees C.

Size: 190 x 204 x 25 mm. (1 module size)

Mass: < 0.2 Kg. **Vcc:** 5 Volts. Power Consumption: < 1 Watt.

Tray 3: Battery

Comprises:-

Power generation – 66 Multi junction photovoltaic cells will be used.

Battery – 10 x 4.0 Ah NiMH with a nominal battery voltage of 12 V DC.

Flight ready set obtained from AMSAT-DL.

Tests continue on a backup set of Suppo NiMH cells.

Included within the battery tray will be the Z axis magnetorqueing coil

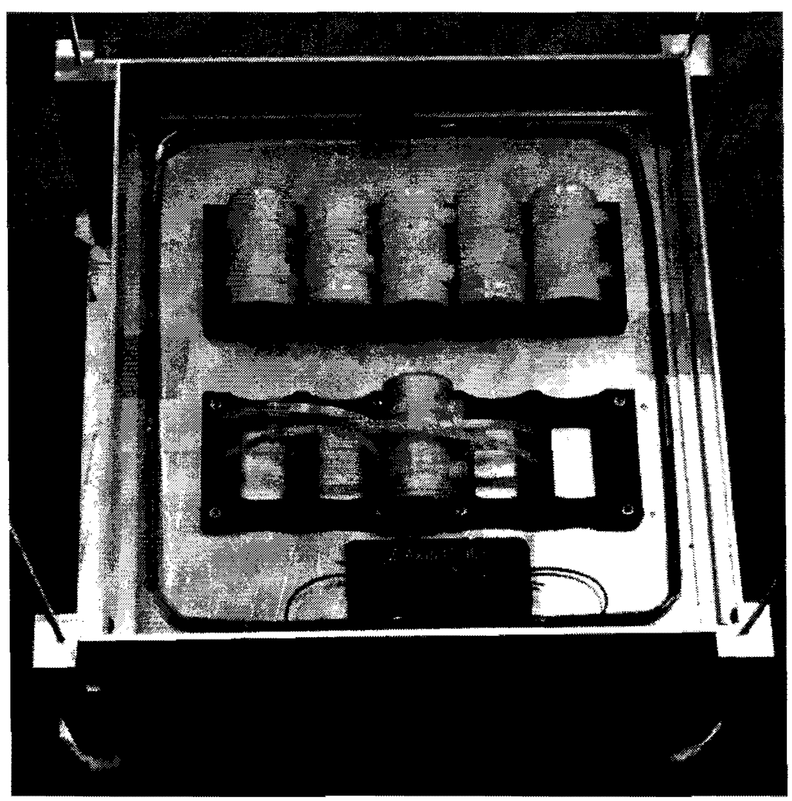


Photo shows sample cells and battery holder with the Z axis coil.

Tray 2: Battery Charge Regulator (BCR)

Used to manage battery charge and protection.

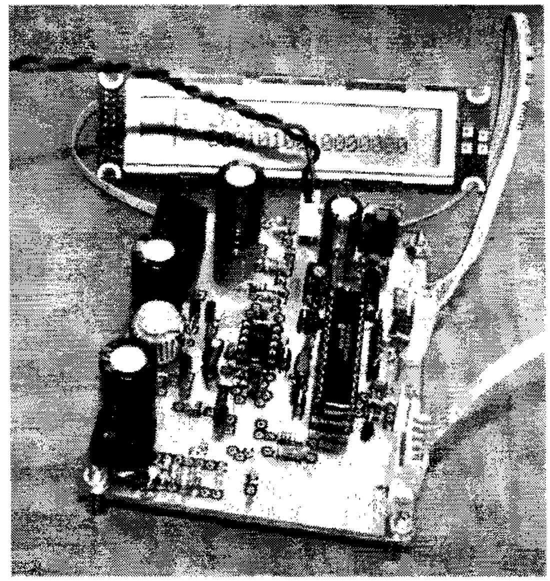
Switching design with 89% efficiency.

Operates autonomously.

IHU to fine-tune default parameters.

The "Smart Battery Charger" will incorporate Maximum Power Point tracking in its design to capture every drop of available energy from the photovoltaic cells.

Engineering design proof of concept prototype shown – Final design under construction.



ZL1HB experimental system board

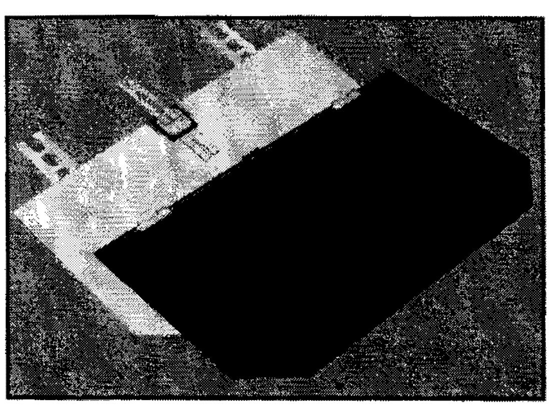
Solar Cells:

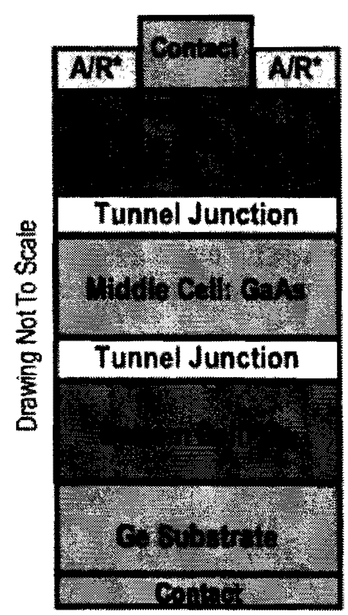
Spectrolab Ultra Triple Junction (UJT) Cells

Efficiency 28.3% min at Beginning Of Life and 24.3 min at End Of Life.

Power out per cell 0.95W at 28 deg. Celsius in Air Mass 0.

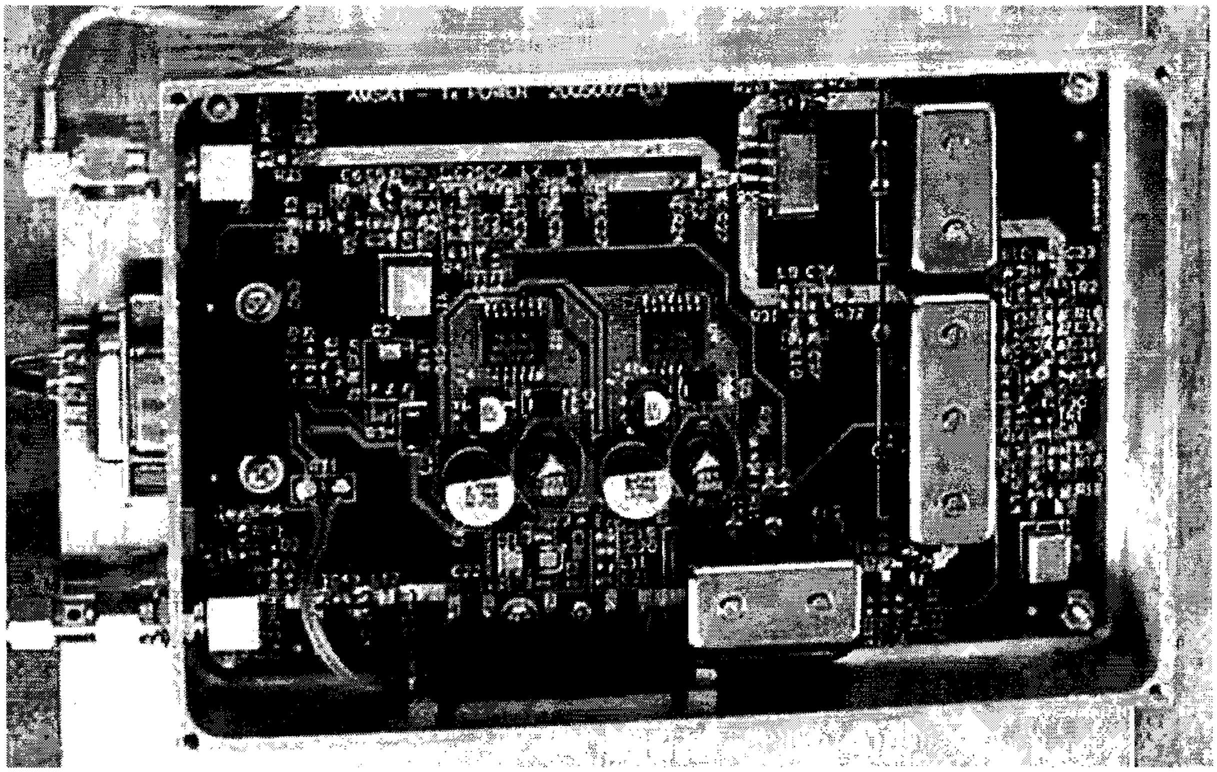
66 cells required to cover the six sides.





*A/R: Anti-Reflective Coating

Tray 1: 2 metre Transmitters and Secondary Sun Sensor



Linear VHF 2 Watt PEP transmitter – (30 kHz bandwidth) (ZL2BAC)

Features:

Ring Mixer.

Toko Helical Filters.

MMIC ERA3 used.

High Side L/O.

M57732 Power Block used.

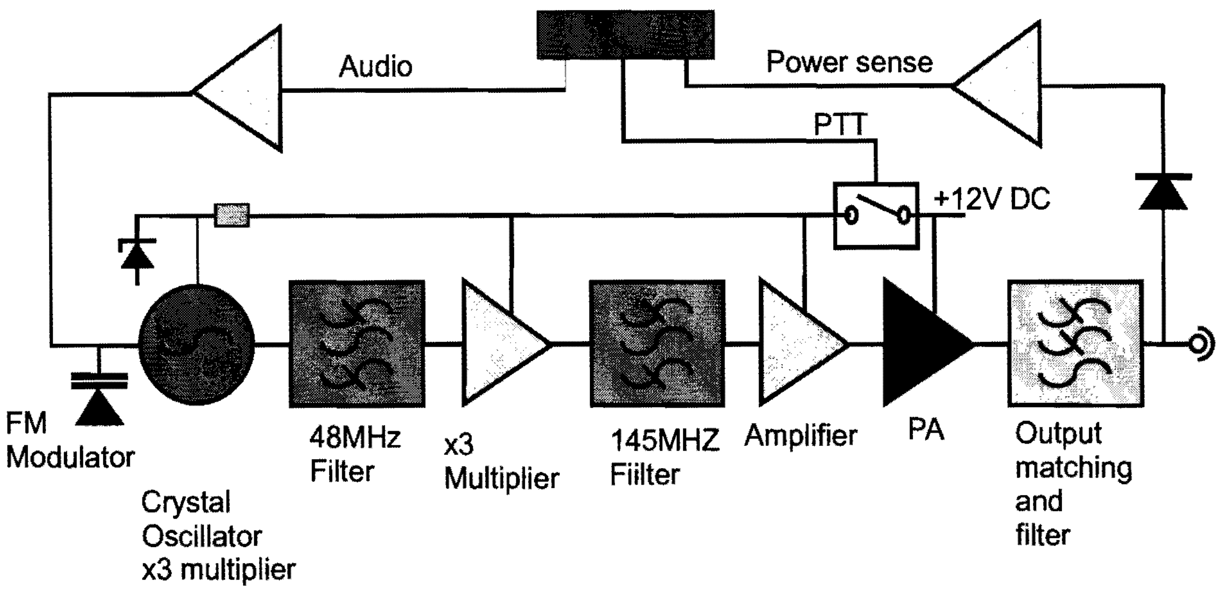
Very good output filter ~ no 3rd harmonic.

DC-DC Converters for best efficiency.

Transponder Frequencies: Inverting to reduce Doppler.

Uplink	435.260 to 435.230 MHz	1268.880 to 1268.850 MHz
Downlink	145.850 to 145.880 MHz	
Beacon	145.850 MHz.	

FM VHF 2 Watt Transmitter by ZL3KB



Frequency 145.865 MHz

Xtal frequency 16.2072 MHz

Output power 1W

Spurious outputs -35dBc

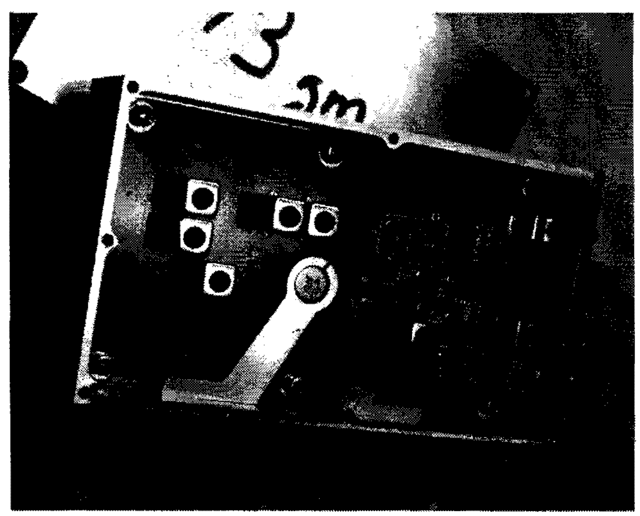
DC input 12V at 260mA

Modulation FM up to +/-5kHz

Temp range -20 +60

Freq stability over temp range +/-10 ppm (1.4 kHz)

Audio input frequency DC – 15 kHz (-3 dB)



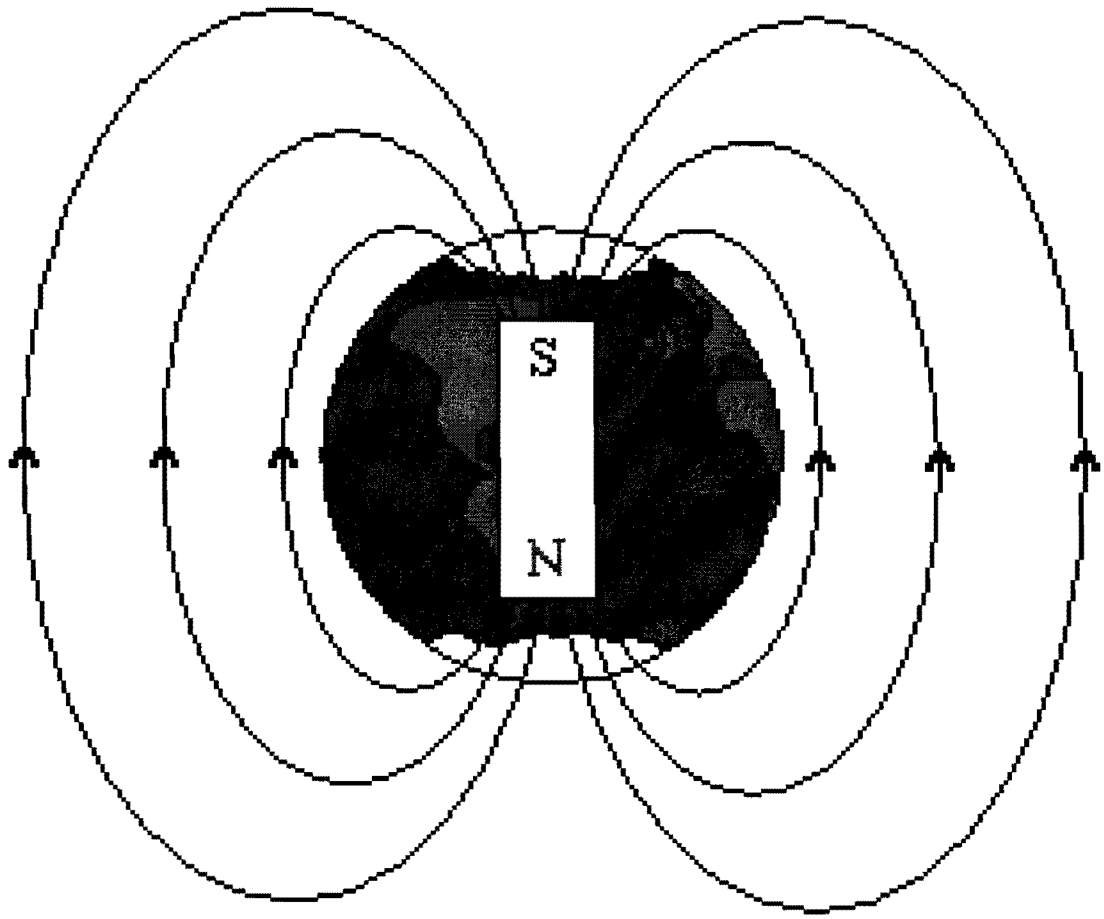
FM repeater mode:

Uplink 435.245 MHz

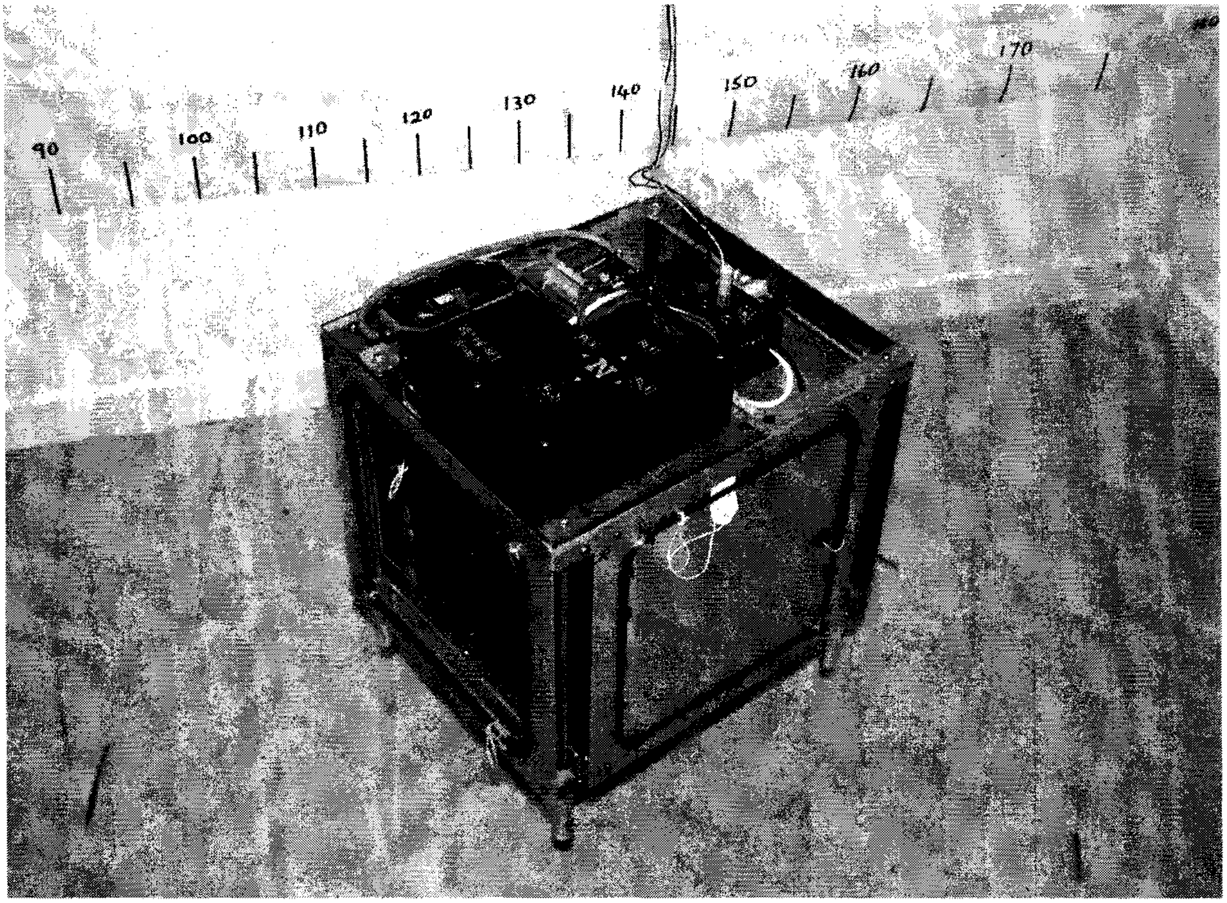
Downlink 145.865 MHz

Science Package (Attic or top layer)

- An Attitude Determination and Control (ADAC) system using the geomagnetic field.



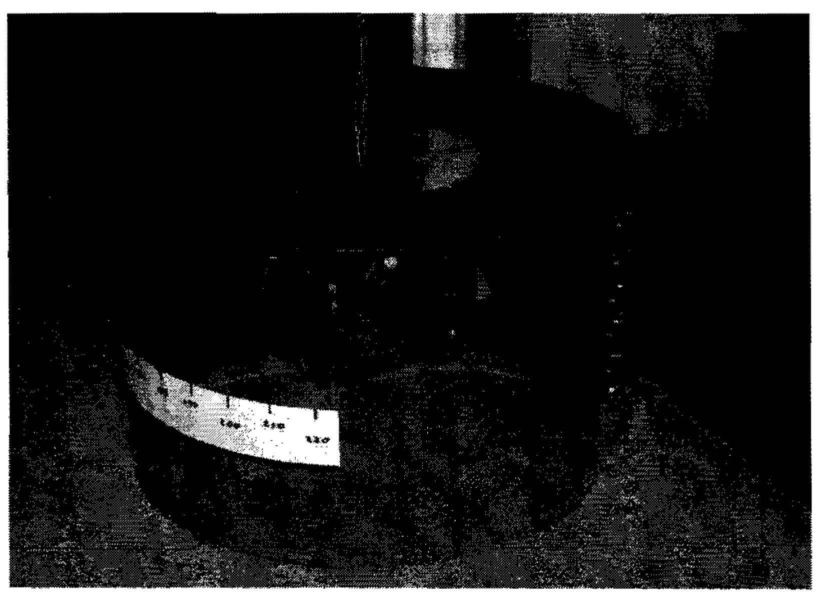
A 3 axis 'air cored' coil system will be fitted with coils on X, Y and Z faces. These will be energized – as required – providing an active attitude control by interaction with the geomagnetic field.



Single axis Attitude Control test rig with Magnetometer

Attitude Control test rig fully shrouded to eliminate air currents from affecting the experiment.

Control of the experiment while on the ground is with an IR remote control.

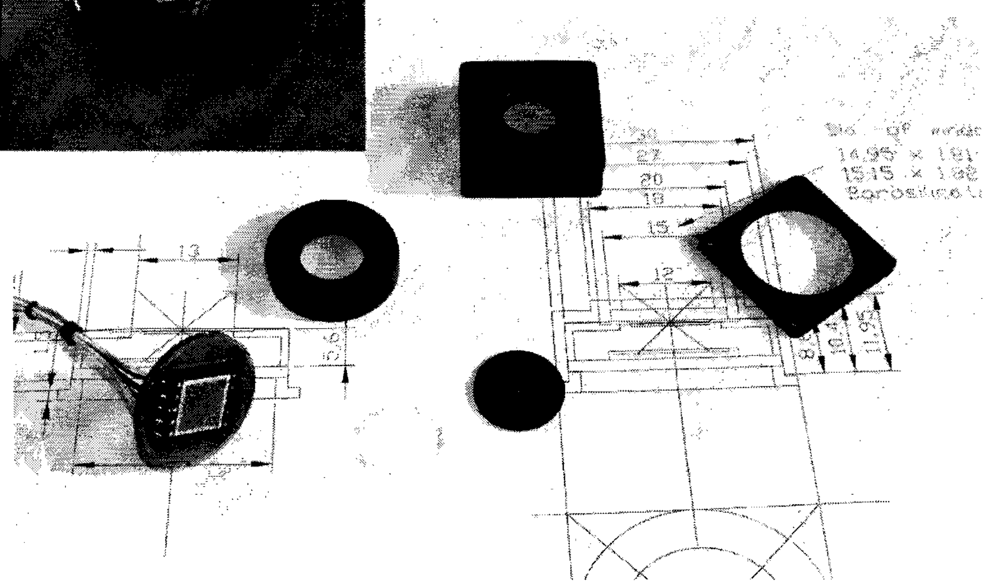


Science Package Attitude Determination Sensors:

- Sun and Earth/Horizon sensors will provide reference information to 'fix' the satellites position/attitude in space.
- A 3 Axis Magnetometer will record / confirm attitude information using the earth's magnetic field.
- A suitable GPS receiver is to be flown for both positional and time data.
- A CMOS fixed focus camera to confirm the attitude calculated from sensor data will be flown.

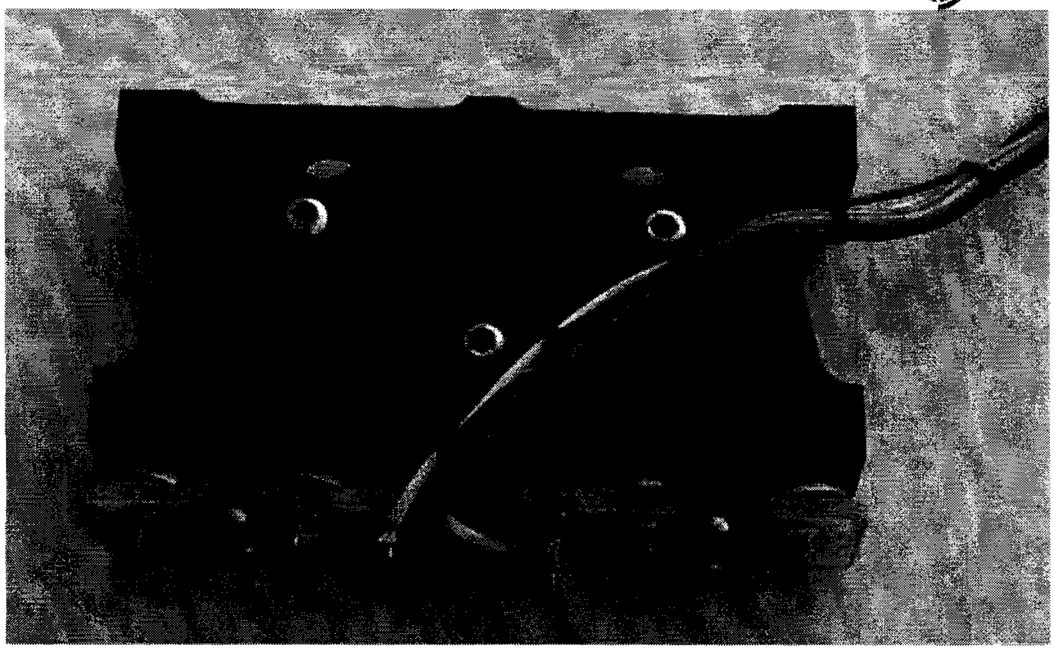
Flight Sun Sensor Mk 2

Size: 30mm sq. x 14mm deep. Weight: 20 gm.

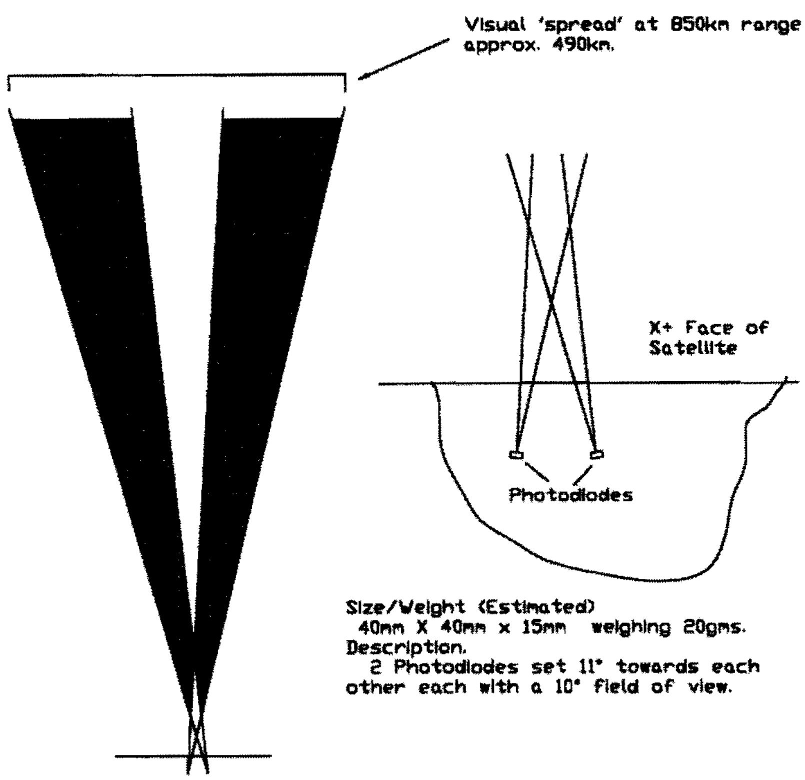


Earth / Horizon Sensor:

- Part of Attitude Determination and Control fit
- Required to establish the X/Y Axis attitude in relation to the Earth
- System must eliminate any responses direct from the Sun or any other light/heat sources.
- 2 Pairs photo-diodes - for visible and near infra red

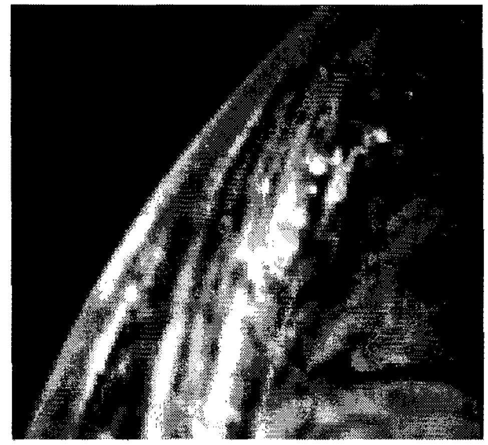


Earth / Horizon Sensor



Earth Sensor Field of View

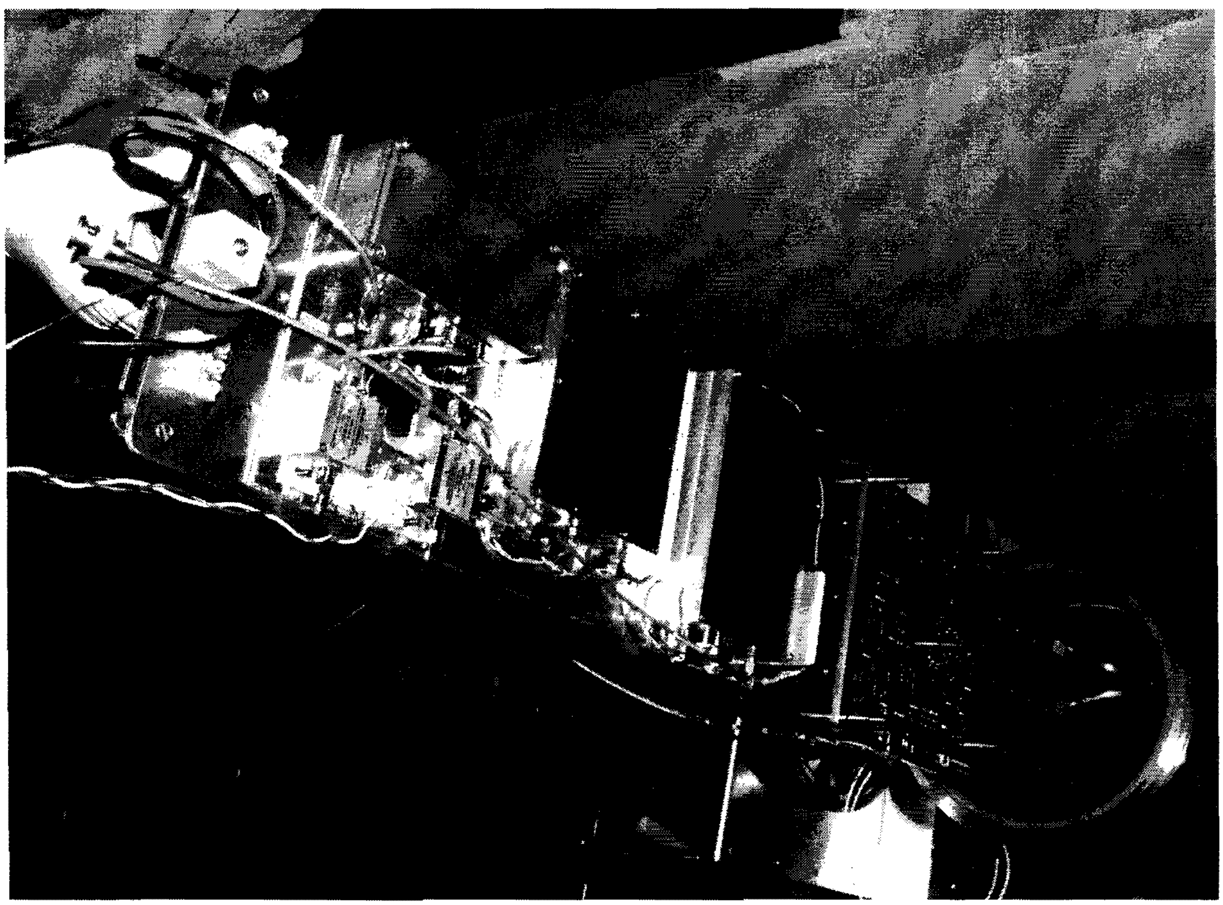
Horizon Sensor - Operation



A small CMOS colour camera module has been located via the University of Tokyo.

Used on their first CubeSAT XI – IV

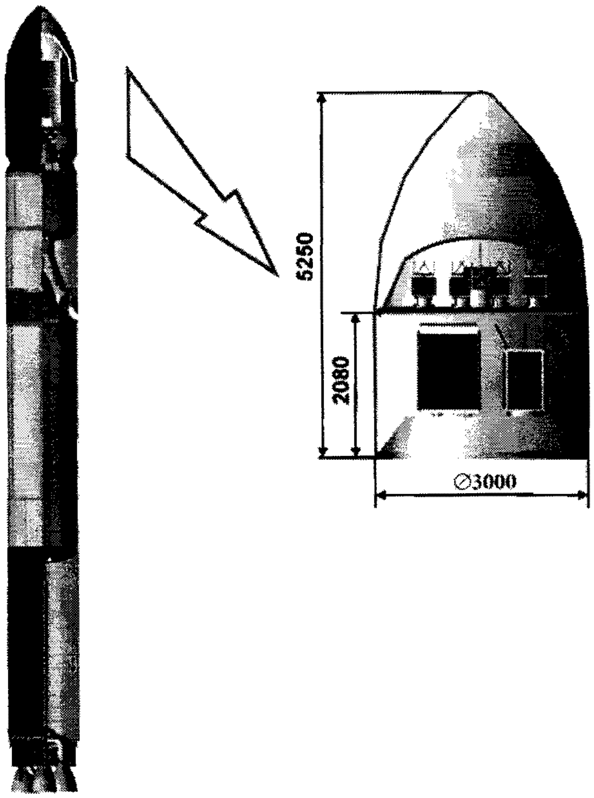
This camera will be used to confirm attitude of satellite.



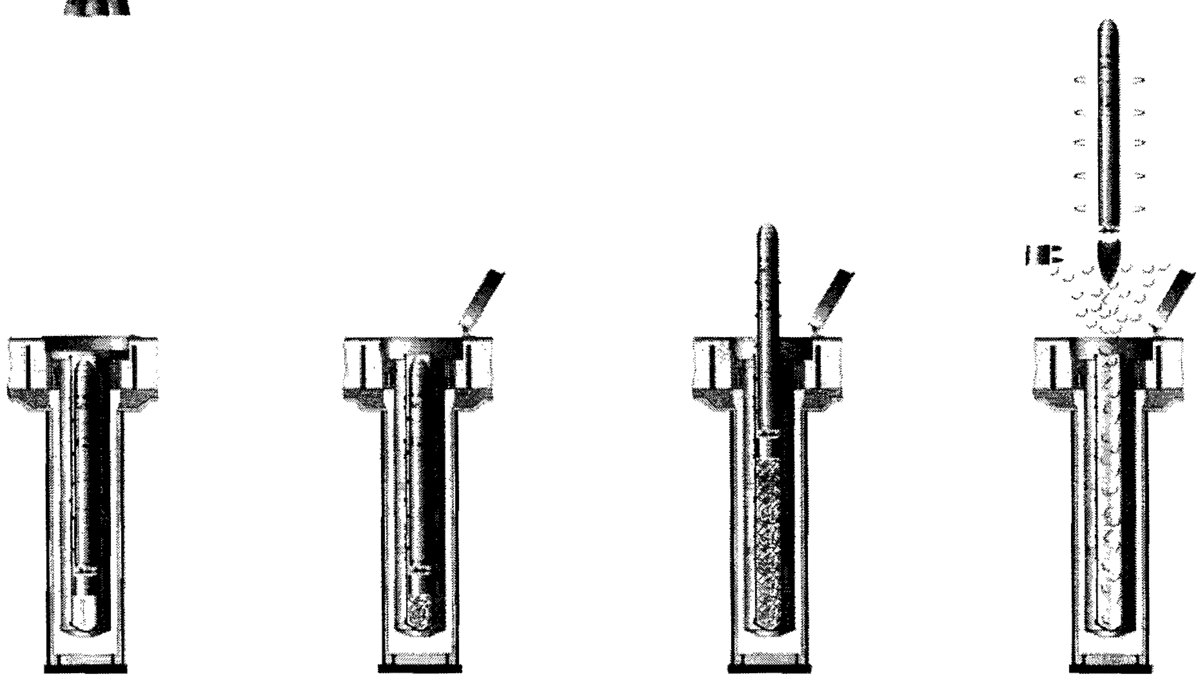
Thermal vacuum testing of Linear Transponder and IHU at Massey University, Albany Auckland

KiwiSAT – Launch Proposals

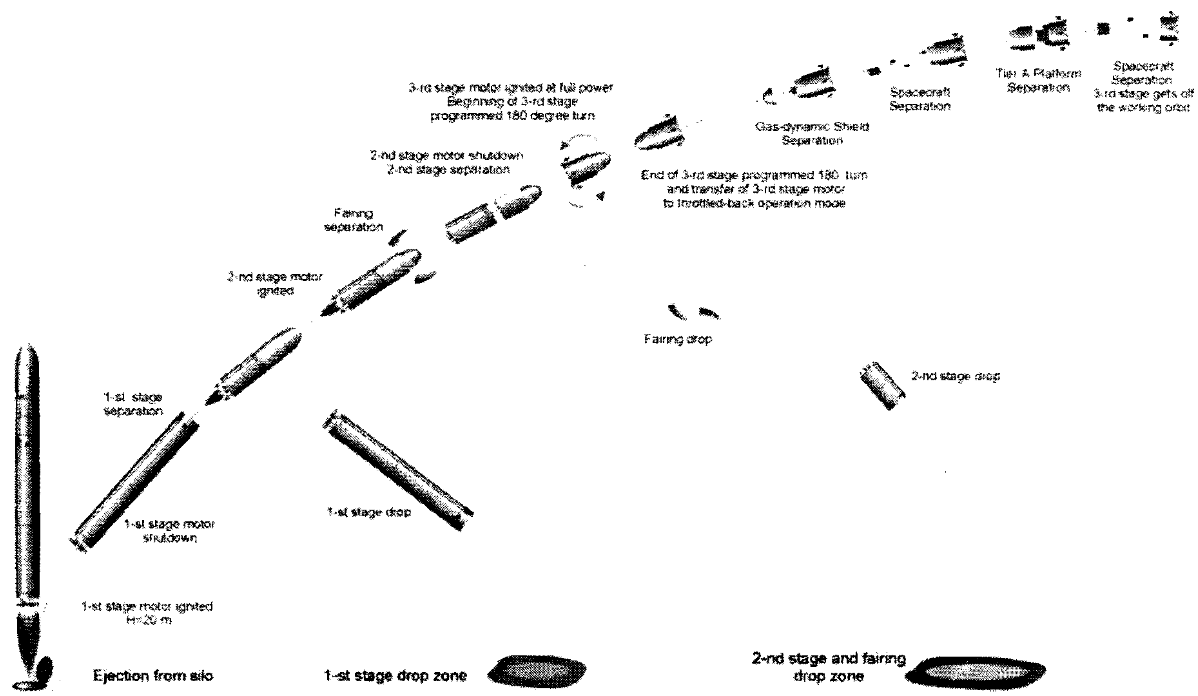
Russian DNEPR Space launch system



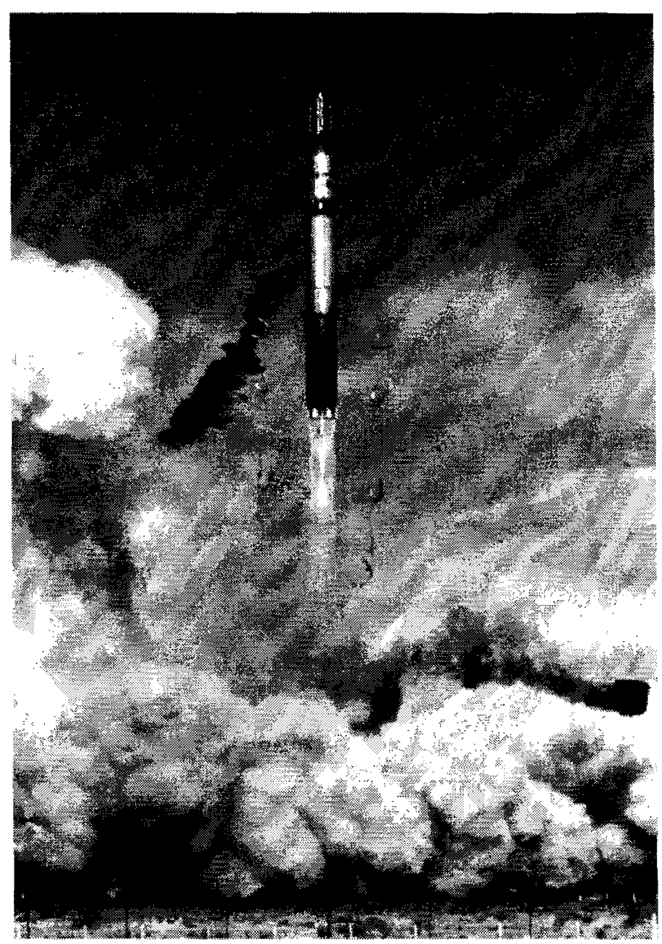
Standard Dnepr-1 Space Head Module configuration is arranged in double tiers, which enables multiple small spacecraft deployment capability (up to 10-15 small spacecraft).

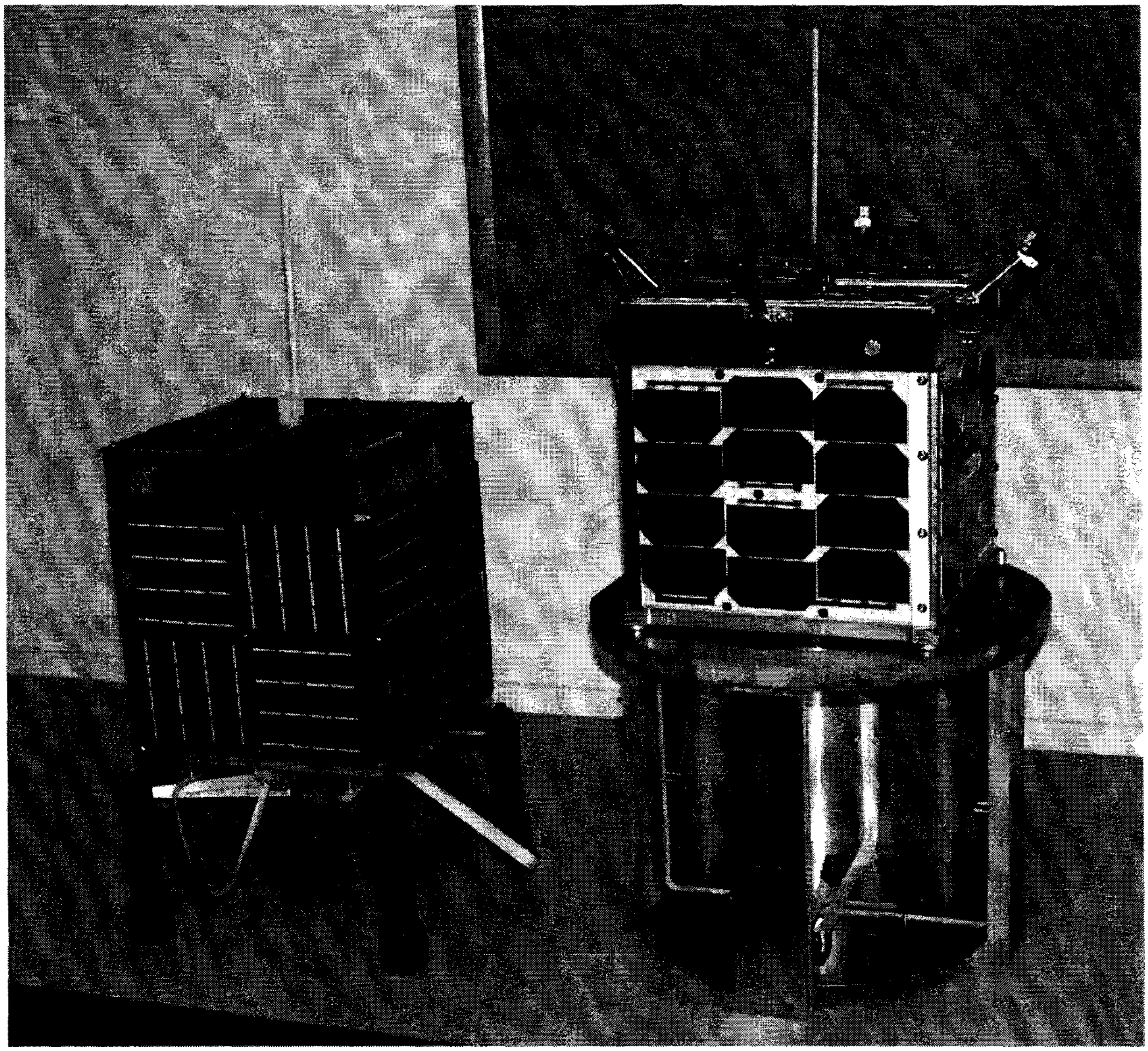


This shows the initial launch of the Dnepr from its silo.



DNEPR Lift-off!





On the left is the first full scale model planned to fly with an ESA interface.

On the right is the planned version with the high efficiency solar cells and mounted on a cylindrical interface (sides cut away for demonstration purposes) to suit the Dnepr launch.

70 cm antenna on top, 23 cm dipoles mounted on the "attic" and the 2 m antennas folded into the mounting cylinder.

Future planning for KiwiSAT is to have a "FlatSAT" by May 2007. Once details of the launch vehicle interface are finalized, the 6 trays can be milled from solid Aluminum and final assembly commenced.

Major fund raising or help from sponsors will be required for the purchase of the solar cells and then for the launch program.

A low cost, FM Exciter for use on AO-51's 1268.7 MHz L-band Uplink

Bill Ress • N6GHz
AMSAT #21049
Member – Project Oscar
Bill@hsmicrowave.com

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The Project Objective

To design and build a low cost, FM exciter for use on the AO-51 1268.7 MHz L-band Uplink that could be built by amateurs with modest building skills

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Why Do It??

- To get better utilization of the AO-51 L-band uplink
- Few commercial products for 1268 MHz exist.
  (Those available are expensive and rare)
- To encourage "home brewing" with a straight forward microwave project
- Take advantage of the "neat" low cost wireless components.
  (Thank you Mouser and Digkey!)
- Simpler than building a 1268 MHz transverter
  (and it doesn't tie up another rig)

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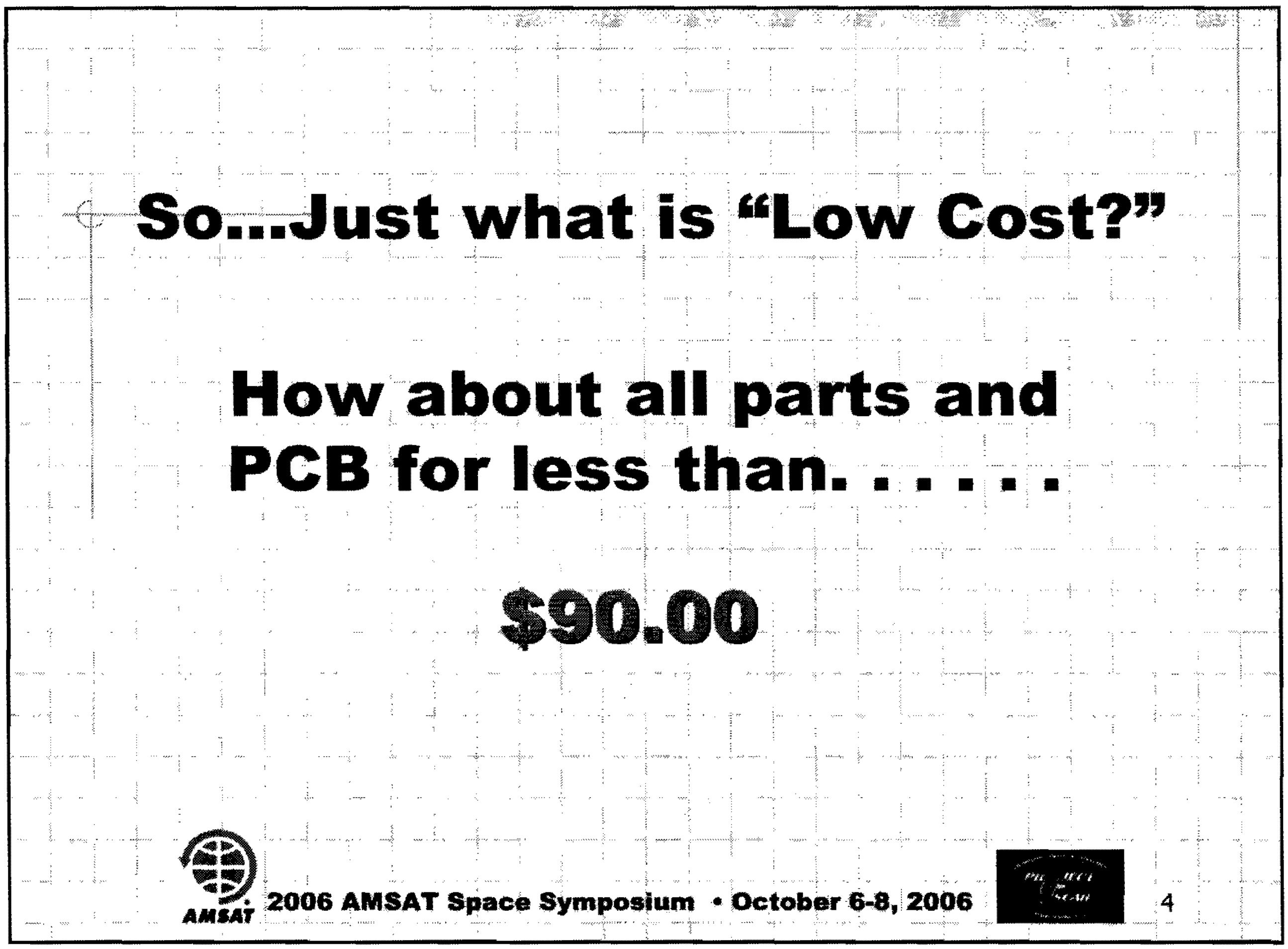
So...Just what is "Low Cost?"
How about all parts and
PCB for less than. . . . . .
$90.00
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Key Parts List

- Crystal - $18.00
- PCB - $16.00
- VCXO/X16 PLL - $10.00
- Audio Op Amp - $0.50
- Audio Limiter IC - $2.50
- Silicon Oscillator – $2.25
- HC4060 - $0.50
- MCL-E3 - $ 1.75
- 418 MHz SAW Filter - $3.75
- MCL-MAR8 - $ 2.00
- MCL-ERA1 - $1.80
- MCL – HPF - $1.80
- HMC428ST89 - $4.00
- 3 Pole Helical BPF - $9.00
- Pots - $6.00
- Misc. Components - $10.00

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The "Technical" Design Goals

- Single frequency, crystal stability
- Electrical tuning of the output frequency to compensate for Doppler
- Narrowband FM modulation (+/- 5 KHz deviation)
- Use of a low cost PC multimedia microphone
- Audio Limiting
- 67 Hz P/L
- 50 mW power output
- Low phase noise – less than –100 dBc/Hz at 5 KHz
- Spurious and harmonics better than -60 dBC

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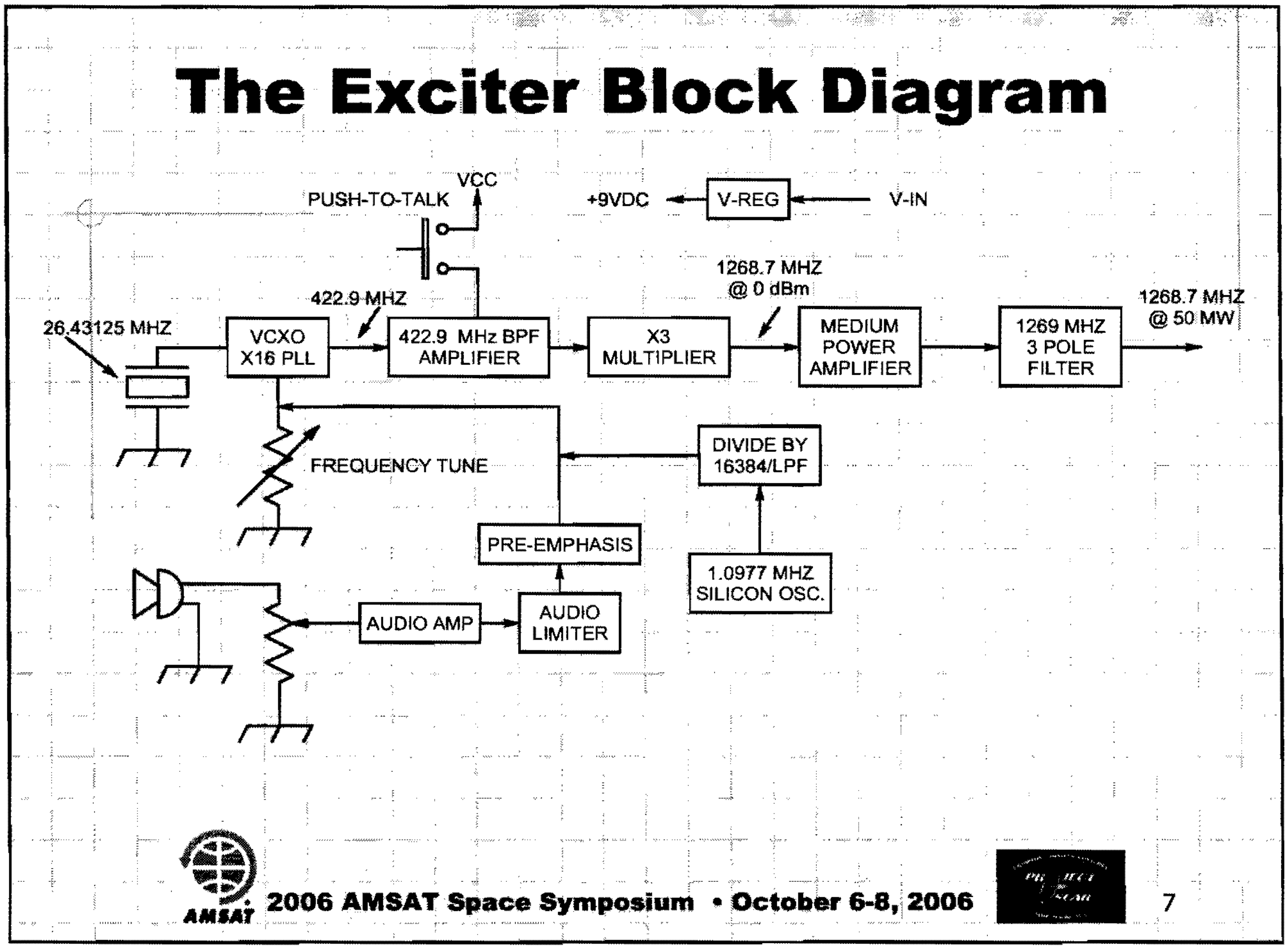
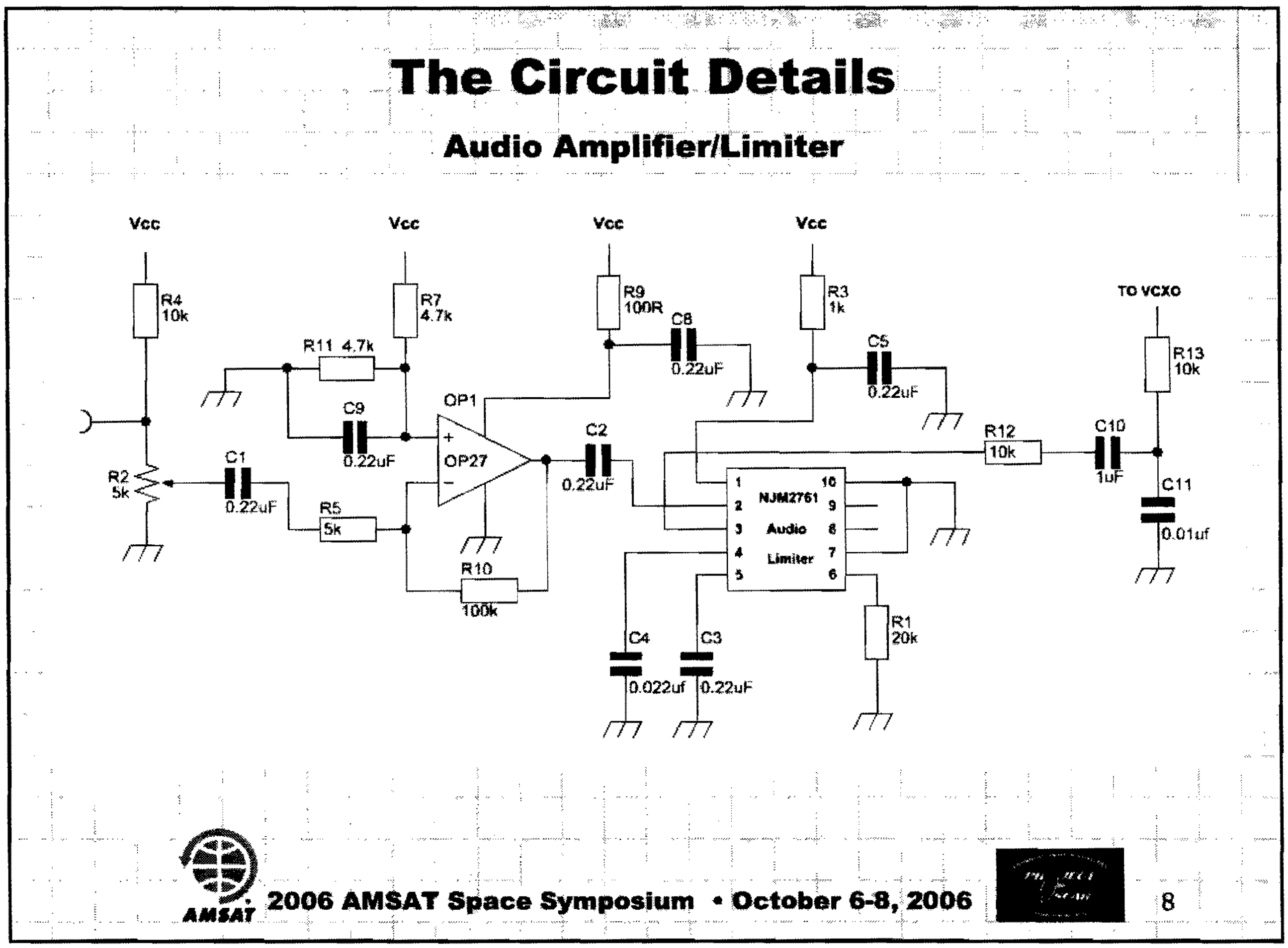


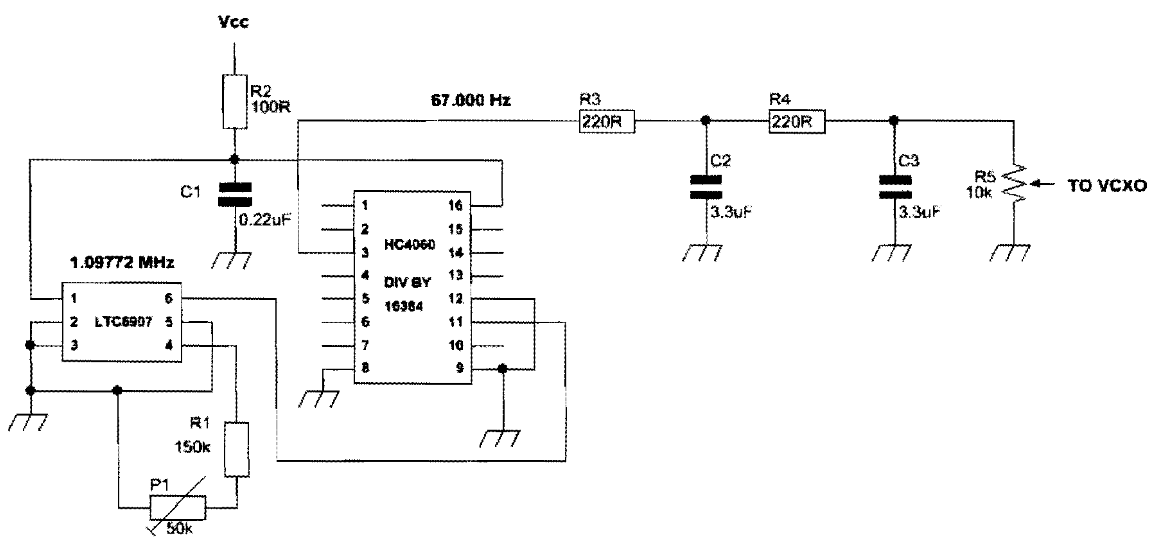
Bill Ress, N6GHz



Bill Ress, N6GHz

The Circuit Details

67 Hz PL Tone



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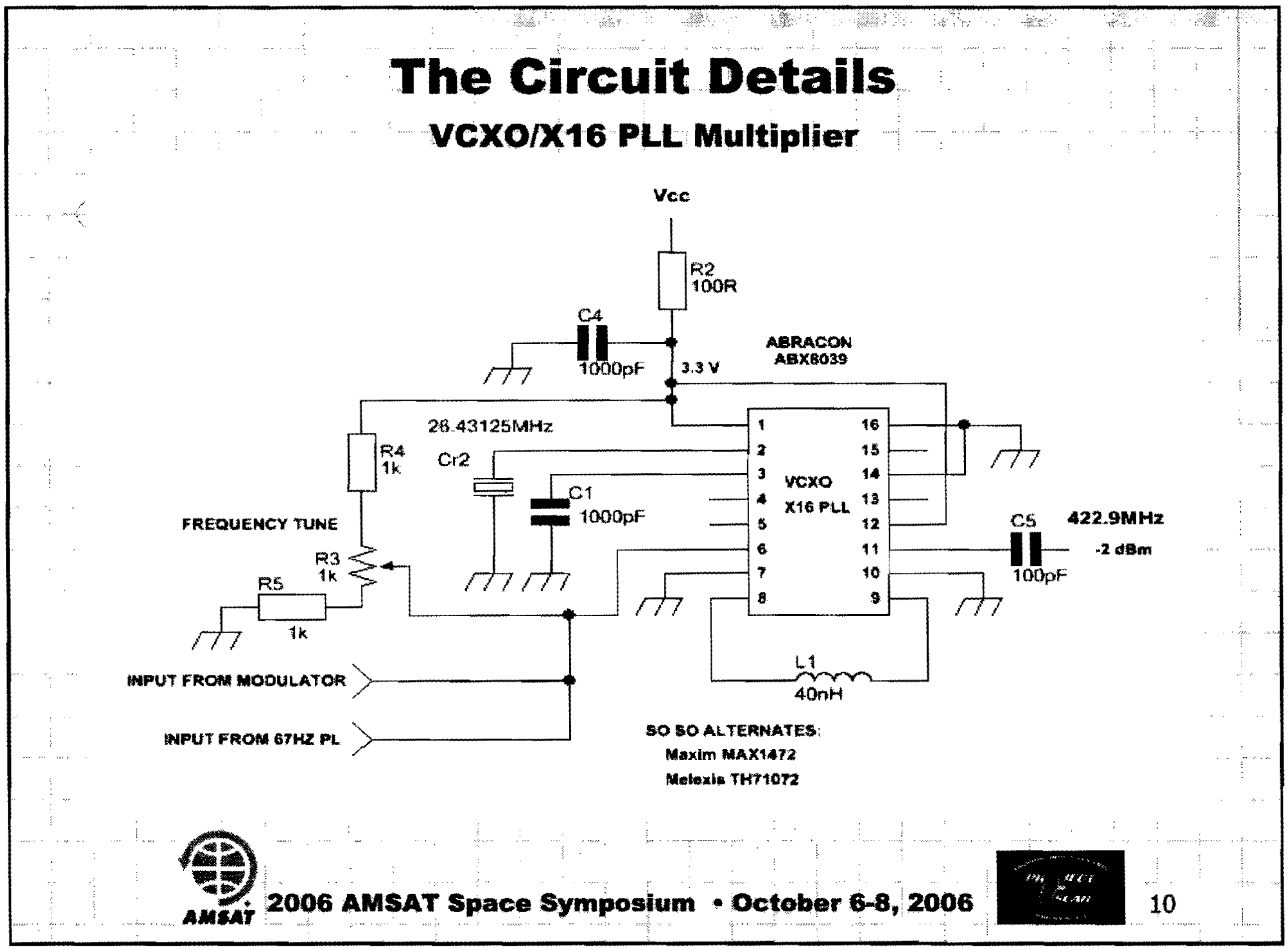
The Circuit Details
VCXO/X16 PLL Multiplier
Vcc
R2
100R
C4
1000pF
3.3 V
ABRACON
ABX8039
26.43125MHz
R4
1k
Cr2
C1
1000pF
FREQUENCY TUNE
R3
1k
R5
1k
VCXO
X16 PLL
C5
100pF
422.9MHz
-2 dBm
L1
40nH
INPUT FROM MODULATOR
INPUT FROM 67HZ PL
SO SO ALTERNATES:
Maxim MAX1472
Melexis TH71072
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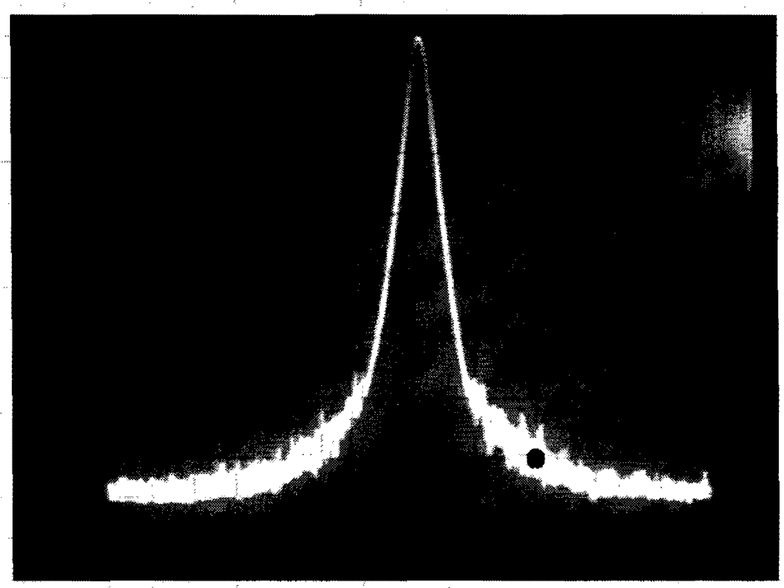
The Circuit Details

VCXO/X16 PLL Multiplier
Phase Noise Performance



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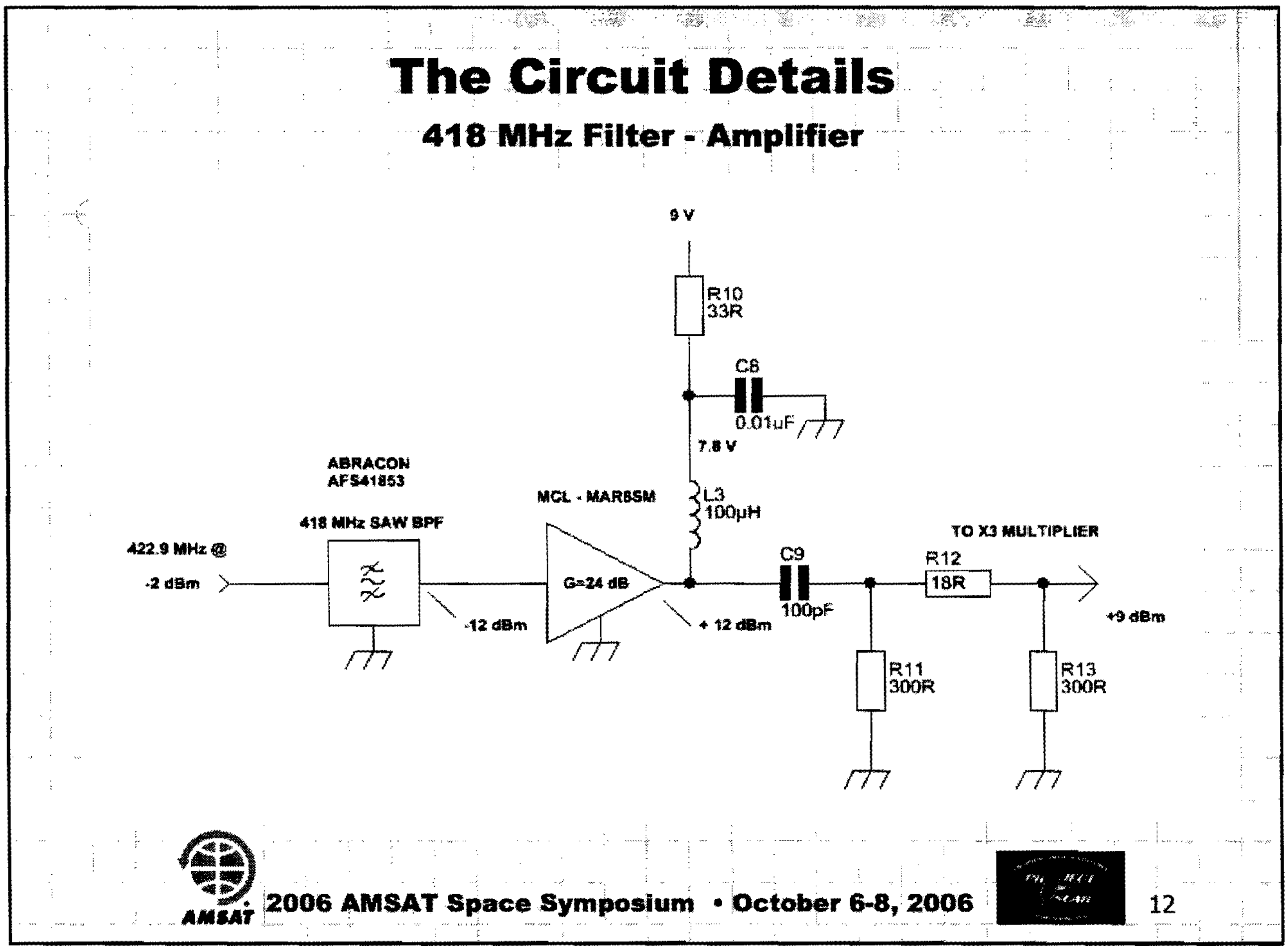
The Circuit Details
418 MHz Filter - Amplifier
9 V
R10
33R
C8
0.01uF
7.8 V
ABRACON
AFS41853
418 MHz SAW BPF
MCL - MAR8SM
L3
100µH
TO X3 MULTIPLIER
422.9 MHz @
-2 dBm
G=24 dB
C9
R12
18R
-12 dBm
+ 12 dBm
100pF
+9 dBm
R11
300R
R13
300R
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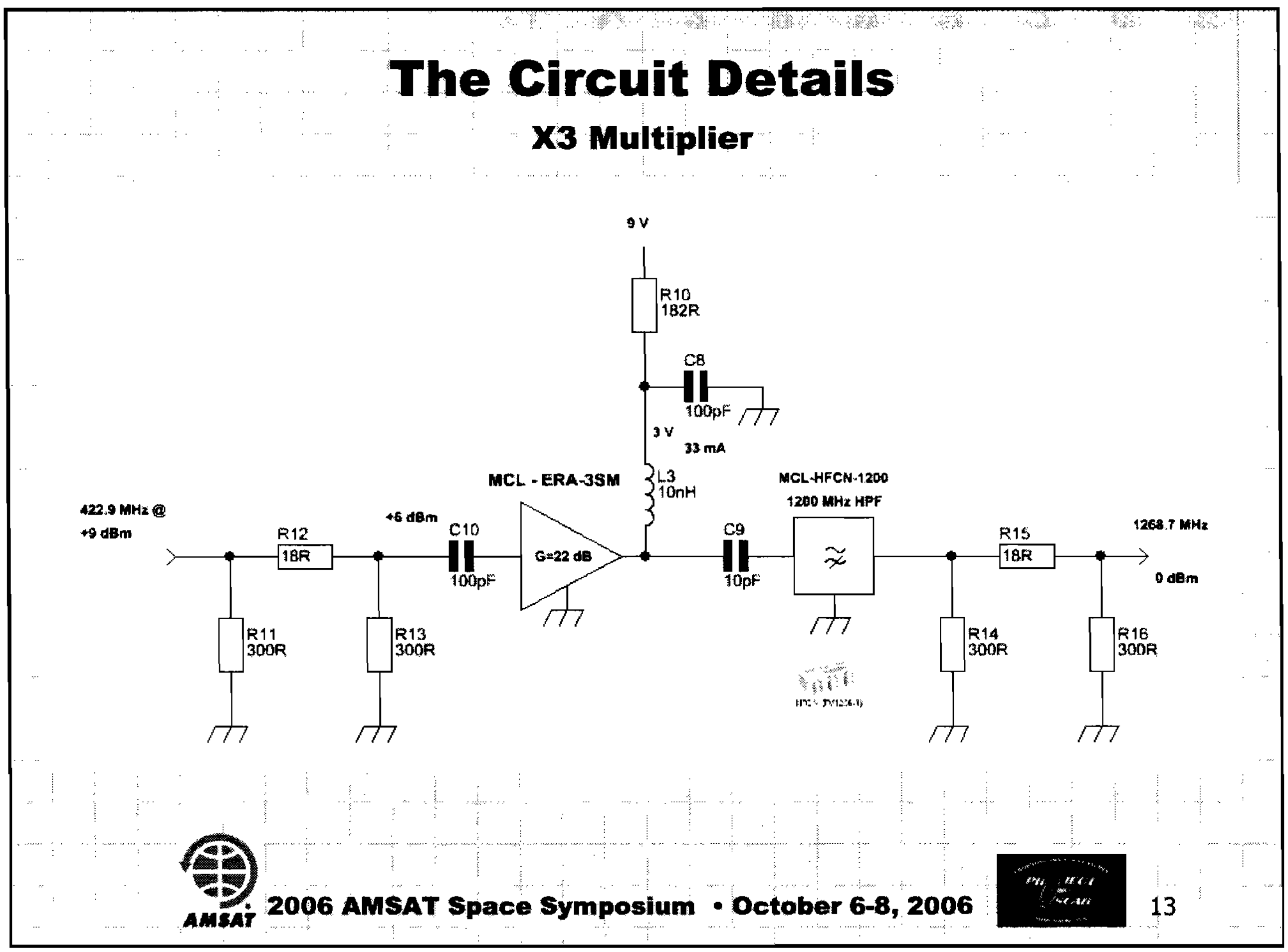
The Circuit Details
X3 Multiplier
9 V
R10
182R
C8
100pF
3 V
33 mA
MCL - ERA-3SM
L3
10nH
MCL-HFCN-1200
1200 MHz HPF
422.9 MHz @
+9 dBm
R12
18R
+6 dBm
C10
100pF
G=22 dB
C9
10pF
R15
18R
1268.7 MHz
0 dBm
R11
300R
R13
300R
R14
300R
R16
300R
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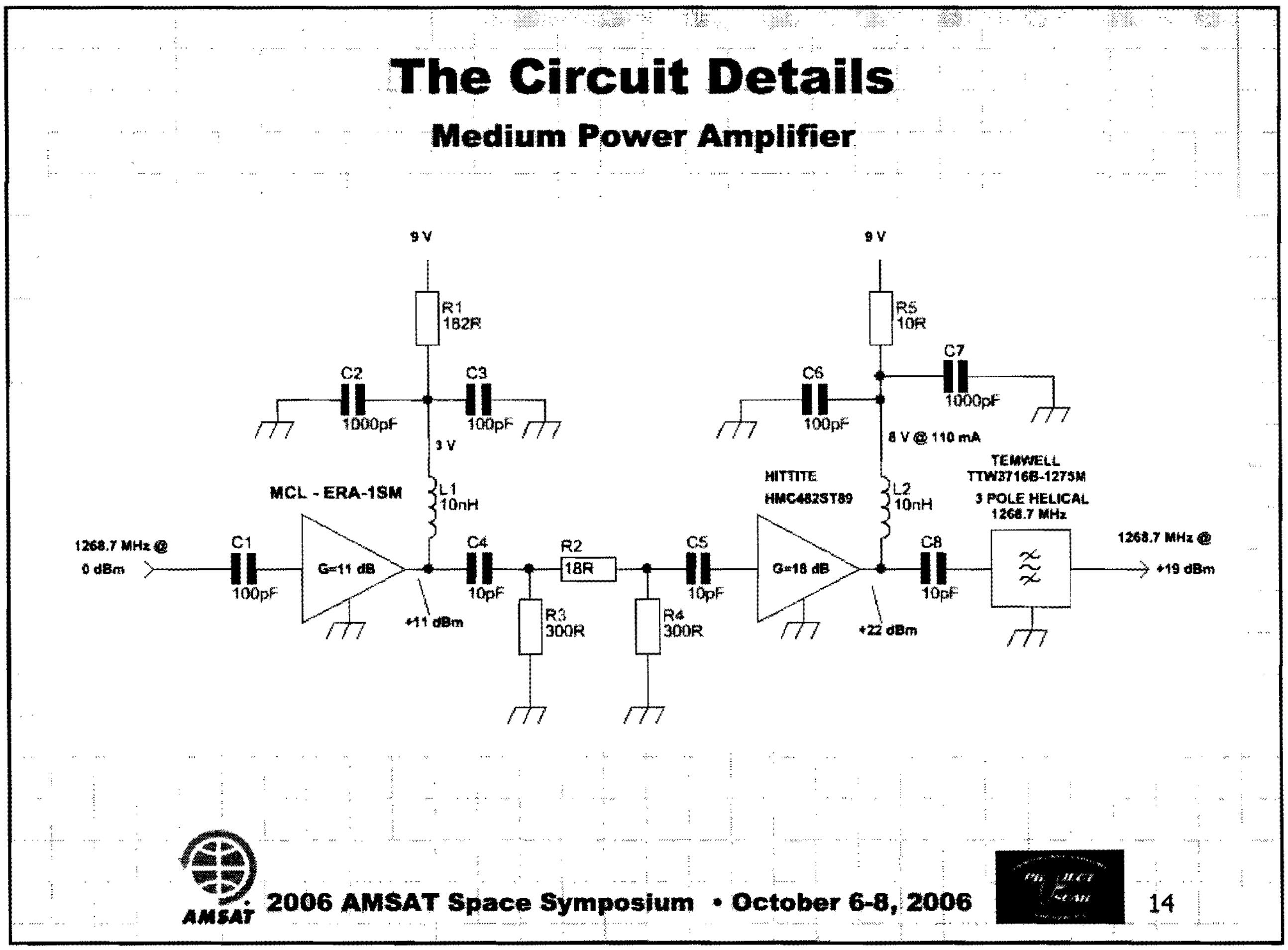
The Circuit Details
Medium Power Amplifier
9 V
R1
182R
C2
1000pF
C3
100pF
3 V
MCL - ERA-1SM
L1
10nH
1268.7 MHz @
0 dBm
C1
100pF
G=11 dB
+11 dBm
C4
10pF
R2
18R
R3
300R
R4
300R
C5
10pF
9 V
R5
10R
C7
1000pF
C6
100pF
8 V @ 110 mA
HITTITE
HMC482ST89
L2
10nH
G=18 dB
+22 dBm
C8
10pF
TEMWELL
TTW3716B-1275M
3 POLE HELICAL
1268.7 MHz
1268.7 MHz @
+19 dBm
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AO-51 L-Band Link Analysis

The first AO-51 "Experimenter's Wednesday" took place on 08/04/2004 in the L/U mode and Mike Sequin, N1JEZ, put together data gathered from 13 operators of that mode and determined the following:

For an occasional contact, 150 watts EIRP.

For medium level performance, 500 watts EIRP.

For superior performance, 1 kW EIRP or higher.

Recent operations on L/U and L/S seems to bear out the validity of Mike's early datal

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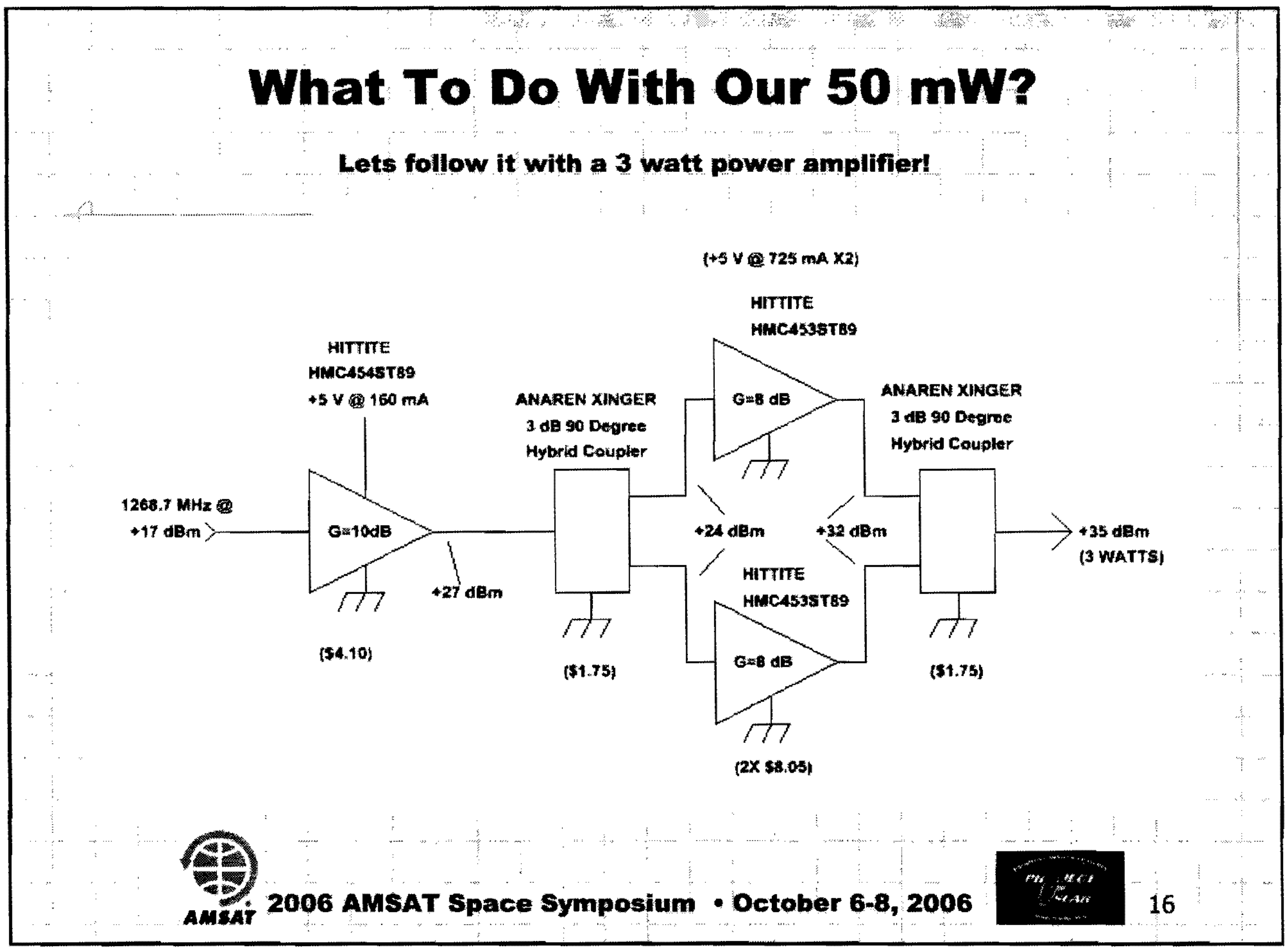
What To Do With Our 50 mW?
Lets follow it with a 3 watt power amplifier!
(+5 V @ 725 mA X2)
HITTITE
HMC453ST89
HITTITE
HMC454ST89
+5 V @ 160 mA
ANAREN XINGER
3 dB 90 Degree
Hybrid Coupler
G=8 dB
ANAREN XINGER
3 dB 90 Degree
Hybrid Coupler
1268.7 MHz @
+17 dBm
G=10dB
+24 dBm
+32 dBm
+35 dBm
(3 WATTS)
+27 dBm
HITTITE
HMC453ST89
($4.10)
($1.75)
G=8 dB
($1.75)
(2X $8.05)
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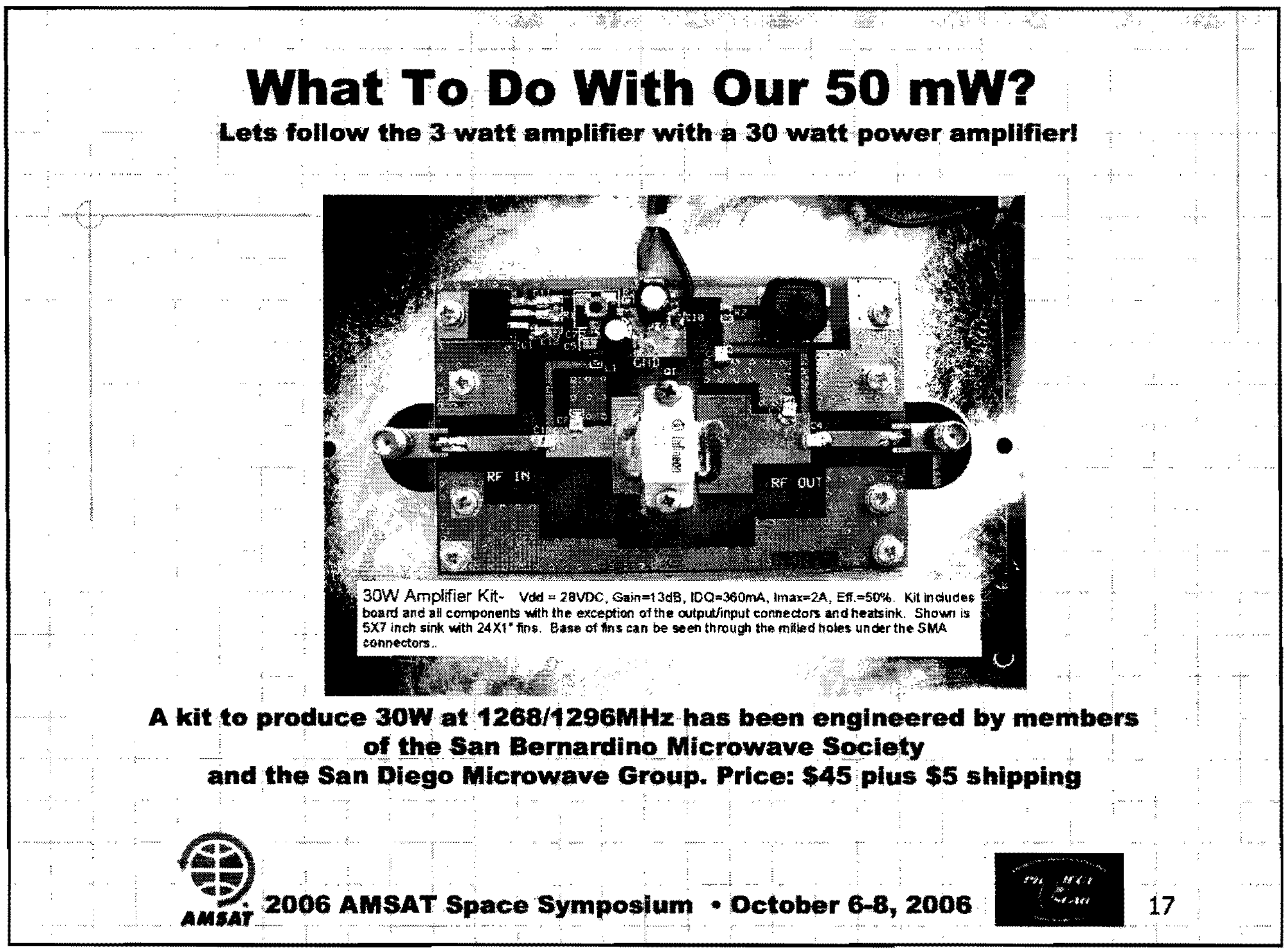
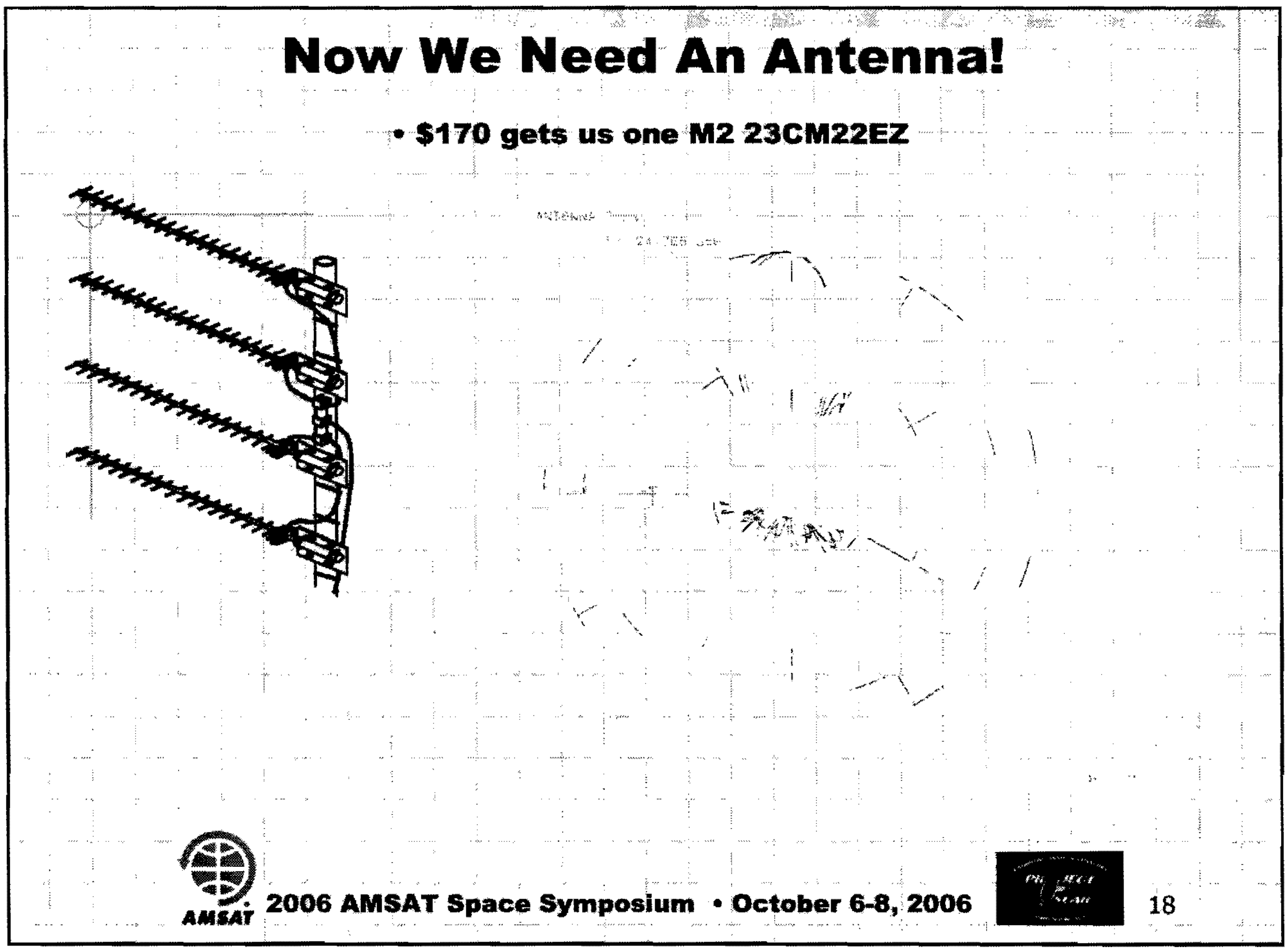


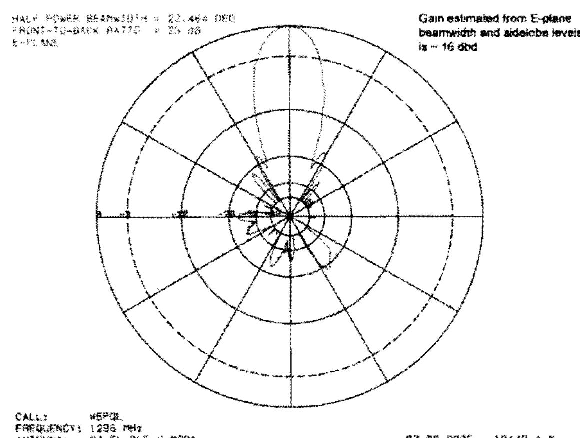
Bill Ress, N6GHz



Bill Ress, N6GHz

Now We Need An Antenna!

Or build the Jim Klitzing, W6PQL, 24 element homebrew antenna published in QST, August 2006



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Our Resulting System?

- Either 23cm antenna's will provide about +14.5 dBi gain.
- Assuming the 30 watt power amplifier is at the antenna...
- We have 600 watts EIRP.
- And that should get us into AO-51 with a fine signal!

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Other Uses For The Design

- Future FM CubeSats – CW Exciter for P3E/Eagle
- LO for a 1268/1296 MHz transverter
  - Remove the audio and P/L circuits
- LO for a 70 CM Satellite Receiver
  - Low Power – 3.3V @ 30 mA (100mW)
  - Small Size – Entire circuit is less that 25mm square
  - Good Phase Noise – less than –110dBc/Hz @ 5 KHz
  - Low Spurious – less than –50 dBc out of the device

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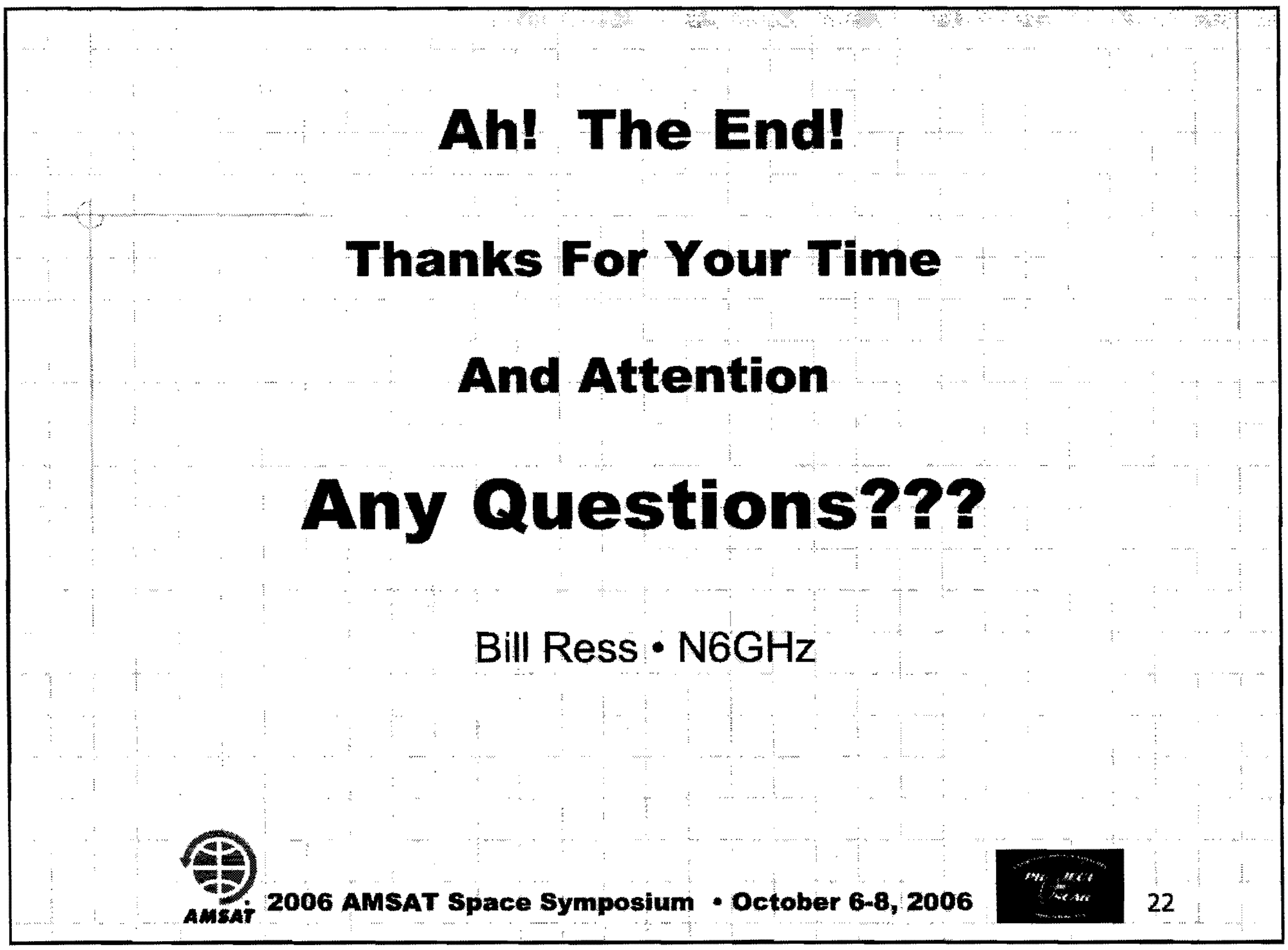
Ah! The End!
Thanks For Your Time
And Attention
Any Questions???
Bill Ress • N6GHz
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Low Cost Ground Station Design for Nanosatellite Missions

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University of Toronto Institute For Aerospace Studies
4925 Dufferin Street, Toronto, Ontario, Canada, M3H 5T6
E-mail: rzee@utias-sfl.net, Web: www.utias-sfl.net, Tel: (416) 667-7864, Fax: (416) 667-7799

ABSTRACT: This paper deals with the design and implementation of a fully capable ground station used to facilitate communications for nanosatellite missions. Nanosatellite missions by their very nature follow a philosophy of a low cost and rapid development cycle and as such the ground station design is constrained to fall within this same framework. To demonstrate the feasibility of such an approach, an S-Band/UHF/VHF ground station design that was implemented for the CanX-2 nanosatellite mission at the University of Toronto Institute for Aerospace Studies Space Flight Laboratory (UTIAS/SFL) is discussed. The design utilizes a central TNC based on a GFSK modem and a single-board ARM computer running an open-source Linux kernel with all other software developed in-house. The TNC is responsible for (de)modulation, control of ground station hardware and the necessary orbital tracking of the spacecraft. A commercially available actuator used for antenna pointing interfaces with a custom rotator controller that provides added mechanical fault detection. A GUI software application running on standard PCs acts as the satellite's operating environment. This GUI connects to the ground station TNC using TCP/IP and even permits scientists to remotely control their own experiments onboard the satellite. The software and hardware used for this ground station was designed to be modular so that the system could be easily modified and upgraded to meet the needs of future missions. The current ground station has been successfully tested by tracking and receiving signals from other orbiting satellites and is prepared for full operation after CanX-2's launch in mid 2007.

1. Introduction

The Space Flight Laboratory (SFL) at the University of Toronto Institute for Aerospace Studies (UTIAS) is a research laboratory with the objective of providing affordable and rapid access to space for research and development using nanosatellites. The Canadian Advanced Nanospace eXperiment (CanX) at SFL provides the framework for the development of new nanosatellite technologies. In order to support the CanX nanosatellite missions, a versatile ground station has been designed and built by SFL.

The CanX program follows a philosophy of low cost and rapid development along with aggressive experimentation. CanX nanosatellites are designed and built by a team of graduate students within a two year period which coincides with the time it takes to complete a master's degree. The team consists of students with backgrounds in aerospace, computer, electrical and mechanical engineering under the close supervision of experienced satellite engineers. Students benefit from exposure to all aspects of satellite development from mission conception to on-orbit operations. CanX nanosatellites utilize Commercial Off the Shelf (COTS) components to take advantage of the latest state-of-the-art technologies and benefit from the significant cost savings when compared to space grade components. Launch cost are minimized due to the low mass of nanosatellites (<10kg) and the ability to share launches with other nanosatellites.

CanX-2

The most recent nanosatellite mission at SFL is CanX-2, which is scheduled for launch in mid 2007 (Figure 1). The primary objective of this mission is to space qualify several enabling technologies for future nanosatellite formation flying missions. These technologies include a 3-axis attitude control system and a cold gas propulsion system. The second objective is to support a suite of scientific experiments for the research and development community. Universities from across Canada contributed these scientific experiments that include a miniature atmospheric spectrometer used to detect green house gases, a GPS atmospheric occultation experiment to characterize the vertical electron and water vapor profiles in Earth's upper atmosphere, a materials science experiment and a satellite communication protocol experiment [1]. CanX-2 also features an array of communications platforms developed at SFL including a UHF transceiver, an S-Band transmitter and a VHF beacon.

The UHF radio onboard CanX-2 allows for bi-directional half-duplex data transfer between the ground station located at SFL and the satellite at amateur radio frequencies. UHF radio communications in both the uplink and downlink direction occupy 35 kHz channels in the UHF band with bit rates up to 4kbps. CanX-2's UHF power amplifier will deliver 1.0W of RF power to antennas that are arranged in a quad-canted monopole configuration to provide near omni-directional coverage [2].

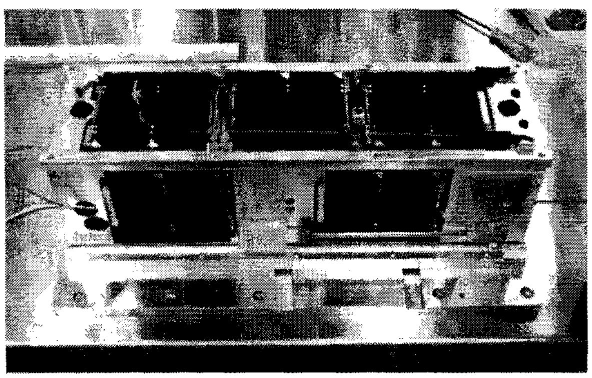

Figure 1: Integrated CanX-2 Nanosatellite

The low power S-Band transmitter (0.5W RF) will be used for the downlink of high data volumes. The S-Band frequencies used by the transmitter are in the science band, which is coordinated through the International Telecommunications Union. The S-Band transmitter will be capable of variable speed downlink between 16kbps and 256kbps. Two S-Band patch antennas located on opposite sides of the spacecraft will provide near omni-direction coverage [2].

Finally, the VHF beacon is intended to aid in satellite identification, tracking and debugging primarily in the period immediately following the launch. The beacon operates in the VHF amateur band. The beacon transmits a Morse code signal that includes the SFL call sign (VA3SFL), the satellite bus voltage, temperature and time. The beacon is permanently disabled at the end of the CanX-2 mission. The beacon signal can be received by anyone with the appropriate amateur radio equipment [2].

Ground Station Overview

In order to support CanX-2 and future nanosatellite missions, a highly capable ground station was developed and located at SFL in Toronto. As part of a nanosatellite program, the ground station was required to fit within the low cost nanosatellite framework while providing support for multiple missions. To meet this requirement, the ground station was designed to be modular so that future upgrades would have minimal affect on other systems. The ground station features a mix of COTS and custom made components. When a COTS component was either prohibitively expensive or functionally inadequate, a custom component was designed to meet the required task.

The ground station is required to support communication over the S-Band (downlink only), UHF (bidirectional) and VHF (downlink only) communication channels. The block diagram in Figure 2 gives an overview of the various hardware and software components that make up the ground station. Existing hardware from the Microvariability and Oscillation of Stars (MOST) ground station also developed at SFL is used to support both the S-Band and VHF communications. This included a 2.08m parabolic dish and radio for receiving the S-Band signal and a Yagi-Uda antenna and radio for receiving the VHF beacon. An addition required for the CanX-2 ground station was two Yagi-Uda antennas that will be used for the bidirectional UHF communication with the satellite. All the antennas are mounted on rotator motors to change the antenna azimuth and elevation to allow tracking of the satellite for the entire duration of the pass.

Modulation and demodulation of the carrier signal will be handled by three commercially available radios, one for each communication channel. Both the UHF and S-Band radios are connected to a Terminal Node Controller (TNC). The TNC acts as the modem, modulating and demodulating the digital data packets sent to and received from the satellite respectively. The TNC computer also performs two additional tasks. First it provides satellite tracking information used for antenna pointing. Secondly, it calculates the degree of Doppler shift and automatically adjusts the UHF radio frequency to compensate.

Finally, custom software applications running on the ground station computer provide the operator interface, perform data logging and route digital packets. In addition, scientists with experiments running on CanX-2 can remotely control their experiments onboard the satellite by connecting directly to the ground station computer over the Internet. All ground station software was designed to be task specific and utilizes a common communication protocol (TCP/IP). Therefore, the ground station can be easily adapted to new missions by simply modifying or replacing the modular software applications.

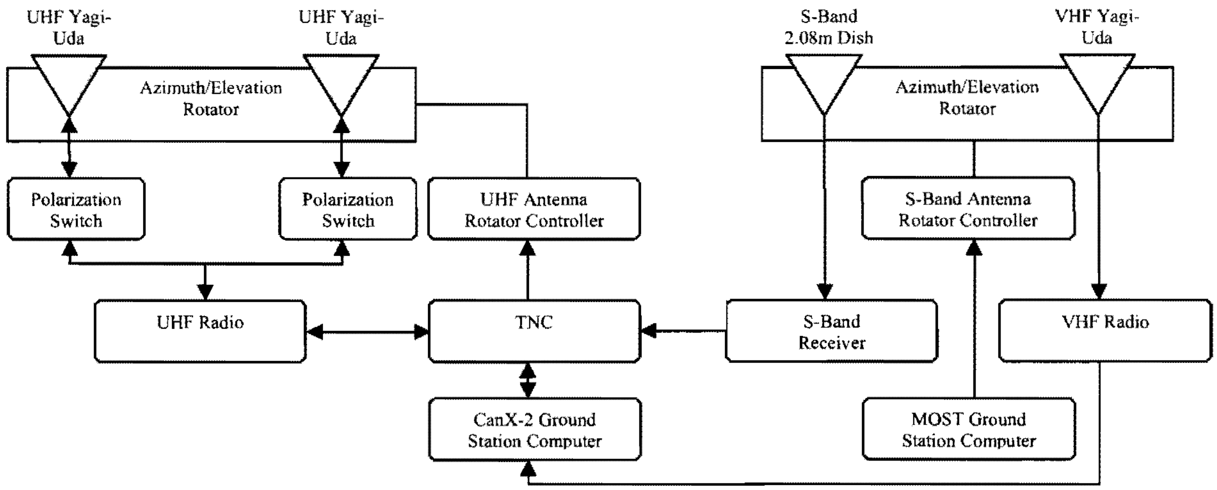

Figure 2: Ground Station Architecture Diagram

The following sections give an overview of the ground station designed and implemented by SFL for the CanX-2 nanosatellite mission.

2. Equipment Overview

Structure

The CanX-2 ground station is located atop the University of Toronto's Institute for Aerospace Studies main building. Constructed using a tripod like structure (Figure 3), the top of which the antenna rotator assembly sits, is approximately raised 10 feet above the roof during operation. It is however easily lowered to a more manageable height for installation and maintenance by removing a pair of bolts.

At the base of the structure is a weather protected rack enclosure in which the ground stations main power supply (+13.8V), 100W PA, LNA, signal lightning arrester and the control electronics for the antenna rotator is housed. Temperatures ranging from -30°C to +40°C can be seen inside this enclosure depending on the season, so all equipment inside must be capable of handling these extremes. To assist in thermal dissipation in the hot summer months, this enclosure is also fitted with a pair of ventilation fans that draw air across the components located inside.

Antennas

The CanX-2 ground station uses two types of antennas, a parabolic dish and Yagi-Uda antennas. The 2.08m parabolic dish (Figure 4) with a right-hand circularly polarized feed is used to receive the S-Band signal sent by the satellite. The dish was manufactured by Andersen Manufacturing and offers 32.2dBic gain along its boresight. Two 435MHz 42-element circularly polarized (with polarization switch) Yagi-Uda antennas are used for transmitting and receiving the UHF signal. These two antennas are combined in phase to provide a total of 21dBic gain. Finally, a single Yagi-Uda antenna is used to receive the VHF signal sent by the satellites beacon.

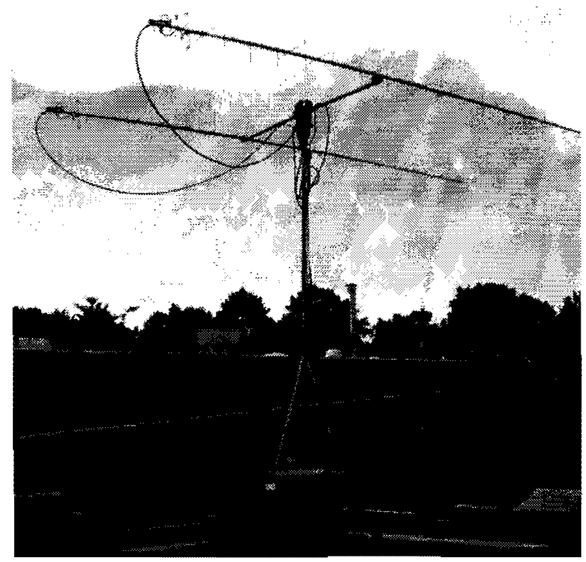

Figure 3: UHF Antenna Structure

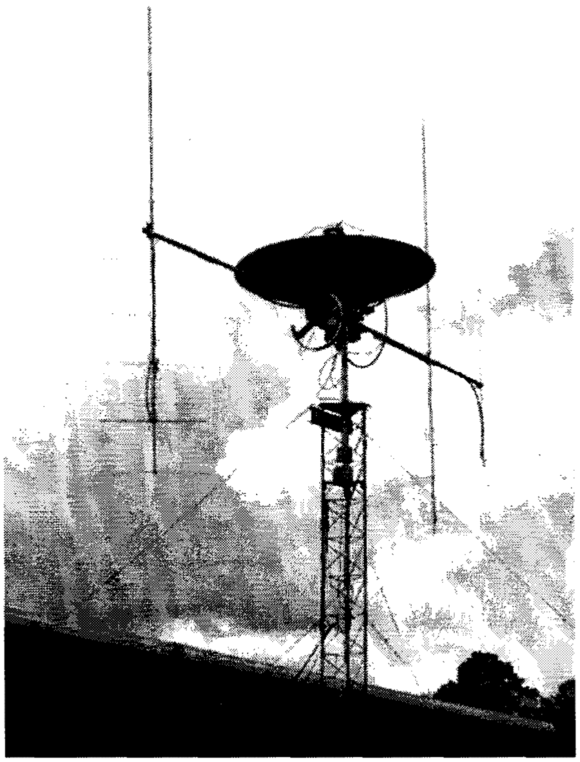

Figure 4: S-Band and VHF Antenna Structure

Radios

Three separate radios were used for the CanX-2 ground station, one for each communication channel. The S-Band signal is sent to a high performance commercial satellite receiver, the PSM-4900 made by Datum Systems. A half-duplex Yaesu FT-897 amateur transceiver is used for the UHF link. The VHF radio is a Yaesu FT-847 that will send an analog Morse code signal to the ground station computer where it will be decoded.

Rotator and Controller

The previous ground station used for the CanX-1 mission had several reliability concerns with the commercial antenna rotator equipment and its controller. To address these concerns, the CanX-2 design utilizes a heavy-duty amateur radio grade rotator actuator and custom in-house designed rotator controller hardware and software. One of the key requirements of the new design was to improve fault detection in the system to prevent damage caused by anomalous situations such as a cable becoming entangled.

Rotator

The rotator, manufactured by AlfaSpid Radio is a full Azimuth/Elevation design. Aside from its heavy-duty build, this rotator was chosen for several other key reasons. First, it provides full 180° travel in the elevation axis. This greatly simplifies the control algorithm as there is no need to deal with "key-holeing" as the spacecraft flies overhead. The rotator also features limit switches on this axis that automatically cuts power to the motor in the event of over travel (approximately 10° on either extreme). Some modifications however are necessary on the Azimuth axis of the rotator. As it is manufactured, the rotator provides no electrical or mechanical limit detection on this particular axis. To provide this necessary functionality, a pair of small, weather-sealed micro switches were employed to prevent over travel and cut power to the motor in that direction, similar to the setup found on the elevation axis. These over travel protection limit switches also serve as a means to recalibrate and self zero the rotator. Simply moving the rotator in both axes until the limit switch is hit gives a known reference point for the current antenna pointing direction. This can be done periodically to combat accumulating position errors.

Controller

Control of the rotator is accomplished through a custom designed microcontroller (Figure 5) board that provides much greater flexibility, reliability and lower cost than other commercially available controllers. The controller uses a simple 8-bit microcontroller (μC), the ATmega32. This μC interfaces with the rotator position switches, the ground station TNC computer for accepting slewing commands and the motor controllers used to drive the rotator actuators.

A pair of low-cost H-Bridge motor controllers that were originally intended for use in radio-controlled models are utilized to deliver power to the two axes motors. The motor controllers take a PWM signal as their input (from the μC) and steers high current for the motors (10A+), which allows them to be run at various speeds and in different directions. The speed control is utilized to slowly ramp up and down the motors at the start and end of antenna slews. This serves two important purposes. First, by slowly easing the motors on and off, a significantly lower amount of mechanical shock is imposed on the gear train and motors that helps prolong their life. Secondly, suddenly stopping the motors can result in strong back-EMF that is fed back through the motor controllers and into the power supply. As the power supply is not specifically designed to handle this, reduction of this reserve potential is necessary.

For position detection, the rotator utilizes a magnetic reed switch on each axis. Every time an axis moves by one degree, the switch closes momentarily. The μC software simply needs to count these pulses to calculate the current antenna pointing position. One minor additional consideration: due to contact bounce on these mechanical switches, a small bypass capacitor is necessary to provide a de-bounce filter on the signal.

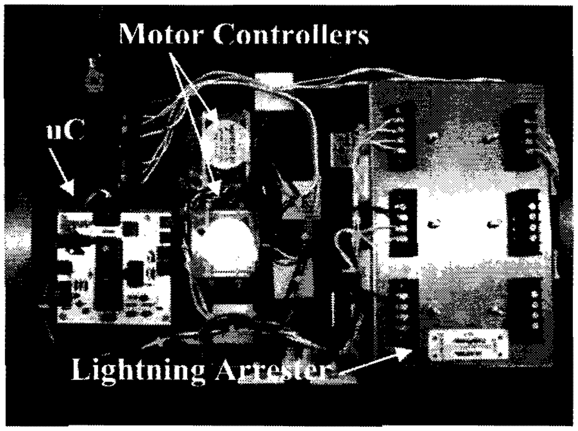

Figure 5: Rotator Controller Equipment

To aid in fault detection, such as a jammed axis, the software running on the μC continually monitors the angular rate of each axis using the position information. This value is continually compared to a predetermined value, and should it fall below this threshold for a specific period of time, a fault is thrown and the rotator will shutdown before permanent damage can occur.

In addition, the controller also has an integrating inductive current sensor mounted to the main output power line from the power supply. By monitoring this sensor for spikes in current draw (caused by a stalled motor), further protection is afforded.

Finally, the controller contains a series of FETs used to switch the polarization on the antennas as well as switching in/out the LNAs and PA in the RF chain depending on the systems mode.

Commands to the rotator controller (such as the direction to slew the antennas towards) are received over a 4 wire differential serial (RS-422) interface. This allows the communication distance between the rotator controller (on the roof) and the ground station TNC computer (located within the building) to be able to reach over the 25 meter wire run. This way, by keeping the rotator controller close to the rotator itself, the length of the high current lines running to the rotator can be minimized. For convenience, the software running on the μC on the controller is also reprogrammable remotely over this link.

Terminal Node Controller (TNC)

The central control point of the ground station is the Terminal Node Controller (TNC). This device is responsible for controlling the various ground station equipment (radio, antenna rotator, etc.), performing necessary spacecraft orbital calculations for position prediction as well as preparing and processing the data that is transferred between the ground station PC and the spacecraft. Custom software applications have been developed for these tasks in C. Hardware for the TNC is comprised of a commercial 200MHz ARM based Single Board Computer (SBC) manufactured by Technological Systems running an embedded Linux operating system connected to a in-house developed control board (Figure 6).

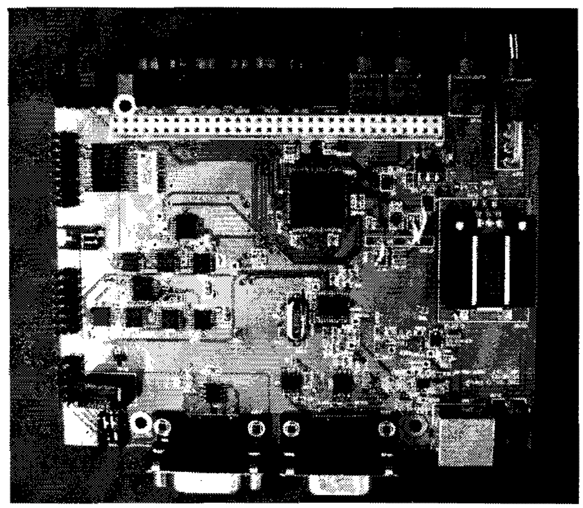

Figure 6: TNC Control Board

TNC Control Board

The TNC control board provides the additional functionality to the SBC necessary for it to become a full TNC.

SCC

A PEB20525 Serial Communications Controller (SCC) lies at the heart of the control board that provides the needed dual synchronous HDLC framed serial interfaces and is interfaced to the SBC over the PC/104 bus. One of these channels is for use by the UHF system and the other being for the S-Band channel. Both of these SCC channels support full duplex operations with the transmit and receive clock being generated externally by either the UHF modem chip or the S-Band modem. For the SCC's digital logic, clocking is provided by a 14.5MHz source coming from the SBC. A separate 14.754MHz crystal is also included for internal baud rate generation for future use.

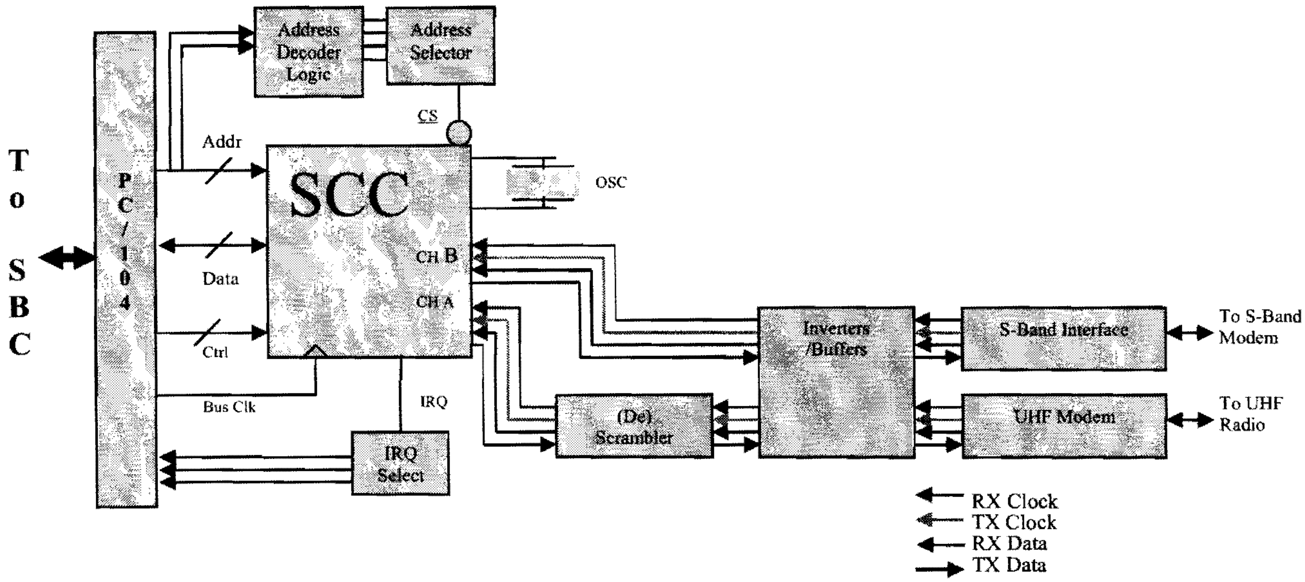

Figure 7: TNC Control Board Architecture

User Interface

On the front panel of the control board are a series of 8 indicator LEDs and 3 momentary push buttons. Each LED provides information about the status of the TNC at a quick glance. This includes if the spacecraft is currently in a pass, data transmission and reception, rotator conditions, errors or other variables of interest.

The push buttons, when pressed together, may be used to signal that a firecode should be transmitted to the spacecraft. Firecodes can also be sent using a command over TCP/IP.

Rotator Interface

This RS-422 interface is used to talk to the rotator controller providing it with slewing commands.

S-Band Modem Interface

Since the TNC control board must connect with a commercially available S-Band modem (DATUM Systems PS2100), some interface circuitry is required. To interface with the modem, a dual differential receiver for RX Data and RX Clock and a differential receiver/transmitter for TX Data and TX Clock are used.

UHF Modem

A CMX589 UHF synchronous GMSK modem is included on the control board and interfaces between the baseband feed of the UHF radio and the SCC. Analog signal-level conditioning stages follow the modem prior to interfacing with the UHF transceiver.

Radio Interface

One of the two RS-232 serial ports provided by the SBC is used to interface with the UHF radio. This interface provides a way for the TNC software to send commands to the radio to change its frequency to account for Doppler shift and trigger PTT.

Scrambler/Descrambler

To ensure sufficient bit transitions in a received data stream, the control board has a (de)scrambler implemented in discrete logic. The scrambler is fed by the SCC's UHF TX channel before going to the UHF modem. Similarly, a descrambler is also present that performs the inverse operation to recover the original data stream received from the spacecraft before being fed into the receive channel of the SCC.

3. Software

Communication Protocol

To facilitate communication between the ground station and the nanosatellite, the Nanosatellite Protocol (NSP) has been developed by SFL. NSP is based on the AX.25 link layer protocol heavily used by the amateur radio community. The protocol is designed to be simple in order to minimize packet overhead, maximizing effective bandwidth utilization.

Each NSP packet consists of a header which contains a destination byte, source byte, five command bits, an acknowledge bit, packet correlation bit and a reply bit. Therefore, each NSP packet has a three byte header followed by up to an additional 256 bytes of data (Figure 8).

Destination Address	Source Address	PF	B	A	Command	Data[256]
1 Byte	1 Byte	1 bit	1bit	1 bit	5 bits	Variable: 0 to 256 Bytes

Figure 8: NSP Packet

The SCC on the TNC control board and a similar chip on the spacecraft encapsulate communications between the spacecraft and the ground in a High-level Data Link Control (HDLC) frame. This HDLC frame adds an additional address byte that can be used for communicating with multiple spacecraft.

TNC Software

The application software on the TNC is split into two processes that execute separately but have message passing capabilities through the use of UNIX pipes. Upon startup of the TNC, a connection is first made with an NTP server to synchronize the computers clock. Then, the two TNC threads are spawned and begin executing, awaiting incoming connections to the ground station software over TCP/IP. Simultaneously, a Kernel level driver is also installed and executed to provide easy user-space access to the SCC device on the control board.

Control Thread

The first user process running on the TNC, the control thread, is responsible for monitoring and controlling the various pieces of hardware on the ground station and allowing access to status information from the ground station PC.

The ground station software interfaces with it by connecting over a standard TCP/IP connection. This allows the spacecraft operators to control the system remotely over the Internet, or locally through an Intranet.

Orbital Propagator

One of the first jobs of the control thread is to propagate the spacecraft's position. This is necessary so that pass prediction can be performed, Doppler tuning can be calculated and rotator pointing direction determined. The orbital propagator makes use of the Plan13 algorithm fed by NORAD TLE's. A set of scripts have been developed that interface with the SpaceTrack website to automatically retrieve new NORAD TLE's. This ensures the most current and accurate orbital element data is always used. Status information from the propagator can be requested and displayed on the ground station PC. This includes TLE's, times/duration of upcoming passes and Doppler information.

Rotator Control

Using data from the orbital propagator, the rotator controller sends commands via a RS-422 link to a small microcontroller mounted close to the antenna rotator actuator. These commands are simply the azimuth and elevation the rotator should move towards. When a command is received by the rotator controller's microcontroller, it issues the appropriate commands to the motors to move the antenna to the desired position.

Five minutes before a pass occurs, the software prepositions the rotator to where the spacecraft is expected to begin its pass. After the pass, the rotator is returned to a parking position to minimize wind loading on the mechanism.

Communications Thread

A second thread, the communications thread, handles the relaying of spacecraft data to/from the ground station software. It does this simply by relaying all data between a TCP/IP socket (in which ground station software connects to) and the SCC driver.

The communications thread also toggles the PTT and LNA signal lines when it is switching between receive and transmit mode. Transmit mode can normally only be activated when the spacecraft is within view of the ground station (as determined by the orbital propagator). However, the ground station operator has the ability to override this if needed.

Operator Interface Software

In order to facilitate manual control of the satellite by the operator from the ground station, a software application was created called the Nanosatellite Interface Control Environment (NICE). NICE was specifically designed for the operation of CanX-2; therefore it features a GUI that allows for full control of all CanX-2's subsystems and experiments. NICE can also be used to monitor satellite telemetry such as the bus voltage, current consumption and temperatures. All data packets sent and received by NICE are formatted using NSP.

To facilitate bulk data transfer to and from the satellite, NICE has an automated data transfer routine capable of identifying and automatically retransferring/requesting missing or corrupt data packets. In addition, NICE will allow several tasks to be automated, such as downloading data and collecting telemetry.

Data Routing Software

Since the ground station must facilitate multiple communication channels (both UHF and S-Band) and relay commands to the satellite from both the local and remote users, a data routing software application was required. The Terminal Interface Program (TIP) was created to achieve this task. TIP connects to both the TNC and the Operator Interface Software (NICE) using TCP/IP. Remote users may also connect directly with TIP over the internet, so that scientists may directly control experiments running onboard the satellite.

Command packets received by TIP are forwarded to the TNC for transmission to the satellite. Data received from CanX-2 is passed to TIP by the TNC and routed to the appropriate user. All data packets sent and received by TIP are time stamped and recorded in a log file. [A diagram of NICE and TIP would be helpful.]

TIP is also used to send manual commands to the TNC. This includes enabling Push-To-Talk (PTT), retrieving satellite tracking information and manually controlling the UHF antennae rotator.

4. Testing

The ground station was successfully installed during the summer of 2006. It is currently configured to track and point towards various different spacecraft in orbit. This includes AMSAT's AO-51 satellite, from which the station has been successfully receiving voice and telemetry transmissions. This has served as an invaluable tool in verifying the ground station's ability to track satellites as well as ensuring the receive chain is working correctly. The ground station will continue to be used in these types of tracking tests until the launch of CanX-2 next year.

5. Future Work

Two additional CanX missions that will follow CanX-2 are already in the development stages. First is CanX-3, also known as the BRIght-star Target Explorer (BRITE) Constellation that will feature up to four nanosatellites that will perform differential photometric observations of some of the brightest stars in the sky. The second mission is CanX-4 and CanX-5, which will feature two identical nanosatellites that will demonstrate precise formation flying in space [3].

These missions will utilize the same UHF and S-Band radios used for CanX-2. Therefore, the majority of upgrades will occur in software. First, the TNC software will need to be updated to track and prioritize multiple spacecraft, selecting only one to track and communicate. These missions will likely also feature multiple ground stations, so the software will need to be updated to combine data from these stations into one data stream. Finally, slight changes to the protocol will be necessary to allow the addressing of a particular spacecraft when two are flying in close formation and both become visible to the ground station at the same time.

6. Conclusion

The successful implementation of the CanX-2 ground station demonstrated that for less than a few tens of thousands of Canadian dollars a highly capable ground station can be built to support a wide range of nanosatellite missions. The ground station model presented here could be directly applied to almost any small satellite program wishing to implement their own ground station with minimal cost and complexity.

7. Acknowledgments

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- Canadian Space Agency
- Ontario Centers of Excellence Inc.
- MDA Space Missions
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AeroAntenna Technology Inc. – Agilent Technologies – Altera – Alstom – Altium –

Analytical Graphics Inc. – Ansoft – ARC International – ATI – Autodesk – @lliance Technologies – Cadence – CMC Electronics – EDS – E. Jordan Brookes – Emcore – Encad – Honeywell – Micrografx – National Instruments – Natural Resources Canada – NovAtel Inc. – Raymond EMC – Rogers Corporation – Stanford University – Texas Instruments – The MathWorks – Wind River.

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Antenna Arrays:

1. Some Theory and Factoids

2. Applications to EAGLE

Presented by

Tom Clark, K3IO

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Abstract

PART 1: Some Theory and Factoids -- Future AMSAT missions will use "smart" antenna arrays in order to achieve the gain needed for solid links to the ground. In this paper we will describe the underlying theory that can be used to predict performance of an array. Since the theoretical basis involves some math, we will attempt to de-mystify arrays and provide some simple rules-of-thumb.

In this discussion, we will demonstrate the similarity between time-frequency Spectrum Analysis and antenna arrays. Just as we have learned in all our SDR activities, time (seconds) and frequency (cycles/second) are related by Fourier Transforms, the antenna pattern (i.e. power as a function of angle) on the sky is related to the “spatial frequencies” that describe the illumination of the antenna. We will attempt to explain these concepts with lots of practical analogies.

PART 2: Applications to EAGLE – Based on this brief exposure to array theory, we will use the concepts introduced in Part 1 to describe possible implementation for the EAGLE spacecraft. Eagle will be a spin-stabilized spacecraft; as the satellite moves away from apogee, the "antenna farm" will no longer face the earth. In professional 3-axis stabilized satellites, the antenna platform might be mechanically pointed to maintain the antenna pointing at the earth; but AMSAT prefers to move electrons instead of metal, and we have designed phased array antennas that can steer the beam with no moving parts. In this paper we will describe some of the possible array configurations and present MATLAB simulations of the beam patterns that the user can expect.

About the Author

Tom Clark, K3IO (ex W3IWI) lives in Clarksville, MD and has been active in AMSAT for over three decades. He has been on the Board since 1974 and was Executive VP from 1975-80; in 1980, he took over from W3PK as AMSAT president. His first (and unpleasant) duty was to keep AMSAT alive after Phase-3A was lost in a failure of the Ariane launch vehicle, culminating in the successful flight of AO-10. After stepping down as President, he was honored by being designated President Emeritus.

Professionally, Tom retired as a senior scientist at NASA's Goddard Space Flight Center in 2001. His research in Radio Astronomy and Geodesy led to the development of Very Long Baseline Interferometry (VLBI) as a tool used to measure tectonic plate motions (now known to ~10-20 μmeters/year) and to study variations in the rotation of the earth (to levels of ~5 μsec/day); these activities led to his election as a Fellow of the American Geophysical Union and the International Association of Geodesy. NASA honored him with the NASA Medal for Outstanding Engineering Achievement and Goddard's Moe Schneebaum Memorial Award. In 2005, he was the first non-Russian to be awarded a Gold Medal by the Russian Academy of Sciences for his VLBI developments.

Software Radios: An Enabling Technology for Satellite, Space, and Ultra-Weak Signal Applications

Presented by

Courtney B. Duncan, N5BF/6

Abstract

Radios such as the SDR-1000, DSP-10, and others, where general signal processing is handled by software (and is thus "infinitely" configurable and adaptable), open vast new frontiers of possibility in amateur space communications. This paper describes the author's experience with the DSP-10 two-meter radio construction, programming, and operating including satellite tracking, QRPpp moonbounce, and even contesting. Further ideas for developments to the benefit of the Radio Amateur Satellite Service and amateur radio operators are presented.

1 Introduction – Space Communications

In 1952, Wernher von Braun published **The Mars Project**[6], a book describing a way in which a crew of men could be sent to the planet Mars and returned using technology that was available then, just after World War II. He stipulates from the beginning that, unlike the science fiction models common at the time, this would not be the effort of one person or a small team, but would require government-scale resources. Nonetheless, the book demonstrates in every detail that there were in the early 1950s no technological roadblocks; no scientific breakthroughs needed at that time to begin the journey, only the will and resources of a major nation. For better or for worse, this work and others related to it, have formed one blueprint of the space program of the United States, in some form, ever since.

In Appendix F of **The Mars Project**, "Interplanetary Radio Communications," von Braun uses the same physical constants and equations to calculate radio link performance over interplanetary distances that we do today but he takes a different approach. While we consider a given set of equipment over a certain path and compute a resulting "link margin", that is, how much signal is left after the minimums for the desired communications scheme are satisfied, von Braun begins from a set of equipment and signaling scheme and determines the maximum range possible.

Of interest to us here is a quote from the summary near the end of that appendix (in the English translation, 1953). Specifying a frequency of 3 GHz, power of 10 kW, Mars ship antenna aperture of one square meter and earth aperture (at an orbiting station) of four square meters, a noise figure of 10 dB ("Noise Factor" of ten), bandwidth of 5 KHz, and 20 dB SNR for speech, he calculates the maximum range at $1.05 * 10^{13}$ cm, that is, 105 million km. (He was apparently required to use CGS units.) Following this calculation (Equation 47.1), he says:

The expedition would reach this limiting range after about 160 days of Marsward travel. Equation (47.1) is based upon the assumption that means have been provided for suppressing image frequencies (see section 46f [on frequency stability and heterodyne techniques]). Such means are relatively simple and effective.

When it is no longer possible to maintain radiotelephone communication by reason of increasing distance, automatic telegraphy can be used. If the bandwidth required therefor [sic] is B = 1,000 cps, and if the signal-to-noise ratio is reduced to a = 20 (13 decibels), the limiting range becomes

$$\text{tau(max)} = 5.25 * 10^{13} \text{ cm}$$

Hence automatic telegraphy is always possible at any distance between earth and Mars, since the maximum distance is $3.77 * 10^{13}$ cm. The range is, of course, even greater when hand key is used. This is due to the modest bandwidth and signal-to-noise requirement of slow dot-and-dash telegraphy with acoustic or optical signal registration.[6] (page 90)

Among insights into radio technology of the early 1950s, von Braun has claimed that the astronauts can speak with earth for about half of a trip to Mars but that radioteletype will always work, and if all else fails, manually keyed Morse Code! He could have been writing an Op-Ed piece for QST....

I became interested in interplanetary navigation upon reading this book in elementary school but did not realize until reviewing it recently that von Braun and his team had also solved the radio communications problems for deep space travel.

Today, while limited by the same physical constants, we have much better tools at our disposal in terms of radio and signal processing technology. While NASA designs Giga-bit-per-second forward link systems that will allow Mars-bound crews to watch the Super Bowl live, radio amateurs on much more modest resources, that is, individuals and small groups, are also positioned to make progress in their own unique way.

In this paper I discuss one venue for such progress, a modern Software-Defined Radio (SDR), its construction, operation, forward-looking applications already implemented, and future potential.

2 DSP-10 Construction

QST for September, October, and November 1999[4] contained a series of construction articles for the DSP-10, a software-defined two-meter radio.[1] When I retired from AMSAT leadership in 1991; I declared that my return to the amateur satellite world would be via a detail-intensive construction and software path. Studying the articles carefully, I realized that this project was as close as I was going to see to fulfillment of that dream. I got in on the first AMSAT DSP-10 kit group buy, managed ably by Dan Schultz, N8FGV. In 2001 I ordered some tools from Jameco and DigiKey. In 2002 I did a little soldering. At the Jet Propulsion Laboratory Amateur Radio Club Christmas Banquet in 2003, incoming president Jim Lux, W6RMK challenged us to "finish up that languishing project in 2004."

Despite best-laid plans, life being what it is, construction progress was made throughout 2004 but by New Year's Day 2005, I was nowhere near "first smoke." I started an "intensive" on 2005 January 8. This involved more parts orders (including the enclosing box itself), much anguish, many late nights, some head scratching and uncharacteristic patience. The blow-by-blow description of this process, as well as the other results summarized in this paper, are detailed on my website.[2]

The first QSO was with WA6OWM, 30 km to the south on 2005 March 29. I was running 20 milliwatts to a discone at 10 meters.

I was a Heathkit builder decades ago when Heathkit sold radio kits. My most complicated pre-DSP-10 construction attempt was an HW-2036, the late-70s two-meter FM synthesized transceiver. Heathkit-like experience is a necessary pre-requisite to this project, but DSP-10 is a step and a half beyond that in difficulty.

New skills needed:

- Surface mount assembly
- Drilling holes in metal
- Computer interfacing
- Sharp eyesight
- Ability to divine truth from printed material in various stages of obsolescence.
- Scrounging your own (sometimes obsolete) parts and spares.

Personally, I am not a "neat" builder but my DSP-10 works anyway. This is encouraging; the design is solid.

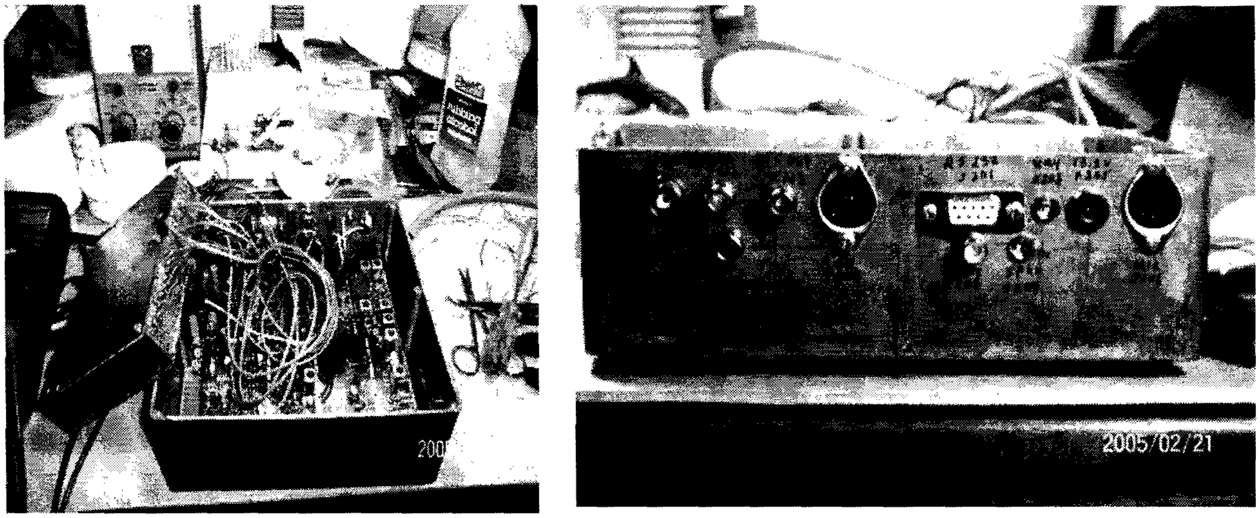

Figure 1 Hardware – DSP-10 ready for debugging – "Front Panel" (not pretty)

3 DSP-10 General Operations

DSP-10 is intended as a 0.144 GHz IF radio for microwave work and many of the builders use it in that way. I have used it exclusively on two meters myself, in conjunction with the "brickette" a linear amplifier (described in June 2000 QST[3]) which takes the 13 dBm transmit output level of DSP-10 and boosts it about 25 dB, to mere "QRP" power levels of 5 – 8 watts.

DSP-10 software has evolved continuously from before the public announcement of the project and is now at Version 3.80 (July 2006). It consists of two main components: UHF3.EXE which runs on the DSP board in the radio and UHFA.EXE, which runs on the host PC. The DSP source code is about 40K lines and the PC source is about 75K lines. The list of features is far too long to reproduce here (see Reference 1) but essentially, it is an "all mode" two-meter rig with all the standard features such as memories and multiple (virtual) VFOs. In addition, it has two classes of features not available on appliance rigs: sophisticated, calibrated signal processing options and a variety of specialized weak signal modes. In addition, special hardware debugging software has been written to assist builders with the task of getting the box going. All software is open source under Gnu Public License (GPL). Although this means that imagination is the only limitation to the appropriately skilled and motivated hobbyist, only the original team has contributed software thus far.

The PC portion of the software is integral to radio operation. All controls from and displays to the operator are routed through the PC. Even the push-to-talk on the microphone is processed through the PC so although it is possible to leave the RF box on and monitoring the last-tuned frequency with the PC off, there is no control (volume level, tuning, transmit) unless the PC and DSP unit are running their respective software and communicating. With this in mind, UHFA.EXE runs under DOS on a '386 class PC. The intent is that a surplus, otherwise obsolete PC of this class will be dedicated for use as an integral part of the radio.

The RF portion of DSP-10 is a dual conversion transceiver with intermediate frequencies (IF) at 19.655 MHz and 10-20 KHz. The second IF is quadrature sampled and processed by an Analog Devices evaluation board based on the ADI 2181 processor. These boards, the "EZKIT-LITE" were initially sold at a loss-leader price of $99 which was an enabler for the DSP-10 community. When the price for this product was raised and, later, it became obsolete and unavailable, Lyle Johnson, KK7P, stepped in and produced an ADI-2185 based replacement, the DSP-x, which continues to be available from TAPR.[5]

CW - SSB

As soon as I had my unit functioning, I set the beacon mode to call CQ on 144.200, the two meter calling frequency, at 20 mW. Eventually, the local community became annoyed enough with this that WA6OWM answered me. We had a pleasant, Q-5, CW QSO. After several weeks of trying to check into SSB and FM nets or make arranged contacts, it became clear that 0.020 watts output was insufficient for general operation.

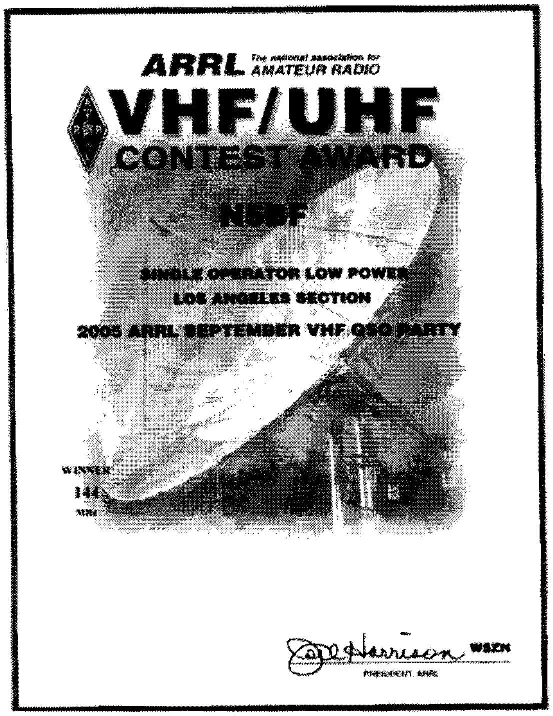

Figure 2 DSP-10 Wins the Contest! (Well, Single-Op, Low Power, LAX, 144 MHz only)

Using the June 2005 ARRL VHF QSO Party as the deadline, I built the "Brickette" (or "slippers") and the combined rig did well, netting 30 QSOs in four grids squares.

Signal reports often include comments on the "good audio." It is clear that other operators cannot tell that this is not a store-bought rig with respect to clean signal performance.

For the ARRL September VHF QSO Party, an M^2 2M12 replaced the old Telex-Hygain Oscar beam and the DSP-10 "won the contest" with 33 QSOs in six grids, one of them difficult from my location (eastern DM04 to CM94). (As discussed below, I have also copied a beacon over the mountains in DM05 but have not heard or worked any stations there.)

Beacon DXing

Of course, operation as a "normal" two-meter rig is just the checkout phase. Our interest in this paper is to open and explore new frontiers in the art of amateur radio, particular in the direction of space. Space being truly vast and the inverse square law for the propagation of energy still being in effect, one aspect of this new frontier will involve weak signals, sometimes *very* weak signals.

About 100 km from my QTH on the other side of a mountain ridge is the Tehachapi two-meter beacon well known throughout California. One day when propagation was unusually good, I was able to copy its entire CW transmission, "N6NB/B DM05sb" followed by a string of dits. Normally, this beacon is not loud enough to be copied in audio at my location.

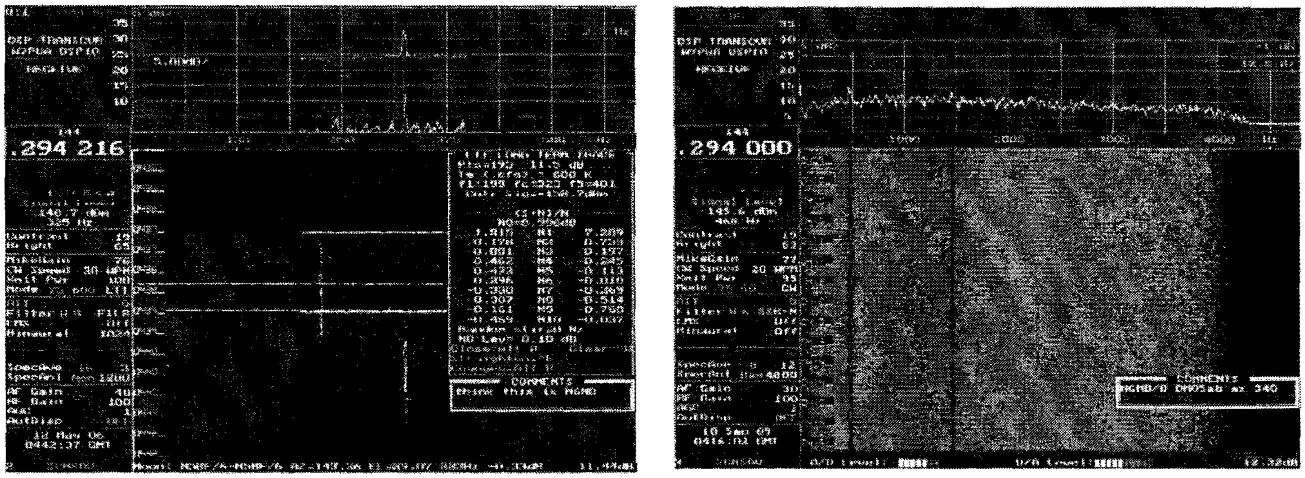

Figure 3 An LTI view and a normal CW waterfall view of N6NB/B

Figure 3 shows two DSP-10 displays of this beacon on days when it was detectably but not copy-ably audible. On the right, the normal waterfall display shows several minutes of activity just below 500 Hz. The darker (blue) parts of the line are periods when dits are being sent. The solid pink parts are when the ID and location are being sent, using more energy per unit time.

On the left is a "Long Term Integration" display of the same signal at a similar level. In the waterfall you see where I've been tuning around to center the signal in the integration window. You can also see a little frequency drift. Is this at the beacon transmitter, my receiver, or both? The box on the right of that display contains statistical information for the long-term integration.

The frequency drift highlights an issue in long-term integration. For the averages to be meaningful, the signals have to be fixed, or at least have to be modeled in such a way that comparable quantities are being added with each sample. Otherwise the results become "smeared."

In the spectral display at top the lower white line is the latest instantaneous spectrum. It is of the same form but with different averaging properties and different background noise level than the spectrum on the right. The yellow trace at the top is the result of 195 averaged points (as seen in the LTI statistics box). Notice how the noise has averaged down to a flat line with ripple at a fraction of a dB while a clear signal peak has formed about 8 dB higher. This integration demonstrates the first 10 dB of improvement in signal detection available through signal processing. Additional improvement and signal modeling will be discussed further below under EME2.

AO-7

The first satellite I actually used as a licensed radio amateur was AO-7, back when it was new in the 1970s. As I was getting DSP-10 going, word came that AO-7 was in a favorable illumination cycle and was being heard again. I was lucky to find AO-7 transmitting on two-meters on one of my earliest listening attempts. A trace of the carrier signal from Acquisition of Signal (AOS) to Time of Closest Approach (TCA) is shown in Figure 4. As with the Tehachapi beacon trace, this signal was barely, sporadically audible. Any CW modulation that was there was not readable. The characteristic Doppler signature in the display is quite clear, however.

In the section below titled AMSAT Tracking Network, techniques for using data such as this for calculating satellite orbital elements will be discussed.

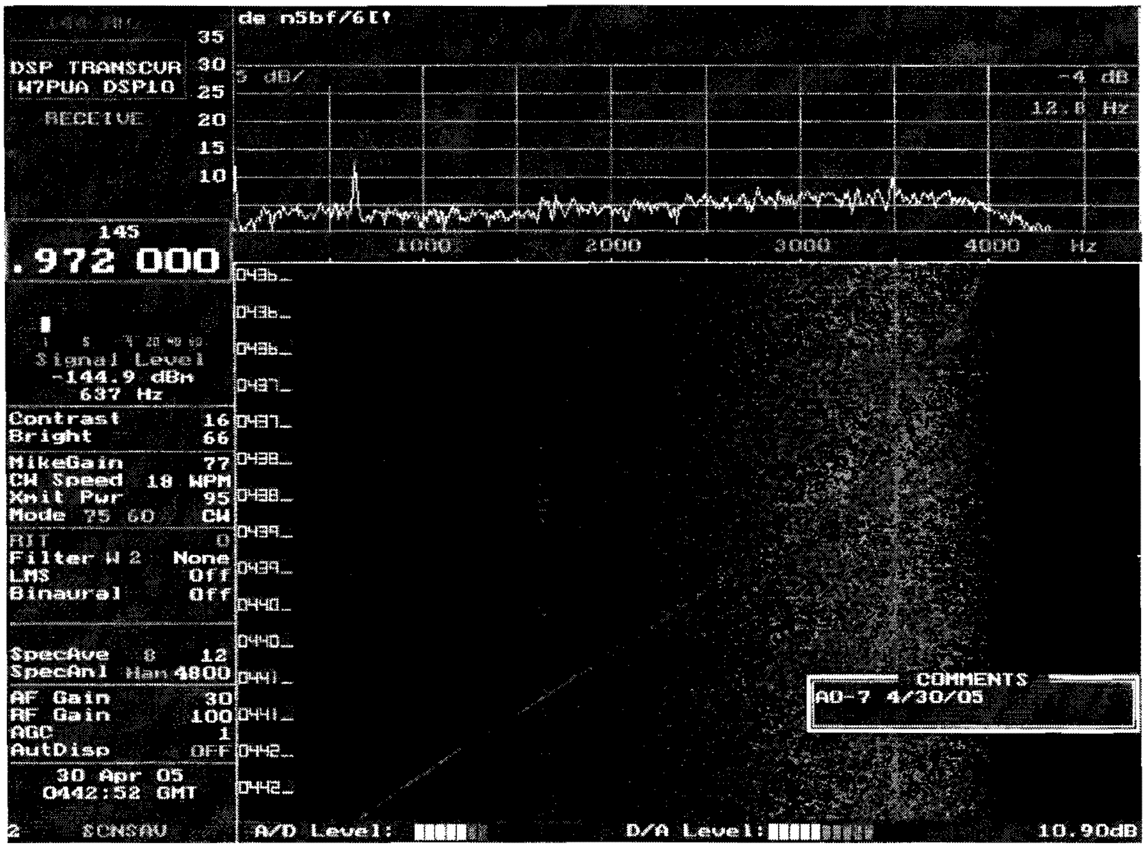

Figure 4 AMSAT-OSCAR 7 carrier trace, AOS through TCA.

4 QRPpp EME2

Von Braun begins his Appendix F, "Interplanetary Radio Communications"[6] with an attempt to establish credibility for the very notion of interplanetary radio communications through the existence proof of radio reflections from the moon:

In 1946 American scientists for the first time succeeded in transmitting radio signals to the moon. These were echoed from the moon and received and recorded on earth. The moon intercepted only a very small quantity of the directed intensity of the transmitter, and only a fraction of the energy actually intercepted was reflected. The power of the "moon transmitter" corresponding to the actually reflected power would have been low indeed. It is therefore obvious that a powerful transmitter in space would have no trouble being received on earth, even at a distance many times that between earth and moon.[6] (page 81)

He then goes on to derive mathematically how this works, cleverly using the same equations he will later employ to demonstrate that earth to Mars communications is eminently practical.

The "Silver Anniversary 25th Annual ARRL International EME Competition"[7] results given in QST for April 2003 gives a brief history of the first amateur radio EME QSO, between W1FZJ and W6HB on July 17, 1960. As has been well known since then, "moonbounce" (or Earth-Moon-Earth, EME) is within reach of a sufficiently ambitious radio amateur.

Space being truly vast and signals propagating through it becoming quite weak, one frontier of space for radio amateurs is the frontier of ultra-weak signal work. EME is near the bottom of the challenge ladder.

Like many amateurs, I daydream about one day owning a station capable of working "OSCAR-0" but the power and antenna needed to hear one's own echoes in an audio bandwidth are fairly large, at least by amateur satellite (what we used to call "AO-13 Class") standards. In the late 1980s, Tom Clark, W3IWI and Bob McGwier, N4HY used early signal processing hardware (25 MHz TI 32010 parts on Delanco Spry boards that plugged into a PC) to demonstrate QRP EME. This showed that digital processing of audio from normal satellite-class radios could bring a form of EME into reach for such stations.

After getting my DSP-10 settled into routine operation and proving to myself that it was a "pretty good radio", I was reading the user manual[8] one day and came across an operating mode called "EME2". This mode is described in detail in the user manual[8] and in **Experimental Methods in RF Design**[9], Chapter 12.5.

The aim of EME2 is to aid the operator in detecting self-echoes from the moon that are far below audible levels. Schematically, it works like this: The round-trip light time to the moon is 2.575 seconds. DSP-10 keys up and sends a carrier for two seconds, then waits 0.575 seconds, then integrates the receiver pass band for two seconds. At five seconds elapsed, it begins the cycle again and continues this, collecting frequency bin sums indefinitely until terminated by the operator. DSP-10 calculates the expected two way Doppler shift from the moon for the selected transmit frequency and adjusts the receive frequency accordingly. It also hops successive transmissions around in a pseudo-random frequency pattern in order to reduce the effect of any low level birdies. Finally, it uses one five-second slot every few minutes to send a station-ID in high speed Morse.

Noting that the moon was up and near the horizon (DSP-10 also calculates and displays moon azimuth and elevation), I turned the beam and activated the mode. I was hoping to see something like Figure 3 above indicating a detection of my reflected signals. Running 7.5 watts to a single yagi, I knew that this might take some time. I was disappointed to discover, and have confirmed by other DSP-10 users, that it would take more than the hour or two attempted in that first session, maybe a lot more. W7PUA claimed a statistically significant echo detection using DSP-10 and Brickette but using a stacked array of four antennas similar to my one and aimed in azimuth and elevation for seven or eight hours of data collection. This was at least 10 dB beyond what I had informally attempted.

It was suggested that I run more power initially to verify that the station was working right or that I add an elevation rotator so I could track longer. Such improvements are planned, but I didn't want to rush into them just for this whim.

The EME2 implementation does not presently allow sessions to be saved and restarted, a feature that would allow longer integrations without the elevation rotator. DSP-10 does support saving of tracking files in several modes, including EME2, for later analysis, however. No program then existed to do such analysis, but it occurred to me that I could write a post-processing program to parse in several of these files and perform the same sorts of data screening and averaging algorithms on them that DSP-10 does in real time. The end result, DSP-10_EME2_Post, is a prototype C++ program of about 7000 lines. This was my first project using Xcode on a Mac PowerBook G4.

I made a list of moonrises and moonsets that were at reasonable hours when I could be at home and started capturing files of each EME2 session. While the rig was sitting there pinging at the moon, I worked on the post-processing software. (I also consulted Meeus[10] Chapter 45 and other sources for more hints as to why I wasn't seeing anything in one or two hours.)

All of the individual sessions ended up looking something like the screen capture in Figure 5.

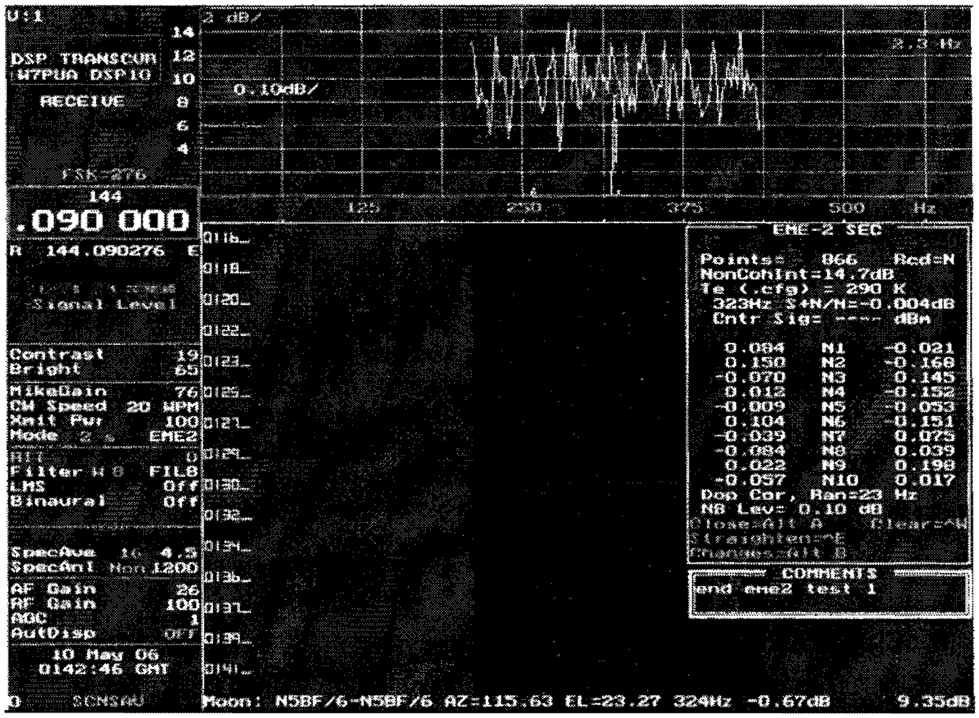

Figure 5 Screen capture from one EME2 session. No detectable result

The yellow trace represents the average over the 866 points taken (72 minutes). The red marks around and centered on 323 Hz show the 21 frequency bins that are recorded into the capture file. Any peak from a lunar reflection would be in the center bin marked by the taller red line. Not only is no such peak beginning to appear here, the central bin actually has a little less than average signal so its relative power is less than 0 dB at this point in summing!

After about twelve EME2 tracking session, a few hours work on my program, and a few moments of despair, I thought I might be seeing a peak emerge. After some more refinement and adding more data, the result improved to the point where I thought I could claim a QRPpp detection. Figure 8 is the plotted result. Notice that the scale is somewhat finer than the scale in Figure 5. The noise bins have averaged down far enough for the tiny return signal to begin to emerge clearly.

The control input to the post-processing program is:

Figure 6 Text file input to EME2 post processing program

```
# Version 1.1, 2006 June 13, n5bf/6.  This is the master file for all
of the EME2 data captured to date. #
PD Summary
PT 600
PX Off
PN 13.05
# These constraint times are from horizon mask to 20 degrees. #
PI 2006 5 21 1918 00 2006 5 21 2038 00
PI 2006 5 26 0000 00 2006 5 26 0128 00
PI 2006 5 26 1320 00 2006 5 26 1351 00
PI 2006 5 27 0100 00 2006 5 27 0236 00
PI 2006 5 27 1406 00 2006 5 27 1442 00
PI 2006 5 28 0203 00 2006 5 28 0348 00
```

```
PI 2006 5 28 1500 00 2006 5 28 1536 00
PI 2006 5 29 0303 00 2006 5 29 0448 00
PI 2006 5 30 1700 00 2006 5 30 1733 00
PI 2006 6  1 0606 00 2006 6  1 0657 00
PI 2006 6  2 0557 00 2006 6  2 0623 00
PI 2006 6  2 0630 00 2006 6  2 0730 00
PI 2006 6  3 0627 00 2006 6  3 0745 00
PI 2006 6  3 2039 00 2006 6  3 2121 00
PI 2006 6  4 0651 00 2006 6  4 0757 00
PI 2006 6 10 0203 00 2006 6 10 0348 00
PI 2006 6 11 0324 00 2006 6 11 0509 00
PI 2006 6 12 0400 00 2006 6 12 0621 00
PI 2006 6 13 0500 00 2006 6 13 0713 00
PI 2006 6 13 1145 00 2006 6 13 1345 00
# The data files. #
PF 5_21_set.dat
PF 5_26_set.dat
PF 5_26_ris.dat
PF 5_27_set.dat
PF 5_27_ris.dat
PF 5_28_set.dat
PF 5_28_ris.dat
PF 5_29_set.dat
PF 5_30_ris.dat
PF 6_01_set.dat
PF 6_02_set.dat
PF 6_03_set.dat
PF 6_03_ris.dat
PF 6_04_set.dat
PF 6_10_ris.dat
# PF 6_11_ris.dat
PF 6_12_ris.dat
PF 6_13_ris.dat #
PF 6_13_set.dat
```

End with a comment to prevent end-of-file parse errors.

All comments begin and end with "#". Some data files are commented out.

'PD Summary' sets the amount of output to be produced.

'PT 600' sets the system temperature to 600K for signal level calculations. This only affects the final signal level estimate and is not involved in the statistics.

'PN' sets the maximum noise level permitted from an input point. Points at a higher noise levels are discarded.

'PI' sets an inclusive time interval. For a point to be included it must be within one such interval.

'PF' names a data file to be processed (possibly recursively in that the file named can contain other file names for inclusion).

As implied by the PN and PI directives, two forms of data editing are performed automatically during processing.

Time intervals are set to restrict the data processed to be when the moon is in view and within the beam width of the antenna. The particular set of "PI" instructions shown here prevents data from below my measured horizon mask or from above 20 degrees elevation from being used. Such data, if used, would add noise to the result but not signal and so would reduce the final SNR.

Each data point captured by DSP-10 contains a power average sum from all 478 bins processed for screen display. This can be used as a measure of background noise from manmade or other sources. (This can also be used as an indicator of whether an antenna is connected or not.) When data are taken with significant background noise, any signal is easily overwhelmed by this noise. This is the same as not being able to hear the satellite when your neighbor turns on his blender. DSP-10 has a feature that excludes data that is significantly noisier (typically 1 dB) than the recent result of a running average. The post-processing program, by contrast, discards all points above the threshold set by the "PN" instruction, regardless of the levels in nearby points. Since we are taking the average noise (measured noise (power ratio) of 11.4172 shown in the output below) as 600K, the "PN 13.05" instruction is equivalent to saying, "Ignore all points above 686K, and this is equivalent to saying, "Wait until my neighbor turns his blender off and try again!"

Without the PI and PN directives, no peak is detected. Some of the files were taken at noisy times. This PN directive causes their data to be discarded entirely.

In the future I plan to measure my actual DSP-10 noise figure to better calibrate these measurements and understand how a good preamplifier or avoiding certain noise sources might help processes such as these. An absolute noise measure is unimportant to the statistical result here so long as there are enough quiet measurements in the entire set.

The raw, tabulated output from the program is:

Figure 7 Text file output from EME2 post processing program

```
[Session started at 2006-07-15 18:24:11 -0700.]

Set System Temperature to 600K

Set time interval from 2006 05 21 1918 00 2006 05 21 2038 00
Set time interval from 2006 05 26 0000 00 2006 05 26 0128 00
Set time interval from 2006 05 26 1320 00 2006 05 26 1351 00
Set time interval from 2006 05 27 0100 00 2006 05 27 0236 00
Set time interval from 2006 05 27 1406 00 2006 05 27 1442 00
Set time interval from 2006 05 28 0203 00 2006 05 28 0348 00
Set time interval from 2006 05 28 1500 00 2006 05 28 1536 00
Set time interval from 2006 05 29 0303 00 2006 05 29 0448 00
Set time interval from 2006 05 30 1700 00 2006 05 30 1733 00
Set time interval from 2006 06 01 0606 00 2006 06 01 0657 00
Set time interval from 2006 06 02 0557 00 2006 06 02 0623 00
Set time interval from 2006 06 02 0630 00 2006 06 02 0730 00
Set time interval from 2006 06 03 0627 00 2006 06 03 0745 00
Set time interval from 2006 06 03 2039 00 2006 06 03 2121 00
Set time interval from 2006 06 04 0651 00 2006 06 04 0757 00
Set time interval from 2006 06 10 0203 00 2006 06 10 0348 00
Set time interval from 2006 06 11 0324 00 2006 06 11 0509 00
Set time interval from 2006 06 12 0400 00 2006 06 12 0621 00
Set time interval from 2006 06 13 0500 00 2006 06 13 0713 00
Set time interval from 2006 06 13 1145 00 2006 06 13 1345 00
Parsing file 5_21_set.dat
Parsing file 5_26_set.dat
Parsing file 5_26_ris.dat
Parsing file 5_27_set.dat
Parsing file 5_27_ris.dat
Parsing file 5_28_set.dat
Parsing file 5_28_ris.dat
Parsing file 5_29_set.dat
Parsing file 5_30_ris.dat
Parsing file 6_01_set.dat
Parsing file 6_02_set.dat
Parsing file 6_03_set.dat
Parsing file 6_03_ris.dat
Parsing file 6_04_set.dat
Parsing file 6_10_ris.dat
Parsing file 6_13_set.dat
Total points seen:         14664
Points processed:          5476 37%
Points skipped:            5604 38%
Points skipped for noise:  3584 24%
Biggest noise value:       13.049

values fixed:      0 0
values not fixed:  0 0
```

```
Noise Bins:  11.4172 0.0409501 10.5756

noise 10.5369, 1.36597

bin    mean     sigma    -noiseMean   noise sigmas    dB
-10, 11.4275, 5.45858,  0.0103158,    0.251911,   0.00392222
 -9, 11.3520, 5.42430, -0.0652031,   -1.59226,   -0.0248735
 -8, 11.4601, 5.45164,  0.0429619,    1.04913,    0.0163115
 -7, 11.4011, 5.51495, -0.0160590,   -0.39216,   -0.00611293
 -6, 11.3565, 5.45260, -0.0606998,   -1.48229,   -0.023151
 -5, 11.4670, 5.44087,  0.0498330,    1.21692,    0.0189146
 -4, 11.4368, 5.44843,  0.0195957,    0.478526,   0.00744755
 -3, 11.4127, 5.47705, -0.00448739,  -0.109582,  -0.00170728
 -2, 11.3962, 5.36449, -0.0209911,   -0.512601,  -0.00799208
 -1, 11.5256, 5.53730,  0.1084100,    2.64736,    0.0410431
  0, 11.5888, 5.61291,  0.1716360,    4.19134,    0.0648022
  1, 11.4736, 5.49392,  0.0564111,    1.37756,    0.0214052
  2, 11.3676, 5.49562, -0.0495403,   -1.20977,   -0.0188855
  3, 11.4038, 5.52712, -0.0133888,   -0.326953,  -0.0050959
  4, 11.4400, 5.55434,  0.0228347,    0.557622,   0.00867734
  5, 11.3677, 5.39753, -0.0495004,   -1.2088,    -0.0188702
  6, 11.4105, 5.54007, -0.00668708,  -0.163298,  -0.00254442
  7, 11.3927, 5.40443, -0.0245146,   -0.598644,  -0.00933504
  8, 11.4739, 5.49146,  0.0567019,    1.38466,    0.0215153
  9, 11.4973, 5.52794,  0.0801300,    1.95677,    0.0303739
 10, 11.4459, 5.46449,  0.0286985,    0.700816,   0.0109028

max 0 4.19134
nxt -1 2.64736
min -9 -1.59226

noise temperature 600K is -167.225 dBm in 2.3 Hz

signal plus noise level of -167.16 dBm over 10952 seconds implies return
signal power of -187.358 dBm which is 5.81949K

DSP-10_EME2_Post has exited with status 0.
```

The first several lines show the PT, PI, and PF instructions being carried out. This is followed by summary data.

The total number of points seen, 14664, represents over 20 hours of EME2 tracking or 8 hours of carrier transmit time at 40% duty cycle. Of these, 5476 points were used in the sums. This is over 7.6 hours of EME2 or about 3 hours of key-down time. The final result, then, is the result of integration over nearly 11000 seconds of carrier representing about 80 kJoules of energy transmitted.

"Points skipped" means that they were discarded because they were outside of all specified time intervals. "Points skipped for noise" means that they exceeded the specified noise limit. Overall, 62% of points were judged to be in range geometrically and 60% of those were suitable for use in the averages.

The table summarizing frequency bins is interpreted as follows: In the mode I was using, each bin is 2.3 Hz wide so the 21 bins, numbered -10 through +10 represent 48.3 Hz of spectrum. The return from the moon is supposed to be entirely contained within the center bin, numbered 0. This is because, at two-meters, the various calculation errors and physical effects such as librations should be limited to about one Hz. The "square wave modulation" (on for two seconds, off for three) will have a first null at around plus and minus a fraction of a Hz so most return energy should be well contained within the central 2.3 Hz bin.

The row labeled "Noise Bins" are the statistics of the row sums given in the following table in bins -10 through -2 and 2 through 10. These are not supposed to contain signal whereas bins -1, 0, and 1 should, particularly bin 0. These values are calculated directly from the power ratios found in the DSP-10 output files. The value 11.4172 corresponds to some voltage on the analog to digital converter in the radio. The value 0.0409501 is the standard deviation on the 18 bins used in the noise calculation. The value 10.5756 is the mean expressed in dB.

The columns in the table have the following meaning:

Column one is the bin number, multiple of 2.3 Hz from the expected reception frequency.

Column two is the mean value measured in that bin.

Column three is the standard deviation of all 5476 values in that bin.

Column four is the difference between column two and the noise mean explained above.

Column five is column four expressed in noise standard deviations as explained above.

Column six is column four expressed in dB. These are the values plotted in Figure 8.

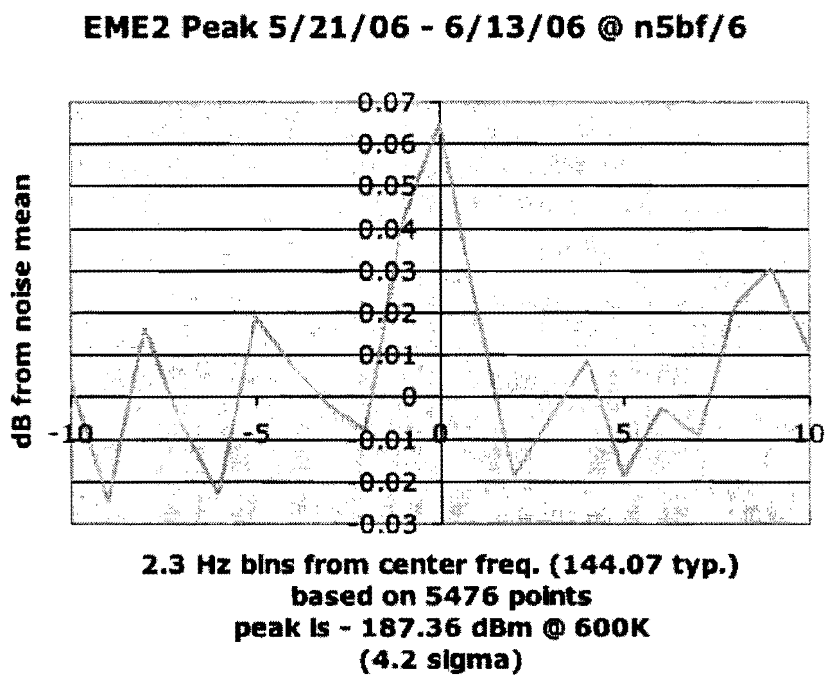

Figure 8 "Yellow Trace" equivalent from 16 moon rise/set data files

At the end are some ancillary calculations to estimate actual signal level based on assumed noise temperature.

News of this claimed detection was met with kudos from most of my colleagues in the DSP-10 and other amateur radio communities and a few in-depth peer reviews. From these comments, several items were added to the list for follow-on experiments.

This is, as expected, detection of a tiny signal. It might be more convincing if the signal had a different design, such as a pair of tones at different frequencies and possibly different power levels. Peaks at bins -5 and +5 would make a more convincing presentation. Circular polarization, with T/R coordinated switching (because the return signal is a reflection), could increase the response by 3 dB (depending on the reflective properties of the moon) and in addition remove the 3 dB Faraday rotation loss.

In "normal" (audible) EME operations, it is possible for smaller (i.e. "Oscar-class") stations to work larger ones, but the entry point for serious participants is to be able to hear their own echoes. Stations that hear their own echoes can, in theory, hear other stations who can hear *their* own echoes.

In this test, although I have detected my own echoes, it will require more equipment, namely a higher level of time and frequency synchronization with a partner station, for me to attempt to work another similarly equipped amateur. Support for such synchronization is one of the major features of the latest DSP-10 software release, Version 3.80.[1]

EVE240

Back in the TRS-80 era, when Tom Clark, W3IWI was president of AMSAT, he editorialized that with the advent of personal computing power it might soon be possible for amateurs to detect reflections from other astronomical objects beyond the moon, the best next candidate being Venus. Now we consider the engineering problem of performing "Venus bounce" from an amateur station.

Figure 9 85-foot (26-meter) aperture at JPL – Goldstone used for first Venus Radar experiments

Radar contact with Venus was first reported during the inferior conjunction of 1961. A brief announcement by Duane O. Muhleman, California Institute of Technology, Jet Propulsion Laboratory[11], made the following report:

- Range was determined accurately resulting in a significant revision of the Astronomical Unit (the average distance of earth from the sun).
- Daily tests were conducted from March 10 to May 10, 1961 at 1.25 cm wavelength.
- Bi-static (separate transmitting and low-noise receiving sites).
- Doppler measurement determined Venus rotation to be synchronous or near synchronous.
- Radio reflectivity (L-Band) was 10% that of a perfectly reflecting sphere, compared to 2% for the moon.

This information will be useful in designing an amateur Venus bounce detection experiment.

I digress briefly to mention that what I am discussing here is not a result from amateurs working on their own time at government installations such as Algonquin, Goldstone, or Jordrell Bank. While these count as amateur operations, they are not in the class of "individual" or "club" station and so are in a different category. Muhleman does not say how much power they ran in these tests, but it was certainly more than the kilowatt level available to amateurs, as was the cryogenically cooled receiving equipment. Under the banner of "Solar System Radar[13]," radar returns have been detected from Venus, Mercury, the Sun, Mars, and the rings of Saturn. (State of the art in this decade is transmitter power levels approaching half a Megawatt and total receive system temperatures below 30K.)

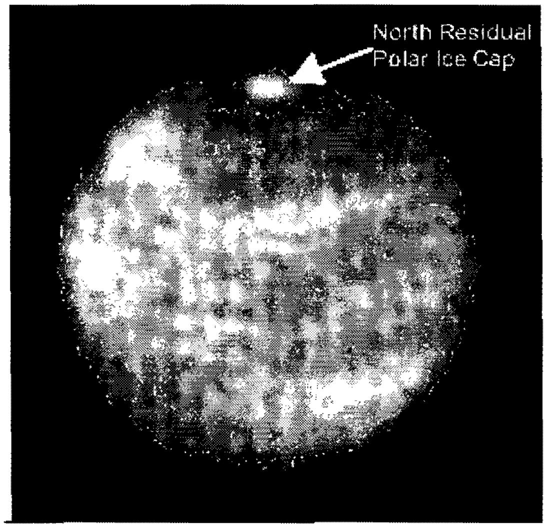

Figure 10 Radar Image of Mars made by transmitting 0.35 MW CW at 3.5 cm wavelength from Goldstone 70 m. dish and receiving at the VLA in New Mexico.[13]

In addition, I am not talking about new science (see Figure 10). Rather, we use "old science," that is, results such as those given above, to aid in comparatively modest detections. Still, we learn useful engineering skill from these endeavors.

I believe that signal processing techniques such as EME2 which are in turn enabled by software defined radios, bring Venus bounce within the range of a well equipped EME station today.

How much harder is a reflection from Venus?

At inferior conjunction (closest approach) Venus is 120 times further away than the moon. At that time, however, it is in the sun, making measurements noisy. We will need several weeks of integrations and Venus will not always be that close. For this back-of-the-envelope analysis, let's say that Venus is 180 times as far away as the moon (effective mean) and note that the radar effect goes with R^{-4}.

Venus is about the same size as earth, approximately four times the radius of the moon and is, per Muhleman, five times as good a radio reflector. (It is acknowledged that Muhleman's result was at L-Band and that the relative reflectivity at VHF may be somewhat different. For now, we still use the factor of five as an estimate.) Combining these terms we have:

Table 1 Earth – Venus – Earth relative to Earth – moon – Earth

Effect	value	dB	Note
Distance	180	-90	R^{-4}
Radius	4	+12	R^2
Reflectivity	5[11]	+ 7	
Total		-71	

For comparison, here are some guesses at other likely objects. All quantities are "EME Relative."

Table 2 EME – Relative Signals Reflected from Nearby Planets.

Planet	"Effective" Distance	(Best)	Radius	Reflectivity	dB EME	Note
Venus	180	120	4	511	-71	In the sun
Mercury	320	240	1.5	2^{19}	-94	Even nearer the sun
Mars	380	210	2.1	4^{19}	-91	Opposition is at night (quiet)

Venus is the next "reasonable" target by at least two orders of magnitude.

My QRPpp EME station runs 7.2 watts to a beam that claims 12.8 dBd gain, approximately 250 watts EIRP. After 10,000 seconds equivalent of carrier integration, I claim a lunar-reflection detection in a presumed 600K receiver. What would it take to improve this by 71 dB?

Table 3 From QRPpp EME2 to EVE, Station / Operational Improvements.

Improvement	Value	Over	dB gain	note
Full Gallon	1500 W	7.2 W	23	
Mighty Big Array[12]	32 boomers	single yagi	17	30 – 12.8 dBd
Mighty Big Array[12]	on receive	single yagi	17	
10^6 second integration	10^6	10^4	10	Non-coherent
Good preamp	60K	600K	10	Difficult on array?
Total			77	

(Note that at two meters, W5UN's Mighty Big Array has about the same aperture as the 26-meter dish at Goldstone, pictured in Figure 9., about 500 m^2.)

Although this seems to be more than enough to reach Venus it must be understood that the uncertainties in these estimates are large enough that in reality there may be no extra margin at all. Also, we might find it more practical to use an antenna somewhat smaller than the Mighty Big Array or an integration time less than a million seconds.

During a measurement season, Venus would only be visible 10 – 12 hours a day and unless the experiment were bi-static, that is, separate transmitter and receiver sites, duty cycle could only approach 50%. Under these conditions, a million seconds of carrier integration would take 6-7 weeks. This could be longer if there were significant periods of high noise as in my EME experiment. Six to seven weeks is a reasonable (high end) for an amateur radio experiment of this type and fits into a Venus inferior conjunction season, similar to the 1961 JPL experiment mentioned above.

Of course, the EME2 software could not be used as is. Unlike the moon, the two-way light time to Venus would change by several minutes over the course of the experiment. Meeus[10] has tables for Venus too, so modeling the range and Doppler of Venus is relatively straightforward (except for the verification testing.)

The rotation rate of Venus adds only about two meters per second (two Hz at two meters, two-way) of spreading to the return signal. In this respect, Venus, like the moon, is a very fortunately cooperative target. Mars on the other hand has a day similar to earth's meaning that Doppler spreading, even at two meters, would be hundreds of Hz. For a case like this, additional signal processing, such as a matched filter, would be required to aid in detection. Such processing is the venue in which the SDR excels.

Use of a higher frequency such as X-Band for this attempt would also lead to the need for better signal modeling since all the Doppler effects would be 72 times greater than at two meters.

Some will be concerned with the regulatory aspects of such an experiment. The most restrictive interpretation of our regulations is that the only legitimate use of amateur radio is to conduct two-way contacts of little value with other amateurs on permitted modes and frequencies. Toward the more liberal readings is that this sort of experiment is well within the meaning of "advancing skills in both the communication and technical phases of the art."[20] While the EME2 experiment is properly identified periodically in high speed CW and is fully attended by a control operator, it is not an attempt to engage in two-way communications with another amateur station nor is it a beacon under the rules for beacons. I will not go into this further here except to note that a Special Temporary Authorization (STA) could be secured for such a test if needed and that I would expect more trouble from the neighbors of a large dish transmitting a kilowatt carrier day after day than I would from the FCC.

The claim here is not that earth-Venus-Earth (EVE) is something that a well-motivated amateur can easily accomplish. The claim here is that signal processing techniques now readily available at the amateur level through software defined radios bring EVE detection within range of high-end EME stations now in existence. The level of effort and expense required to design and conduct such an experiment is doubtless smaller than that required to build and deploy an amateur satellite or conduct a high-end DXpedition. The claim, then, is that such an attempt is now within reach of amateur radio and we only await the person or group with the skill, motivation, and resources to tackle it.

To paraphrase from von Braun, actually working another similarly equipped station at destinations such as Venus or Mars would be comparatively simple. While we wait for repeaters or crews, however, "radar" will have to do.

5 AMSAT Tracking Network

Weak signals from space are not the only area in which SDRs can contribute to the state-of-the-art at the amateur level. One of the fundamental needs in the amateur satellite community is practical knowledge of where the satellites are.

When I was first licensed (1972), the state-of-the-art in amateur satellite location was the Oscarlocator[17]. In a simple, analog, graphical device made only of polar graph paper, transparency materials, and a marker, pass times and antenna-aiming coordinates sufficient for amateur use were available. "Reference orbits" were transmitted by CW bulletin from W1AW daily and these could be extrapolated, with hand calculations, into the future to initialize this calculator.

Today we take Keplerian elements direct from the government, distribute them via the internet, feed them semi-automatically into personal computers, and watch 3-D maps of several satellites orbiting the world while our antennas are automatically pointed at the selected one.

In both of these cases, data about the satellite trajectory has come from somewhere outside of our amateur stations, in fact, nearly always from outside of the amateur service itself. A few years ago (early 2003) as various provisions of the Patriot Act and related legislation were taking effect, there was a scare that we would lose our access to government-generated satellite ephemeris data. Fortunately, this has not occurred, at least not yet.

On this scare, I started thinking of ways that we could, within the amateur community, determine and disseminate information about our own satellites. Several methods of estimating ephemerides are possible within amateur resources.

- Listening on the air and making educated guesses.
- Phase tracking beacons.
- Phase tracking transponded signals.
- Ranging transponded signals.
- Optical tracking.
- Monostatic or bi-static (passive) radar.

The first two require a satellite that is transmitting a signal based on an oscillator that can be modeled sufficiently well (parts per million).

The next two require a working transponder with deterministic delays that can be modeled sufficiently well.

The last two would work on objects that are not transmitting, down to a certain size-reflectivity product, which would be determined from experience. Amateur-sized payloads could be within that range.

Radio Tracking

The power of a software approach to tracking and demodulation of signals is that arbitrary levels of control can be achieved without resorting to intractable and inflexible hardware schemes. For example, when first tracking AO-16 some fifteen years ago, many of us used a bi-phase-shift-keying (BPSK) demodulator built from a kit at the audio output of our receivers. This demodulator locked on a 1600 Hz tone and demodulated 1200 bit per second (bps) data while providing frequency stepper outputs that were intended to keep the radio output at 1600 Hz by pulsing the radio microphone "frequency down" function.

There were many problems with this approach. It had to be started manually. Stepping the radio could cause the modem to lose synchronization on the signal. When signals were strong, the modem could lock incorrectly on a modulation side lobe rather than the central carrier. None of the hardware in the process was aware of the product, a stream of AX.25 packets and so tracking sensitivity to demodulation needs was not possible. And, for orbit determination purposes, there was no reasonable way to extract sufficiently accurate RF frequency information.

If all of these functions from tuning to demodulation to decoding are hosted in an SDR such as the DSP-10 or SDR-1000, a much more seamless approach is possible. The software demodulator, for example, can be aware of data side lobes and choose the correct signal peak to track. The DSP-10 switches intermediate frequency (IF) in 5 kHz steps. Any resolution below that is determined in DSP. Several such steps would be required in tracking a full 437 MHz pass. If such a frequency step resulted in tracking or decoding problems, the software could be aware of these problems and "schedule" such switches to occur between bits or even between packets so that data was not lost. Phase could be estimated across the break so as to produce a seamless record or at least an indication of the quality of the record. With sufficiently well disciplined SDR time and frequency, the process could be entirely automated (the SDR can even do the orbit predictions) such that a data collection process might need operator attention only every few days rather than every few seconds during each pass.

The end product enabled by an SDR in this case is a radio that can track satellite carrier frequency for orbit determination purposes automatically, without the need for operator intervention between or during passes, that would also demodulate the data stream on the side.

None of this was possible in the early AO-16 era on amateur resources. If it is not possible today it is only because the SDR software for this particular application has yet to be developed.

Additional complexity like this comes at a price. The software is harder to develop, understand, and maintain than the much simpler hardware from the past. This is a matter receiving considerable attention in the professional software development field today. Such tricks as I have just described, on the other hand, are either impossible or prohibitively expensive in hardware, hardware that would then be single-use. In an SDR, by contrast, a user can be working the weak ones in the VHF QSO Party one minute, and taking data from AO-7 to refine knowledge of its orbit in the next.

Tracking a carrier originated from a satellite ("one-way") or originated on the ground and transponded by a satellite ("two-way") are the same process in the ground receiver. A similar but different technique is ranging via transponder in which features of the signal originated on the ground, such as some modulation pattern, are correlated at reception to measure the two-way "light time" and, from that, the range or distance. Sequences or histories of phases or ranges are used to improve orbit knowledge as described below. Ranging (pseudo-random code) was performed on AO-13 in the early days as an experiment, but the technique was never made operational on an ongoing or widespread basis.

Optical Tracking

Satellites can be tracked optically near the morning and evening terminators where the ground observer is in darkness while the satellite is still in sunlight. Amateur satellites such as AO-7 and AO-8 would be visible in a modest telescope if and when the orbital geometry was right. Images from charge coupled devices (CCD) at the focus of such telescopes could be analyzed using techniques similar to those we are using here to extract weak signals from radio noise. Of course, optical tracking is not amateur radio, but advanced amateur astronomy hobbyists are already doing much of this problem, producing intriguing images of the International Space Station and the planets, for example. Radio amateurs might well find collaboration with other such hobbyists useful to their own purposes.

RADAR Tracking

Full gallon amateur transmitters do not produce much return signal from small objects in orbit, but if the T/R sequencing can be made fast enough (on the order of a millisecond or less) an SDR should be able to detect and make coarse measurements of turn-around range from sufficiently large objects, such as the International Space Station. This is called "monostatic" because transmission and reception are from one site.

Possibly more useful is bi-static or passive radar where phase predictions are used to intercept signals from powerful broadcast or other stations reflected from objects in joint view, then arrival times of the direct versus reflected signals are compared (aided by the broadcast modulation, such as "Rock-N-Roll") to inform the geometry problem leading to a trajectory solution or refinement. Eric Blossom, K7GNU[18] has, on an amateur budget, had some success detecting airplanes with this technique, as has anyone who uses an analog television set for over-the-air reception near a major airport! The next steps would be to detect objects in orbit using such techniques, then make time delay measurements of sufficient precision.

Orbit Determination

For any such observations, the technique for improving ephemerides works like this:

- A prediction is used to detect or acquire the object. (This can range from plain luck within a large survey to successful acquisition from a narrow search based on well-refined ephemerides from prior tracking.)
- Numerical data is taken while the object is in view. This can be ranges, "pseudoranges" or Doppler signatures, reflection delays, or pixel interpolations on a CCD.
- A computer program is used to "model" what these observations should be based on the prediction and knowledge of the sensor being used (radio and antenna, telescope and CCD, pointing, and so forth).
- The modeled values are subtracted from the observed values to form a "residual," that is, difference between what we think the observation should be and what it actually is.
- Linear algebra is used improve the "estimate" of the ephemerides (and other relevant quantities such as oscillator frequency) based on these residuals. This process is an art/science known in the navigation community as "filtering" (e.g. "Kalman filter", etc.). (Software for navigation filtering of deep space missions is what I do professionally.)
- Several sets of observations may be taken from one or many locations to improve "the solution." The fact that an observer is moving with the surface of the earth in a well-understood way makes one location into multiple locations over time.
- The internet (or other means) can be used to collect observations from multiple locations semi-automatically.
- The solution is transformed into an appropriate format (i.e., Keplerian elements in "two line" arrangement).
- This feeds the existing amsat-keps distribution network.

Apart from Figure 4 and this outline, I have done no work toward an early demonstration of the first steps of this process with DSP-10. Perhaps my paper at next year's AMSAT Symposium will be a description of results from such work.

I have only touched on two SDR applications here: Ultra-weak signal work and satellite tracking. The ARRL Software Radio Working Group[16] has a long list of interesting ideas such as electronically steered antenna arrays which are also enabled by variants on SDR technology.

6 Other Platforms, Institutional Incentives

While this paper deals with my experiences and ideas for the DSP-10 platform, there are several other experimental platforms in place today, including the SDR-1000[14], the USRP and GNU Radio[15], and others in various stages of availability, deploy-ability, and adaptability. As these are developed they seem to gravitate heavily towards the application interests of their developers. The DSP-10, for instance, is largely directed towards VHF through microwave weak signal work while the SDR-1000 is a modern low band radio, useful on crowded HF bands.

There is nothing in principle that prevents any of these for being used on the new frontiers discussed here. The main roadblocks appear to be

- Availability. While it was "fun" for me to spend a few hundred hours building and debugging my own radio, others prefer to spend their limited hobby hours in other ways. SDR-1000 is more accessible. Others are less accessible.

- Development environment. The environment in which software is developed for a particular platform is often problematic. There is little portability or compatibility across different platforms. Sharing algorithms is not yet "easy."
- Motivation and focus of the developers. Occasionally, someone in the DSP-10 community will do some work on a new user interface and most successful builders conduct on-the-air tests with existing software, but so far there is very little community-wide signal and data processing software development. This is mostly a problem of finding the proper cross section between motivation, skill, and availability discussed above.

For weak signal or navigation work, there are some issues in station design that should be kept in mind:

- All frequencies should be kept to a single reference. The phase relationship between local oscillators (LO) in the radio and any converters should be coherent and understood. (This is not common in amateur practice except inside single radios.)
- Time and frequency discipline of that reference is required, as in GPS or other standards-derived references.

Commercial rigs have some potential for this sort of work as well, either through internal processing or external interfaces like the increasingly common computer soundcard interface. These rigs are often optimized for other uses, however, and those optimizations often work against applications for which they weren't intended. For instance, the highly selective filtering that makes a rig good for contesting adds amplitude and phase characteristics to the signal that must be accounted for in processing and such accounting always introduces additional processing error. Internal signals may or may not be coherent. An external reference input may or may not be supported. Commercially produced rigs are more difficult (and risky) to modify and internal software development in the larger experimenter community is practically impossible both for proprietary and logistical reasons. Most of the internal software is typically for speech processing, filtering, and noise reduction though some are beginning to handle digital modes "in the box."

A larger issue in my mind is the incentive structure within amateur radio. DXCC, for example, has been around for several decades and has been a very successful program in terms of encouraging considerable on-the-air operation, some of it quite challenging. These challenges are well choreographed in manageable steps (such as endorsements) and provide motivation for individuals and groups to upgrade station components, for manufacturers to produce equipment in support of these types of operation, and for organizations to stage on-the-air tests to improve participation even more. DXpeditions costing hundreds of thousands of dollars are staged. When a new amateur band, such as 17- or 60-meters becomes available, the first thoughts of many operators are towards DXCC and other similar operating achievements on that new band. Much of the capability of the current SDR-1000 software suite is directed towards this type of operation.

On the new frontier under consideration here, the next 20-30 dB into what is now our noise floor, are there institutional incentives that can encourage the operations, stations, equipment, and operating events that can motivate and focus the experimenters and manufacturers in new directions? Can we formulate a set of goals that will lead us in the right directions in the right sized steps? My QRPpp EME achievement was in some ways like Worked All States or a clean sweep in the ARRL Sweepstakes in difficulty. Would a graded set of awards (like DXCC endorsements), "Self Echoes," "Worked Someone Else," "Worked Someone Else at Some Distance," ... "EVE," ... motivate the equipment and operating opportunities that we want to see produced? A solid EVE attempt would cost less than a major DXpedition does now. With broader support and a graded system of achievements, the size of the experimenter community can increase and the cost can become even more reasonable. We need only to cleverly induce the motivation.

The old ARRL Official Observer (OO) program was certified through an operating event called the Frequency Measuring Test (FMT). Today, a set of amateur satellite tracking events could be used to certify those who would participate in the AMSAT Tracking Network. This would allow interested operators to compare and contrast different techniques on different platforms and make improvements to the system that we haven't yet even thought of.

It is endeavors like these that will spearhead the vibrant Amateur Radio Service and Radio Amateur Satellite Service of the future. One of the enabling technologies, the Software Defined Radio, is now here, waiting to be fully exploited. After removal of a few minor roadblocks, all that we lack is imagination and properly orchestrated motivation to venture on past these frontiers into new, exciting regions. Let's go!

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Application of Software Defined Radio Techniques in Satellite Transponders

Presented by

Howard Long, G6LVB

Abstract

The rapid development of Software Defined Radio (SDR) techniques over the past few years primarily for use in terrestrial applications such as cellular telephony and wireless LAN technology has practical applications in satellite transponders. This article describes the recent progress and application of these techniques.

About the Author

Howard Long started his career in electronic communications and computers early, building his first radio at age nine and then writing his first computer program aged eleven on paper tape using a teleprinter. At the age of thirteen he built his first computer, and produced his first computer design aged fifteen. A licensed radio amateur since 1982, the natural combination of communications and computers led to him attaining a BSc(Hons) degree in Electronic Computer Systems at Salford University in 1986.

After graduation, a varied career has included the design of production line automated test equipment, writing wide area voice and digital network optimization design software, and developing ports of traditional green screen mainframe banking applications to PC GUI front-ends and database development and administration. In 1991 Howard set up his own company to provide troubleshooting to the investment banking industry concentrating on analysis and resolution of financial trading systems' performance bottlenecks including front-end, network, middleware, database and server layers.

After a period of several years of inactivity in amateur radio, in 1999 Howard rekindled his interest and since then has concentrated almost solely on amateur satellite technologies.

Howard is involved heavily in the ARISS program in the UK, organizing a total of eight school contacts with astronauts since 2003.

In 2004/5, Howard specified ground station hardware and software for ESA's SSETI Express satellite launched in October 2005. He also spent many hours in the clean room at ESA's research and development facility at Noordvijk in the Netherlands testing the communications links.

Howard lives in London's South Kensington Museum district, and when not nailing down problems with London's financial trading systems or working on his latest amateur satellite project, he collects fine wine from around the world and writes restaurant reviews.

1 Introduction

In July 2005, at the AMSAT-UK Colloqium, the author demonstrated the prototype automatic frequency selective notching technology (Satellite Transponder and Equalizing Level Limiting Adapter, STELLA) on a PC with an I/Q modem that could either be a plug in replacement, or an optional transponder payload for existing 10.7MHz IF transponders. Since the original proposal, the demand for such a device has become widely accepted as the future of transponders, in particular for High Earth Orbit satellites.

Primarily, the design takes into account the problem of 'alligator' stations that artificially suppress transponder passband gain for other stations. It has since become clear that there are many other applications for such a device.

Coincidentally, AMSAT-NA were also considering such a device at the same time, and AMSAT-NA, AMSAT-DL and AMSAT-UK have since combined efforts in the design of the Software Defined Transponder (SDX). Currently, the following satellites are incorporating SDX payloads:

- AMSAT-DL Phase 3E
- AMSAT-NA Eagle
- AMSAT-UK mode U/S transponder on ESA SSETI ESEO

Primarily, this paper will be discussing the hardware of the ESEO design, although there are many fundamental similarities between this design and that of the AMSAT-NA and AMSAT-DL.

2 Hardware Design Considerations

When designing for space, there are many different concerns to designing the hardware for terrestrial use. Primarily for ESEO purposes, it is necessary to consider the following:

- Reliability
- Power consumption
- Radiation mitigation
- Device packaging
- Availability of development tools

An example of an SDX payload is shown in Figure 1, and this is the ESA ESEO design. AMSAT-NA Eagle and AMSAT-DL P3E have different hardware requirements such as HELAPS and are being designed separately[i], although the SDX core and code are similar. Both a traditional AGC transponder is included in addition to the DSP transponder. A traditional hardware command uplink demodulator and downlink telemetry demodulator are included. Communication with the remaining spacecraft payloads is via the CAN bus.

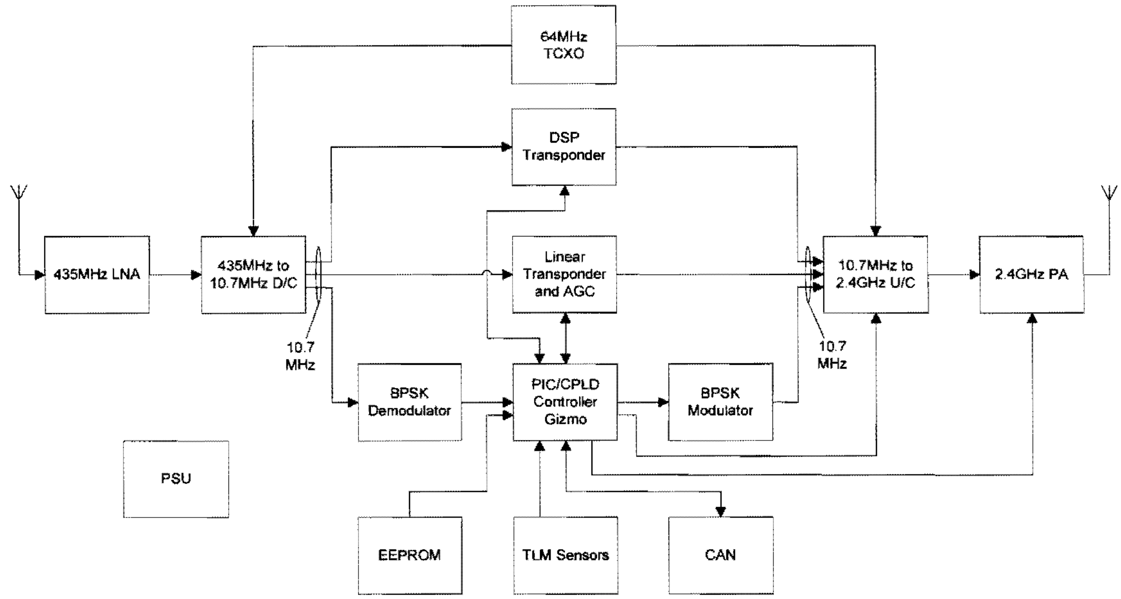

Figure 1 The AMSAT-UK ESEO payload

A more detailed view of the DSP and control aspect of the payload is shown in Figure 2. Communication to the parts internal to the AMSAT-UK's ESEO payload is by means of either an I2C or SPI bus, dependent on the individual device requirements. The payload's MCU in place at the present time is the PIC24H256GP610[ii,iii] device that includes an integrated CAN controller as well as dual I2C, dual SPI, dual USART, 32 channel ADC, 256K bytes program ROM and 16K bytes RAM. This performs basic non-DSP command and telemetry, interface to the rest of the spacecraft via the CAN bus, data capture and booting of the DSP. For most peripherals, either the DSP or the MCU may be bus masters on the SPI or I2C busses. Arbitration is maintained by the MCU, so that while the MCU asserts a DSP reset the MCU maintains control over the main I2C and SPI busses, otherwise it is the role of the DSP. A secondary I2C bus is maintained by the MCU where it is always the master, containing the serial EEPROM area holding alternate DSP boot images.

The topic of power consumption is all encompassing. In the domestic PC market the current generation Pentium class microprocessors are more than able to perform the computationally intensive work of DSP. However in space, their power consumption is not generally well matched to space use: the large heatsinks and fans used on these CPUs in desktop computers are of little or no use in the vacuum of space. Initially, the DSP device chosen was the TMS320VC33 for its floating point capability and low power consumption. This device is now quite old and the development tools available for it are also obsolete. A large amount of effort was spent investigating devices from Motorola (Freescale), Analog Devices and Texas Instruments. Based on power consumption and the floating point facility, development moved on to the TMS320C6713 (for which a reasonably priced development platform is available) and subsequently the TMS320C6726[iv],[v].

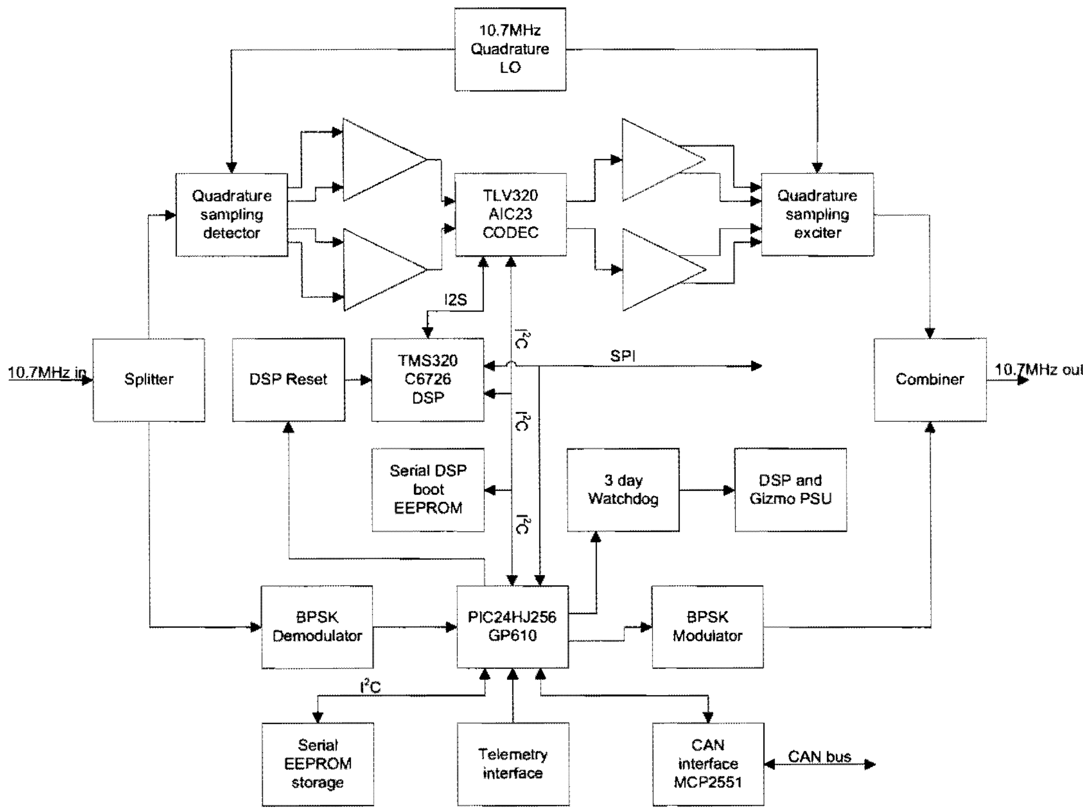

Figure 2 AMSAT-UK's ESEO payload: DSP and control system

The TMS320VC33's ancestors have history of space flight as part of some SSTL payloads, as does the TMS320C6416, the fixed point version of the TMS320C6713/6726. There are also radiation reports published on the TMS320C6701 and TMS320C6713. Of importance here is that the report on the TMS320C6713[vi] showed that it was necessary to cycle power on some occasions to recover from a SEFI (single event functional interrupt).

Almost all areas of the design are subject to power consumption limitations. For example the amplifiers used on initial design in the quadrature sampling exciters and detectors were very power hungry indeed. The CODEC has been re-specified, from a 192kHz differential device (Cirrus Logic CS4272) to a low power 96kHz single ended TI industrial temperature range device (TLV320AIC23B[vii]).

As an example of design considerations, the PSU watchdog circuit is shown in Figure 3.

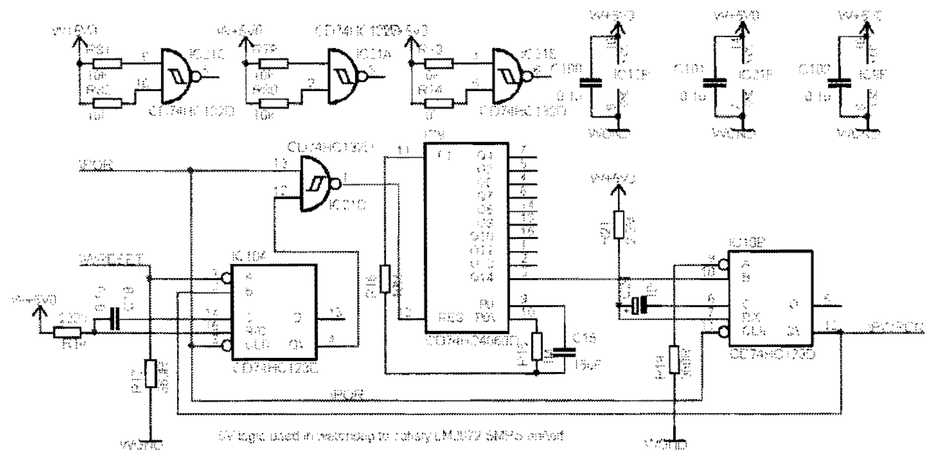

Figure 3 The PSU reset circuit

The design of the PSU reset incorporates Schmitt trigger, edge triggered inputs in an effort to remove false triggering, as well as the use of CD74HC parts that operate over an extended temperature range.

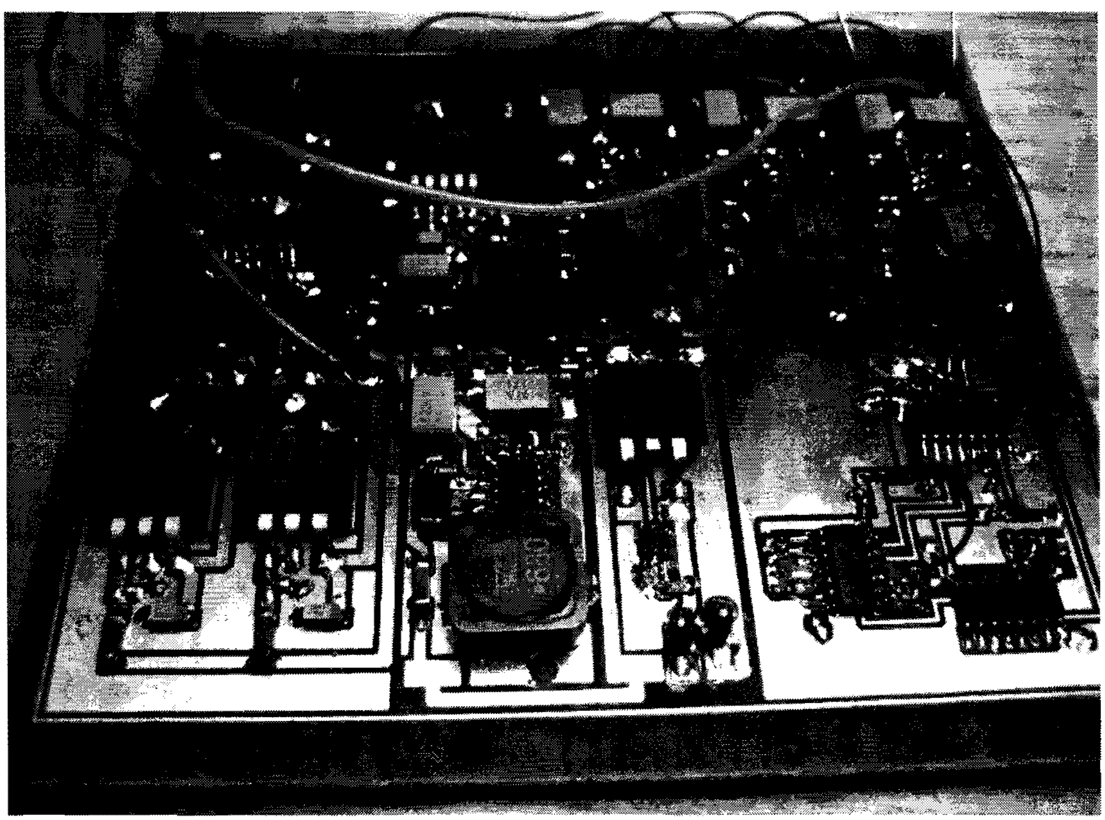

Figure 4 Prototype PSU for the ESEO SDX

As a mixed signal device, the DSP transponder is subject to potential interference between the analogue and digital sections. When designing the PCB, care is taken to separate the analogue circuit parts from the digital parts, and incorporate separated analogue and digital power planes in the design[viii]. As well as adequate decoupling in the form of both ceramic and low ESR capacitors, parts are chosen that are well in excess of required specification.

Particular care is taken to use the correct ESR tantalum capacitors: in some cases if the ESR is too low or too high, it is possible that certain PSU devices become unstable. The tantalum devices in use are from the AVX TAJ and TPS ranges, already proven in space applications by SSTL. The prototype PSU is shown in Figure 4.

In addition, clock circuit power pins are isolated using closely placed ferrite chips and surface mount EMI filters together with sufficient decoupling.

To keep overall power consumption and power dissipation to a minimum, switch mode power supplies are used extensively (see Figure 4), laid out to manufacturers' specifications. The analogue segments use linear regulators after step down switch mode PSUs in a further effort to reduce noise.

The switch mode power supplies include both a soft start option and are synchronized to a crystal controlled clock. The frequency is specifically chosen to keep the devices' switching frequency outside the transponder IF passband. Even if this crystal controlled clock fails, the switch mode power supplies will still run from their own internal clocks.

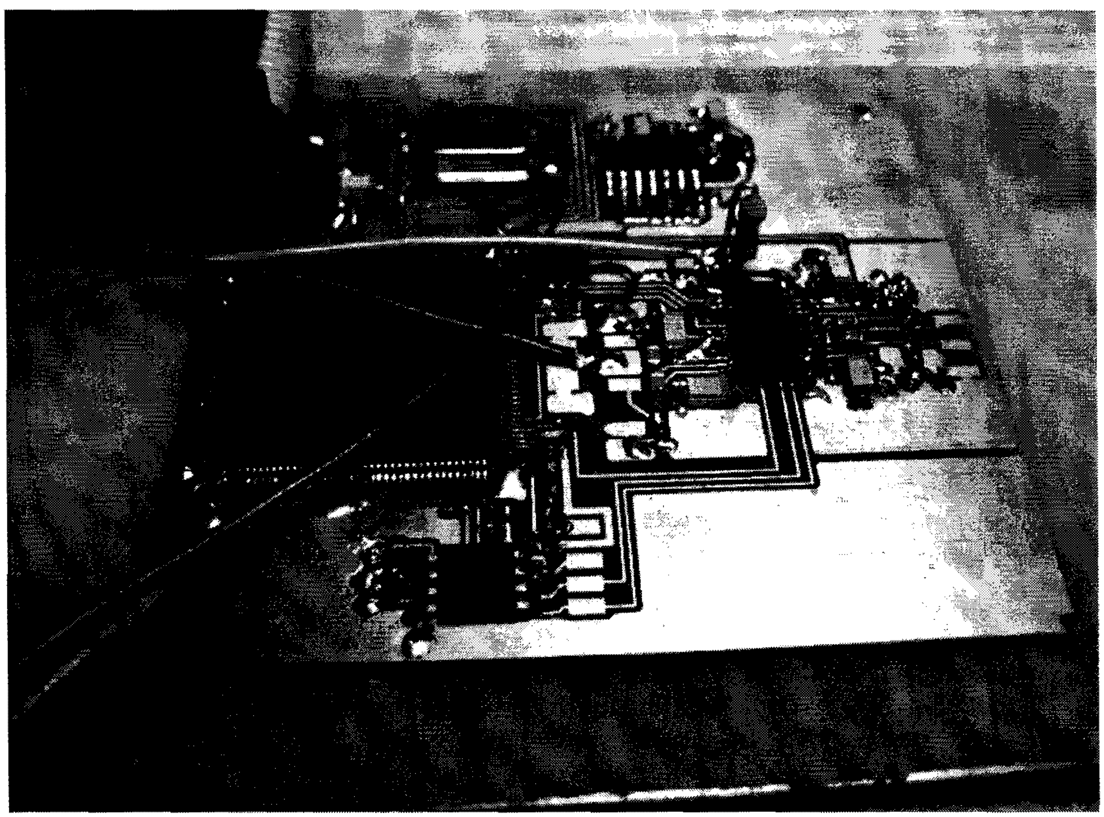

Figure 5 Prototype DSP section for the ESEO SDX

Maintaining power compatibility with the rest of the spacecraft is of utmost importance in the event of failure of a single payload. With this in mind, a MAX5903[ix] device is used in conjunction with a P channel MOSFET to control power consumption in the event that the transponder fails in a high current mode.

Physical construction around the DSP itself (Figure 5) is subject to many constraints, with particular attention paid to the design of the thermal aspects[x,xi,xii,xiii] as well as positioning of the multiple supply rails together with decoupling capacitors. In total there are 44 decoupling capacitors for the DSP chip alone mounted on the underside of the PCB, most of which are 0402 size, plus some case A style tantalum surface mount capacitors (see Figure 6).

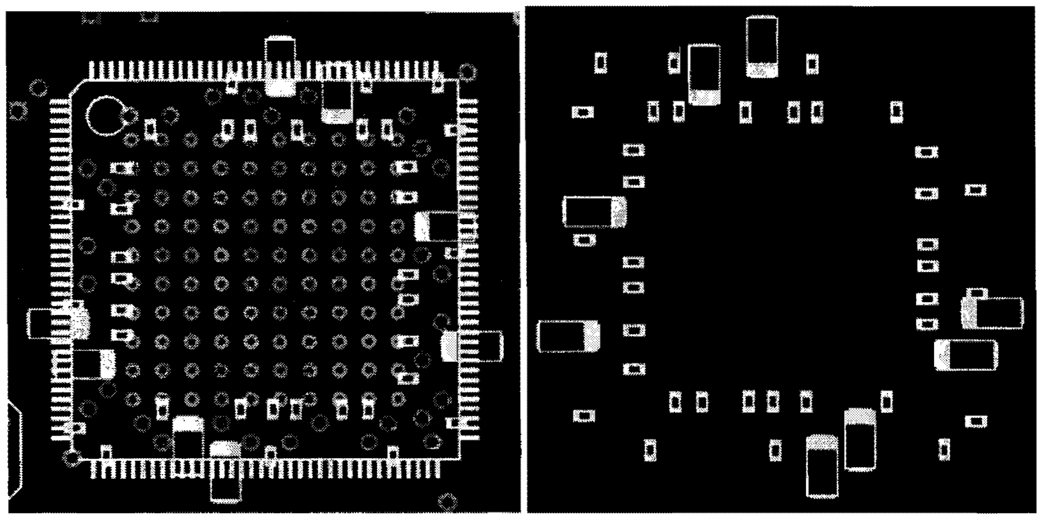

Figure 6 Layout of the PCB top and bottom, showing the thermal pads, ground power supply plane and underside mounted DSP decoupling capacitors

3 Software Design Considerations

The design of software for the embedded DSP has maintained compatibility allowing development performed on a PC platform to be ported to the embedded platform. The primary embedded test bed at present is the TMS320C6713 DSK. As well as hardware that can be interfaced directly to an I/Q modem, the package includes a full development environment including an optimizing C compiler. This standardization approach allows the final software framework to be open for software contributions from many sources.

The embedded DSP software already includes a STELLA transponder that will automatically notch any signal above a certain level over the transponder noise floor. In addition, the Phase 3 standard BPSK telemetry format has been developed as well as a simple CW beacon. I/Q imbalance correction has also been incorporated. The front end PC version of the software is shown in figure 7.

The ability to reprogram the transponder in order allows us to monitor and profile the nature of unwanted sources such as radar. With this information it is possible to design algorithms to defeat the effects of such interference.

For the AMSAT-DL Phase 3E and AMSAT-NA Eagle projects, there are also opportunities for enhancements to both the efficiency and linearity of PA designs. The subject of PA linearity and efficiency is currently very topical primarily due to the plethora of battery powered terrestrial devices requiring long battery life.

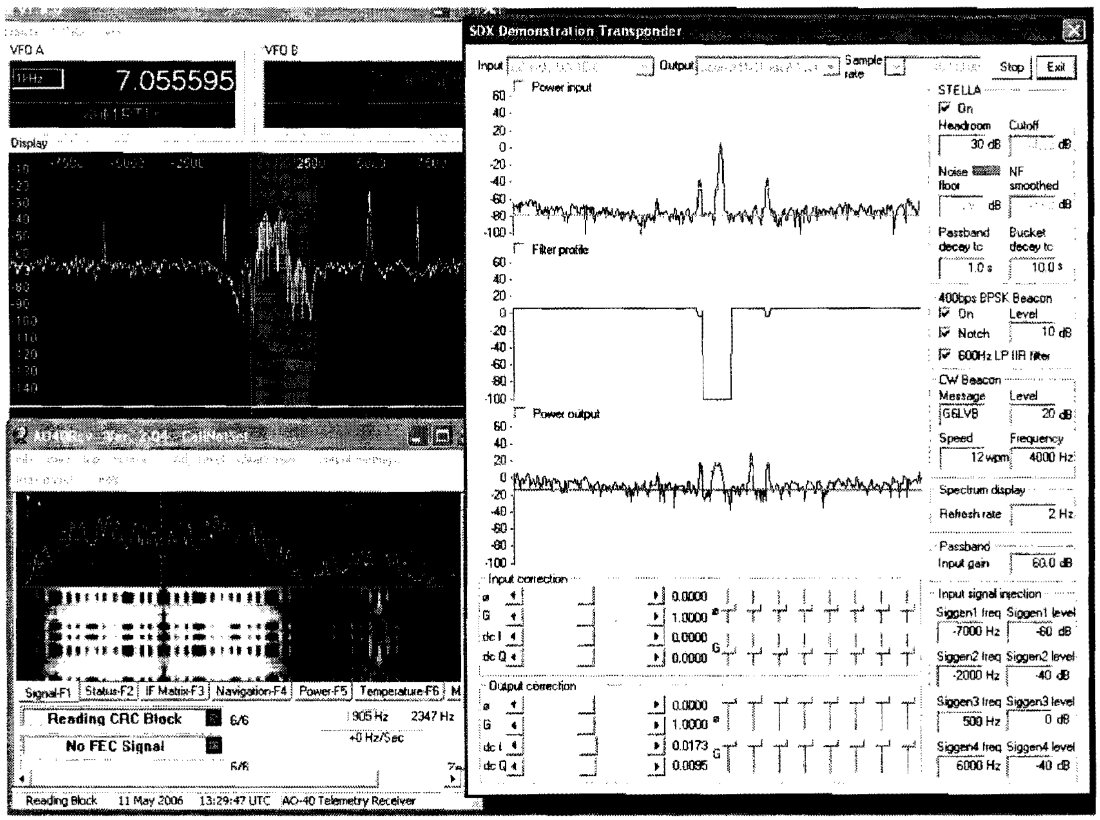

Figure 7 PC version of the transponder software showing telemetry decoding

As well as traditional analogue and digital communications, many other functions are lining up for implementation, in particular ranging and other time/space applications.

4 Conclusion

The first public demonstration of the embedded DSP hardware was at the Dayton Hamvention in May 2006, where it performed flawlessly over the three days.

At the AMSAT-UK Colloquium in July 2006, the transponder was demonstrated for the first time as a full mode U/S transponder using prototype hardware for ESA's ESEO mission.

The DSP transponder is a reality, and will inevitably fly on board a number of satellites. The ability to reconfigure in orbit, and the benefit of collective contribution will enable satellites using the payloads to be the subject of long term experimentation and design.

5 Appendix

The initial ESEO SDX prototype schematics are shown in Figures 8, 9 and 10.

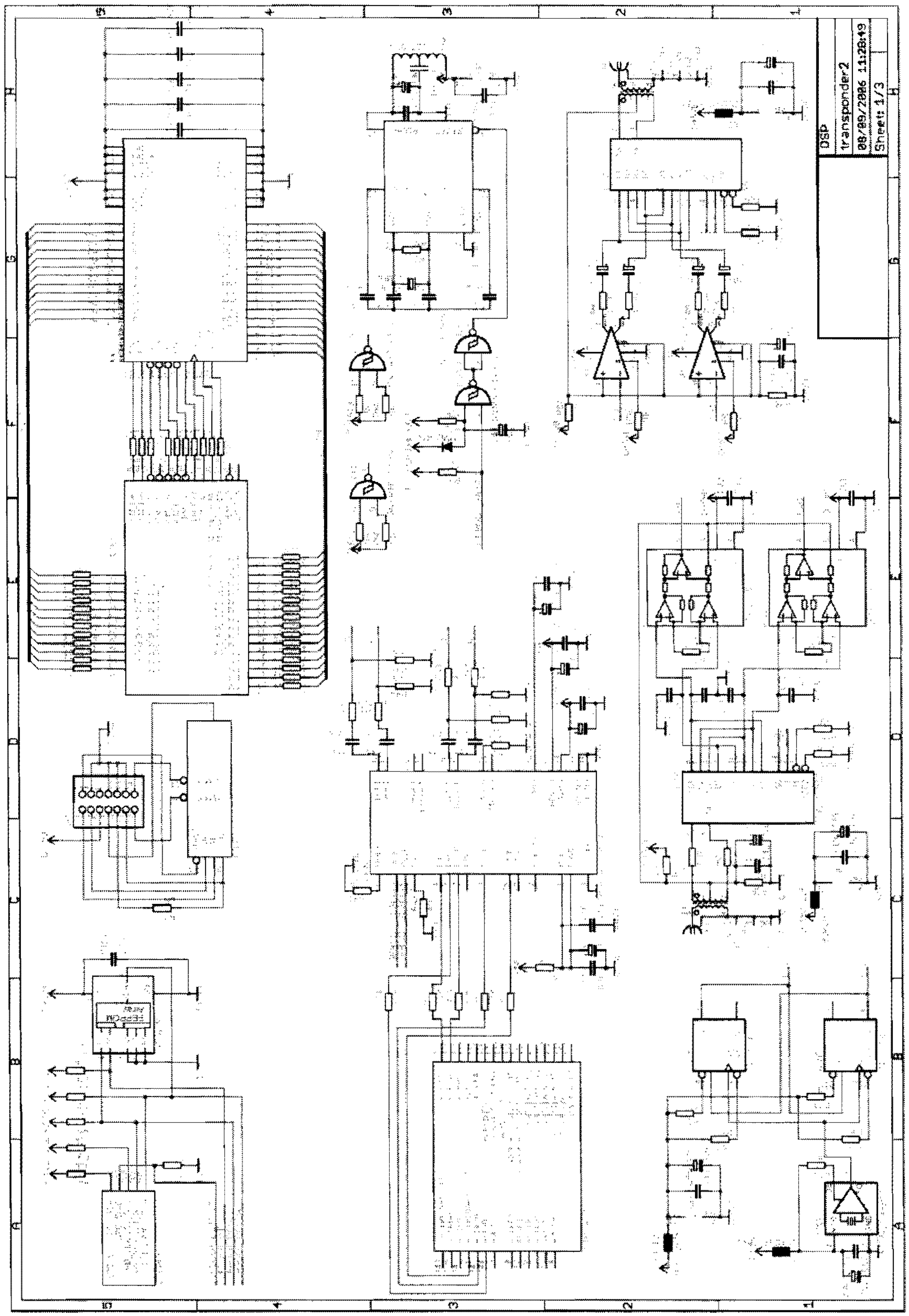

Figure 8 ESEO SDX DSP Section

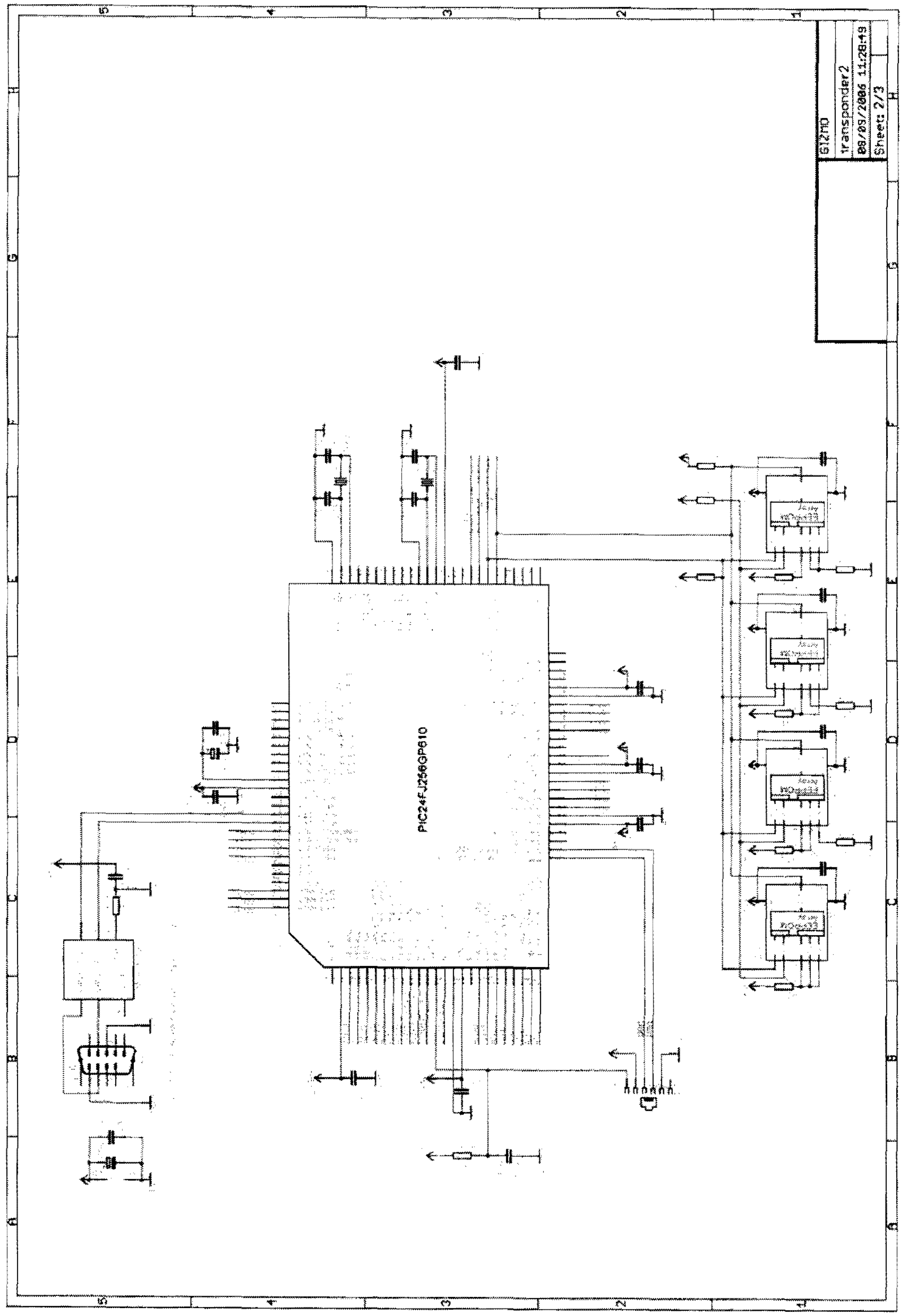

Figure 9 ESEO SDX MCU Section

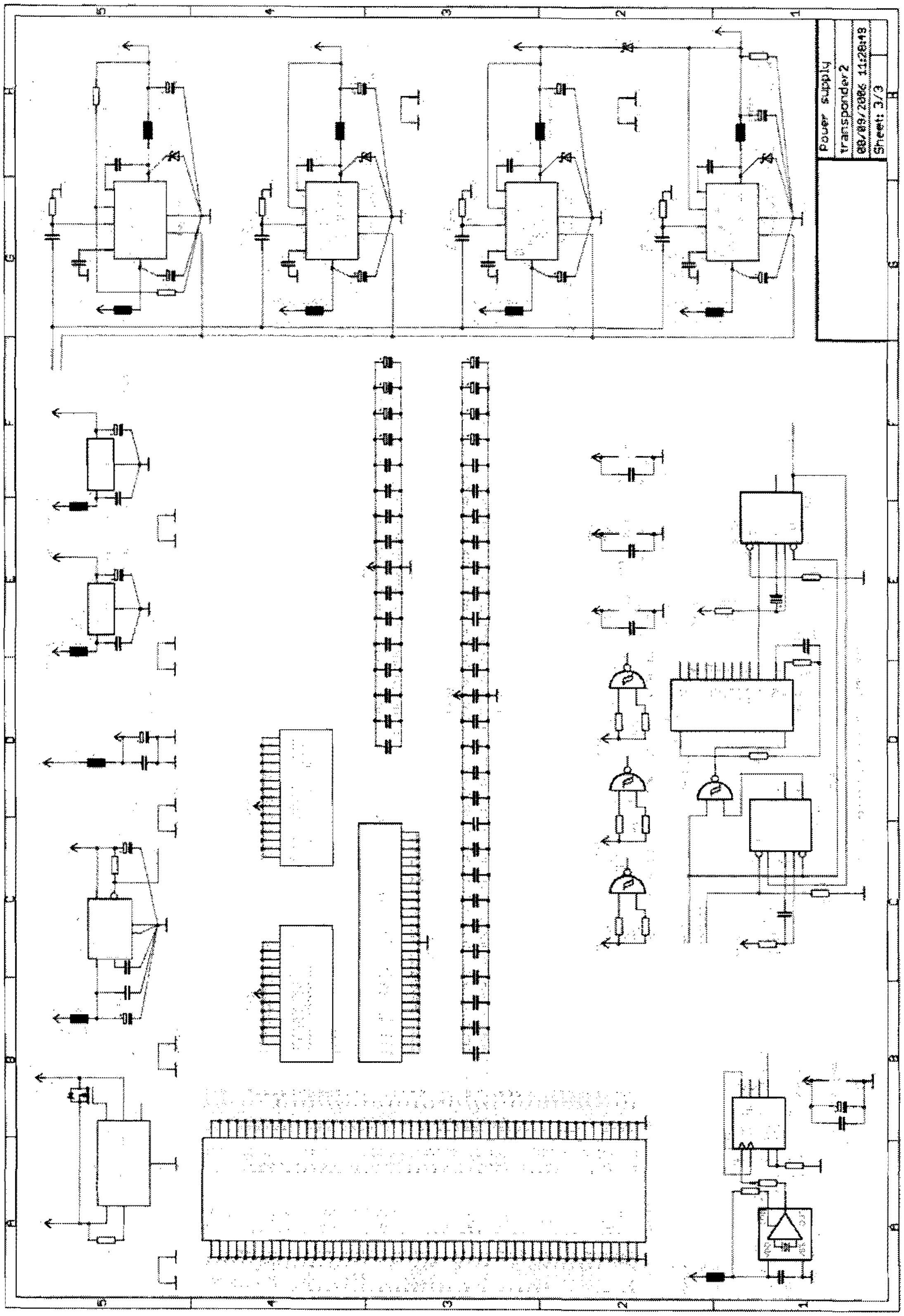

Figure 10 ESEO SDX PSU Section

6 References

[i] SDX Block Diagram, Lyle Johnson, K7PP

http://www.amsat.org/amsat-new/eagle/EaglePedia/uploads/6/6e/SDXBlockDiagram.pdf

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http://ww1.microchip.com/downloads/en/DeviceDoc/70175D.pdf

[iii] PIC24H Rev. A2 Silicon Errata

http://ww1.microchip.com/downloads/en/DeviceDoc/80280A.pdf

[iv] TMS320C6727, TMS320C6726, TMS320C6722 Floating-Point Digital Signal Processors (Rev. D) http://www-s.ti.com/sc/ds/tms320c6726.pdf

[v] TMS320C6727, TMS320C6726, TMS320C6722 DSPs Silicon Errata (Rev. B)

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[vi] SEFI Mitigation Technique for COTS Microprocessors, D. Czajkowski et al, http://www.klabs.org/mapld05/presento/139_czajkowski_p.ppt

[vii] TLV320AIC23B Stereo Audio CODEC, 8-to 96-KHz, With Integrated Headphone Amplifier (Rev. H)

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[viii] Mixed-Signal and DSP Design Techniques, Section 10: Hardware Design Techniques; Low Voltage Interfaces; Ethan Bordeaux, Johannes Horvath, Walt Kester

http://www.analog.com/Analog_Root/static/pdf/dataConverters/MixedSignal_Sect10.pdf

[ix] Simple Swapper Hot-Swap Controllers

http://datasheets.maxim-ic.com/en/ds/MAX5902-MAX5903.pdf

[x] TMS320C6x Thermal Design Considerations (SPRA432)

http://focus.ti.com/lit/an/spraa87/spraa87.pdf

[xi] PowerPAD™ Thermally Enhanced Package

http://focus.ti.com/lit/an/slma002a/slma002a.pdf

[xii] PowerPAD™ Layout Guidelines
http://focus.ti.com/lit/an/sloa120/sloa120.pdf

[xiii] PowerPAD™ Made Easy
http://www-s.ti.com/sc/psheets/slma004b/slma004b.pdf

Proposed Eagle Advanced Communications Package Downlink Design

Presented by

Matt Ettus, N2MJI

Abstract

A proposed communication system for the AMSAT Eagle Advanced Communications Package (ACP) downlink is described. The C-Band downlink must accommodate varying classes of users with antenna ranging from 60 cm to 2 m dishes, and varying data rates from 4800 bps to 256 kpbs. The system will handle multiple downlink streams at each rate, for an aggregate throughput in the range of 500-750 kbps, with a raw symbol rate of 5.7 Megasymbols per second (=6*950kbps) .

1 Introduction to the Eagle ACP

The Advanced Communications Package (ACP) on Eagle will provide high rate data services to amateurs worldwide. The ACP will serve two classes of user, called (for historical reasons) 2 and 3. Class 2 users will have a 60cm (2 foot) dish and will be able to uplink and downlink at up to 18kbps and 90kbps respectively. Class 3 users will have all the same hardware with the exception of a 1.8 meter (6 foot) dish. Class 3 service will allow for up to 160kbps uplink and 900kbs downlink.

ACP Ground stations will be codesigned with the space segment to ensure that they will:

- Function well together as a SYSTEM
- Be ready and available at the time of launch
- Be easy to deploy

Ground stations will be available to users as a complete system, including antenna and tracking system, with no additional components to buy. The vision is to have a small digital "black box" which will be mounted at the antenna. This box will connect back to the user terminal by Ethernet. Another goal for the system is for the ground station to be useful for other amateur radio activities outside of satellite use. Local digital voice and data communications would be the obvious uses.

2 Satellite Antennas

As Eagle will be spin-stabilized, it will have a constant pointing vector which will only point directly at the earth around apogee. In order to make the links work when the satellite is in other parts of the orbit, there are 2 options – point the antennas, or use very low gain, minimally-directive antennas. Only the first option would allow for the link margins we need, but mechanically steering an antenna in space is difficult and unreliable. Instead, the team has decided to electrically steer the antennas!

Both the transmit (C-Band) and receive (S2-band) antennas will be comprised of approximately 36 patch elements, each having its own LNA or PA as appropriate. Steering patch arrays is a well-defined and solved problem. The interesting twist with Eagle is that the satellite is spinning. This is not a problem at apogee, when the antenna beam is steered more or less on-axis. When in other parts of the orbit, however, the beam is steered off axis, and so will rotate with the satellite. Thus, the beam will need to be derotated. The satellite will be spinning at a rate on the order of 1 rotation per second, so this is non-trivial, but not impossible. The receive antenna can be steered closed-loop because of the feedback from the received signal strengths. The transmit antenna will need to be steered open-loop, with periodic calibration with the help of the satellite control stations on the ground.

3 Uplink Introduction

This paper concentrates on the downlink, so the uplink will be discussed only briefly. All users will transmit in a subset (approximately 5 MHz wide) of the S2 (3.3 GHz) satellite band (3400-3410 MHz), on their own frequency. The assignment of these frequencies will be some combination of random and least-recently used. The signal will be coded unfiltered BPSK, thus allowing for highly efficient nonlinear amplifiers. The satellite will receive and demodulate all signals simultaneously from the different frequencies.

For users in countries which do not allow satellite uplinks on S2-band, an alternate uplink on L-Band (1.2 GHz) will be provided, sharing some of the SDX L/S transponder antenna and some circuitry. This uplink will probably require either higher power or more gain to get the same performance due to the reduced gain on the L-Band antenna. It will also cover a much narrower band, accommodating fewer users. Thus, those who can use S2 would be encouraged to do so. The standard ground station package we will be producing will be designed for S2.

4 In-Satellite Processing

The signals from the various users are all received and demodulated in the satellite. The satellite will make minimal policy decisions about how to handle the data, and it will all be multiplexed onto a single downlink signal. Also multiplexed onto the same signal will be telemetry, other satellite data like pictures from an onboard camera, and control and protocol data. The satellite will not store anything, and will make no other decisions about downlink data other than possibly prioritizing it if there is more uplink data than the downlink can handle.

5 Downlink Signal Design

Overview

The downlink will be on the 5 GHz satellite band (5.83 to 5.85 GHz) and will be about 10 MHz wide. There is a single wide signal which will have multiplexed user and satellite data. The total transmit power of 20 Watts will be generated by 36 amplifiers, each attached to a single antenna in the phased array.

Modulation

The modulation will be unfiltered BPSK. BPSK was chosen because it is the most power efficient basic modulation (with the exception of M-FSK for large values of M), and it is easy to generate and demodulate.

In most uses, BPSK is filtered, usually with a root-raised cosine filter, in order to minimize bandwidth occupancy. The cost of filtering is that all amplification must be linear, and this reduces the efficiency of the power amplifiers. Since there is more than enough bandwidth available (the C-Band satellite downlink allocation is 20 Mhz wide), and we are heavily power-constrained on the satellite, there will be no filtering. It is anticipated that Class-C or Class-E amplifiers will be used, and that efficiency may approach 50%

Coding

Because we have a lot of bandwidth available to us, we can use a very strong, very low rate code. Coding on the downlink will use CCSDS standard rate 1/6 turbo codes. This means that for every data bit, 6 encoded symbols will be sent. Code blocks will contain 1784 bits, which will become 10704 symbols. The 1784 bits will usually be made up of data from several different users. This allows us to fill up code blocks faster than if we had to wait for that many bits from a single user, allowing for lower latency on voice communications.

6 Packet Format

The ACP downlink will be one continuous stream. The stream will consist of code blocks of 10704 symbols. Each code block will be preceded by a "tag" which will be one of 2 orthogonal codes, about symbols long. The tags can be used for carrier tracking and for bit timing recovery. They will convey one piece of information: Whether this block is a repeat of the last block, or whether it is a new block.

Interspersed in the block will be fixed sync bits to aid in carrier tracking and bit timing recovery. Approximately 3-5% of the channel symbols will be these fixed sync bits.

The code blocks will all be whitened, to ensure adequate transitions for timing recovery.

Multiple Data Rates

To support Class 2 users, who have a weaker receive SNR (by about 10dB), data must be sent to them with about 10dB more energy per bit. This can be accomplished in one of 3 ways:

- Increasing the power by 10dB when transmitting to them
- Slowing the data rate down by a factor of 10
- Repeating each code block destined for them 10 times

The first 2 are impractical in this system, so the third has been chosen. By sending each code block destined for Class 2 users 10 times, you effectively send them 10X the energy per bit, but with one tenth as many bits. They can coherently add the 10 copies together before attempting to demodulate.

The purpose of the Tag is to allow the receiver to determine whether each block is new, or a repeat of the past one. The tag is 100 bits long to ensure that even weak receivers can reliably decode it. To decode the stream, the receiver waits for a tag indicating a "new" codeblock, and records the symbols. For every subsequent code block marked "repeat", the codeblock is coherently added to the recorded symbols. Once a "new" codeblock comes, the previous one is decoded since no more copies will be coming.

The system is also scalable – if it is determined that receivers need more or less than 10dB gain, more or less copies can be sent. If the satellite is lightly loaded, more can be sent to get better error rates.

Eagle and Erlang:

A Platform for Satellite Text Messaging and Other Wonders

Presented by

Frank Brickle, AB2KT

Abstract

As a system, AMSAT Eagle will depend on software to an unprecedented degree. This is true of the terrestrial end of the system as well as the orbiting end. A proposed Text Messaging facility to operate on the U/V link will require the cooperation of a network of terrestrial servers, the development of a new, inexpensive handheld terminal, and the adoption of a suitable protocol. These requirements place unusual demands on portability, reliability, maintainability, and fault tolerance of the underlying ground-based software.

Erlang/OTP is a mature programming language and operating environment originally developed at Ericsson for implementing reliable, scalable, distributed telecommunications applications. It is Open Source and is available for free for all major hardware platforms and host operating systems. Under consideration for implementing Eagle Text Messaging (SatChat) is the Jabber/XMPP protocol. The most complete server for XMPP is ejabberd, which is written entirely in Erlang; ejabberd also happens to be the most compact and portable implementation. However, the overall features of Erlang/OTP suggest that it would be a valuable platform for other amateur satellite applications beyond simply the SatChat messaging service. In particular we propose that Erlang/OTP be used in the development of a ground-based network for access and control of shared remote stations on the Eagle high-bitrate digital channels.

About the Author

Frank Brickle, AB2KT is a member of the Eagle design team concerned with the Software Defined Transponder (SDX) and the Text Messaging service. He is co-author with Bob McGwier, N4HY of DttSP, the software radio core currently used with the FlexRadio SDR-1000 in the Linux, Windows, and OSX versions. He is also part of the team developing the SDR for SuitSat II

1 Texting with Eagle (SatChat)

Everybody knows by now that AMSAT Eagle is going to use Software-Defined Radio technology. What has been a little less publicized is the design team's firm commitment to making the Eagle project a complete *system,* including terrestrial stations. An important part of the plan is providing an inexpensive, easy-to-use, self-contained handheld terminal that can be used with Eagle from anywhere in its footprint, or even point-to-point on the ground where appropriate. The advantages for the antenna-compromised user, and for emergency communications, are hard to miss.

The most effective way to accomplish this goal is to use, not voice, but text messaging as the primary medium. Messaging is an efficient way to achieve broad usage with modest resources. At a minimum, this facility would resemble the Short Message Service (SMS) familiar from cell phones. Unlike cell phone SMS, however, it would work where there was no cell infrastructure – out in the wild, for example. Furthermore, if system bandwidth will allow, the text service could also be extended to realtime interactive messaging – chat, in other words. For this reason, and because it's a cute name, I have proposed calling this service "SatChat."

Cute names aside, one thing the world doesn't need is yet another person (or committee) devising an untested protocol. After studying the existing published protocols supporting text messaging on the internet, we have focused on the Jabber/XMPP standard for supporting the Eagle text service. There are abundant reasons. For the present, we will simply observe that the protocol is simple, but it supports a very deep and rich set of features, far beyond what the Eagle service requires, but which can be dynamically enabled or disabled as dictated by circumstances. It is also Open, under active development, and supported by a wide variety of client software including embedded processors. It would appear to be a fairly straightforward and routine matter to provide a decent range of messaging capabilities on a modest handheld terminal.

The Eagle Messaging Service will be routed *through* the satellite, but the service itself will be provided by a collection of terrestrial hosts running servers. For Jabber/XMPP there are a number of server programs available. However, only one version implements pretty much the whole extended XMPP spec, which includes some desirable features like presence notification (letting you know when certain users are currently online) and offline message retrieval (so you can recover what was sent while you were outside a usable pass). That server happens to be ejabberd, and it is implemented using Erlang/OTP.

In the brief discussion that follows we will merely point out the highlights of Jabber/XMPP and Erlang/OTP. The best and most concise descriptions, tutorials, reference documentation, and source code are all available on the web. We will provide links to these repositories at the conclusion of this note, so you can sample them at your leisure and enjoy speculating on the range of possibilities that are opened up by these simple, free capabilities.

2 Erlang/OTP

Erlang is a programming language devised at Ericsson specifically to support robust, error-tolerant, distributed telecommunications applications. It has been around for a number of years, and several large, mission-critical applications use it. OTP – the Open

Telecommunications Platform – is the environment in which Erlang runs. It provides the critical infrastructure, including networking and toolchains, for Erlang programs to operate. Full versions of Erlang/OTP are offered for all major architectures and operating systems, as Open Source.

Erlang/OTP has extensive library support including a distributed database system. One of its primary aims is to make distributed concurrent programs easy to write, debug, and modify. In other words, it is meant to take the pain out of writing programs which by intent may have many simultaneous operations going on, taking place on (potentially) hundreds or thousands of machines connected by a combination of local and wide-area networks. At this it has been unusually successful.

Nevertheless, a single Erlang/OTP node is a fairly economical device, well-suited to running as a daemon on a desktop computer, and the language itself is extremely simple. Erlang is a Functional Language. Descended as it is from Prolog, it calls for a style that might be unfamiliar to many programmers. Once the basic concepts are grasped, however, it is possible to ramp up to useful work very quickly. The concurrency and messaging primitives follow closely the fundamentals laid out in C. A. R. Hoare's classic *Communicating Sequential Processes*. Where library support is not provided, there are cookbooks listing proper Erlang code for many customary tasks. As with everything else about Erlang/OTP, all of the information is reachable online.

A simple client-server program connecting two nodes on a network can be expressed in less than a page of source code, and it will run without modification on or between any of the supported operating systems.

Since Erlang is not intended to be a general-purpose computing environment, it offers features that facilitate communication and cooperation with programs in other languages. For example, extensive support is provided for interoperating Erlang with C, C++, Python, Ruby, and XML-RPC.

3 Jabber/XMPP

Jabber began life as an Open Source replacement for proprietary Instant Messaging (IM) protocols. You may have already been using it yourself, through chat clients like Gaim, or with Google Talk. You might also have exchanged messages with another user whose client speaks Jabber, but through a gateway that translates among chat formats.

Thanks to its thoughtful design, Jabber quickly grew to encompass nearly every class of internet text service currently in use. For example, it has features for Short Message Service (SMS), Instant Messaging (IM), something that looks and tastes very much like conventional email, file transfer, and more. These services are modular, however, since an individual Jabber host can choose to provide a selective subset of the full repertoire. There is a protocol for letting a given server announce which capabilities it provides, and which ones might or might not be permitted to a varying subset of users. Jabber server nodes are designed to be distributed and stateless, which means they can go on or offline without damage to the larger Jabber network. These features are especially desirable on a system like Eagle Messaging, where the collection of server nodes will be changing constantly depending on the satellite's footprint, and which will have a limited channel capacity. Some services will need to be regulated dynamically depending on the system load.

In addition, and very importantly, Jabber provides standard mechanisms for security and validation, making the system relatively immune to abuse.

Jabber was eventually codified as XMPP into a series of standards and extensions by the IETF. In this form it was adopted as the backbone of the Google Talk service.

In essence, Jabber is just an enhanced XML specification. The real impact is this: ultimately it's *all* human-readable text, protocol, administration, everything. This also makes a good fit with the projected Eagle U/V link, since it requires only a fairly low bitrate to achieve useful results. It also means that clients are uncomplicated to write, on whatever platform is suitable for a given application. You can write a complete Java client for Jabber that will run on a cellphone-class processor without having to know a lick of XMPP, thanks to an Open Source library targeted at embedded processors.

Servers are another matter. There are quite a few to choose from. While the XMPP capabilities have expanded, the array of servers has generally fallen behind in providing the full set. A notable exception is ejabberd, which not coincidentally is implemented using Erlang/OTP. The core functions in ejabberd are expressed in about 20k lines of code. I will attest personally to the ease with which a complete novice can get into and get oriented in that codebase. This alone is a persuasive reason to consider seriously the Erlang path to SatChat. Some of the extensions found in ejabberd and not all the others are critical to the Eagle application. Most prominent is the ability for a client to retrieve messages offline from an arbitrary server, a necessity when working with a moving footprint.

4 Further Applications

In looking over the broad range of capabilities that the OTP offers for distributed interprocess communication and control, it's hard not to speculate about how Erlang/OTP could contribute to the development of new and unprecedented satellite applications. The only existing Erlang textbook itself has a chapter devoted to a sketch of a satellite control system in Erlang. While it's only suggestive, the sketch does confirm our suspicion that a number of the other pieces of Eagle software – especially the extensive pieces that will live on the ground – may profit from being looked at from the Erlang perspective.

As we've mentioned, it's important to think of Eagle as a *system* which encompasses both the orbiter and the ground stations. We talked a little about the design of a minimal handheld terminal to exploit a low-bitrate channel for expanded text messaging facilities. The real strength of Eagle will be found in the higher-bitrate channels, however. These channels will need more firepower on the ground, particularly in the antennas.

It's getting harder and harder for amateurs to put up the antennas they need and want. At least, it's getting harder and harder to *co-locate* them with their operating positions. Compensating for this may be the rapid expansion of broadband networking in the home. In other words, it's getting hard to put up antennas on our roofs, but it's getting a whole lot easier to connect to remote antennas and gear from our shacks. Since the high-bitrate Eagle channels – voice included – are digital to the core, it's entirely feasible to run a remote Eagle terrestrial station from halfway around the globe. It doesn't even put a significant strain on local bandwidth. A remote facility can also be easily shared among a community of users.

At this point in time, all the pieces of such a remote system either exist or can be readily assembled from existing software. What's missing is the glue – the software system that puts it all together. I would submit that this is exactly the sort of job that Erlang/OTP was designed for. Thanks to the interoperability features built into OTP, it may even be possible to run much existing software within an Erlang/OTP environment without modification.

A nice side-effect of such a development is, perhaps, unforeseen. Amateur satellite work has been seen customarily as the domain of specialists. A comprehensible ground network of home stations can open up satellite operation to a whole new range of interested operators. But the depth of the ground software requirements is such that it can engage a whole new range of programmers, with expertise in the area of user interfaces and applications. It offers a whole new playground for interested but hitherto uninvolved contributors. Moreover, the development and implementation of such a system can proceed independently and at its own pace, since it represents a value-added enhancement of the basic Eagle system and not a mission-critical component.

In any event, the Eagle system is offering unprecedented opportunities for innovation in the software arena. Our belief is that Erlang/OTP is one of the most promising vehicles with which to move forward in that arena.

5 Links to Erlang/OTP and Jabber/XMPP

Erlang/OTP:

http://en.wikipedia.org/wiki/Erlang_programming_language

http://www.erlang.org/

http://www.planeterlang.org/

http://www.erlang-projects.org/Public/rpmdeb/erlang_repos_1.0/view

http://schemecookbook.org/Erlang/

http://en.wikipedia.org/wiki/Ejabberd

http://ejabberd.jabber.ru/

http://wagerlabs.com/articles/2006/01/01/haskell-vs-erlang-reloaded

Jabber/XMPP:

http://en.wikipedia.org/wiki/Jabber

http://www.jabber.org/

http://planet.jabber.org/

http://en.wikipedia.org/wiki/Ejabberd

http://ejabberd.jabber.ru/

http://gaim.sourceforge.net/

http://www.jivesoftware.org/smack/

Changes in Latitude, Changes in Attitude

Presented by

Bob McGwier, N4HY

Abstract

During the past year, the Eagle project has undergone significant revisions. The revisions have been driven by multiple factors. These include the need to allow for a possible return to launches from Cape Canaveral as well as the need to have the necessary platform to provide for sufficient power generation and antenna territory to meet the design goals as set forth in the AMSAT vision statement.

A discussion of these competing goals and how they have impacted the design will be given here.

About the Author

Bob McGwier is a veteran of AMSAT affairs. He is a former director and officer of AMSAT as well as its current V.P. of Engineering. First licensed in 1964, Bob has held the call N4HY since 1976. He is co-author with Frank Brickle, AB2KT of DttSP, the software radio core currently used with the FlexRadio SDR-1000 in the Linux, Windows, and OSX versions. He is also part of the team developing the SDR for SuitSat II. Bob will return to the board of directors of AMSAT at this conference.

1 Introduction

This paper discusses some of the history of and lessons learned from our previous "Phase 3" missions and suggests how we might apply these lessons in the design of a new spacecraft. In addition, we review the Eagle design and how it has changed in the past year. We will suggest that at the same time we attempt what might seem to be contradictory goals of being less complex yet more capable than our previous design efforts. The design philosophy followed will be one that attempts to allow for failures in our complex experiments at the same time we attempt some complex operational goals. The design of the spacecraft will have the goal of making its operation as simple as possible for the command stations and provide adequate, if not perfect, solutions to meet our goals.

Since July 2001, when Dick Jansson WD4FAB presented his seminal proposals for an approach to building our next spacecraft, it has been the goal of AMSAT to learn from its past experiences in complexity and the management of complex engineering construction tasks in our distributed design process. Dick was a member of the mechanical design team on AO-40 and on AO-13. In both cases we learned many valuable and some painful lessons and Dick has attempted to capture these thoughts in the cubical Eagle.

AMSAT-NA has set some goals for the organization in a vision statement:

> "Our Vision is to deploy high earth orbit satellite systems that offer daily coverage by 2009 and continuous coverage by 2012. AMSAT will continue active participation in human space missions and support a stream of LEO satellites developed in cooperation with the educational community and other amateur satellite groups."

2 How We Got Here

We wish to overcome some of the problems, which caused engineering complexity in the areas of propulsion and control. We learned from our previous experiences that while we can build, fly, and operate rocket motors using the hydrazine and nitrogen tetroxide as fuel and oxidizer respectively, we have yet to achieve the goal for which we flew this rocket motor. The goal of such a motor was to achieve a Molniya orbit. The ground track for such a spacecraft would appear in the Mercator projection of a tracking program as depicted in Figure 1.

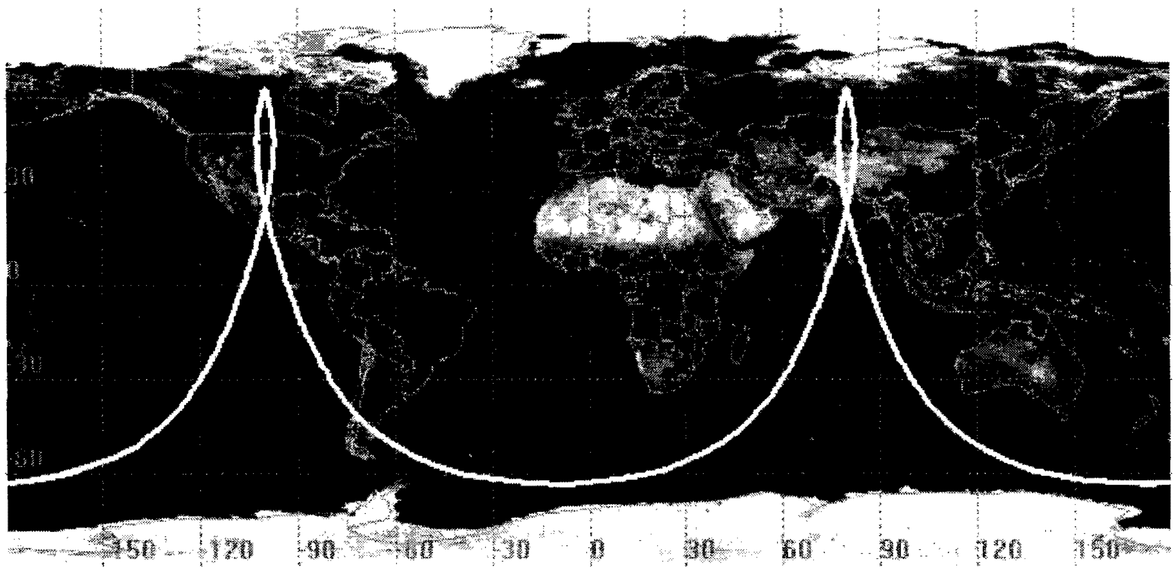

Figure 1: Ground track for a typical Soviet/Russian Molniya satellite

This orbit has some very interesting features, which may be determined through the study of orbital mechanics. Studied in greater detail, you will find that the angle between the orbit ground-track at an ascending node (going from south to north across the equator) is very close to 63.4 degrees and the orbital period is 12 hours. If one designs a satellite system for this orbit, it will appear in the same spot in the sky every day and will not move much at all over time. The inclination of 63.4 locks the argument of perigee.

This means that the apogee would hang over essentially the same sub-satellite latitude in each orbit. The twelve-hour orbit means that the sub-satellite longitude would be the same ever 24 hours. We are ignoring some perturbations but they are substantially true. The Russian program consisted of putting multiple satellites into the same orbital plane but at different phases. This would allow for one satellite to leave the "area near apogee" as another appeared. This allowed stations in high latitude to have stationary antennas. Furthermore, the antennas for the northern hemisphere stations were pointed at a high elevation which might avoid ground objects such as building and/or trees.

These are wonderful goals and would be nearly ideal to serve most of the amateurs in the world. We like the goals so much we attempted it 4 times and will attempt it again with Phase 3E but we have not yet succeeded. The problem with not succeeding in getting to the target orbit can be anything from annoying to catastrophic.

Given our experiences, we are much more likely to succeed in achieving a near equatorial orbit and building a satellite that can accommodate any ride to an orbit that will get us there is in our interests. If we miss the near equatorial orbit by a few degrees, it will not be catastrophic. We learned from AO-13 that missing the Molniya stable point magical 63.5 degree inclination by a few degrees can lead to catastrophic orbital perturbations from the sun and moon. AO-13 was lost to reentry which no one believed possible when we started. However, this does ***NOT*** free us from the need for a motor.

We are investigating launches at this time that are sponsored by the U.S. government and flown from the Cape Canaveral. All launches from Cape Canaveral that do not attempt to change the plane of the orbit will deliver a ~28.5 degrees inclination. The target for these launches is to have the apogee of ~39,500 km above the equator with a perigee of at most a few hundred km. The apogee residing over the equator will minimize the change of velocity needed to change inclination and give the longest possible useful period for this burn. The mechanics of such a burn are actually quite straightforward. (See Figure 2).

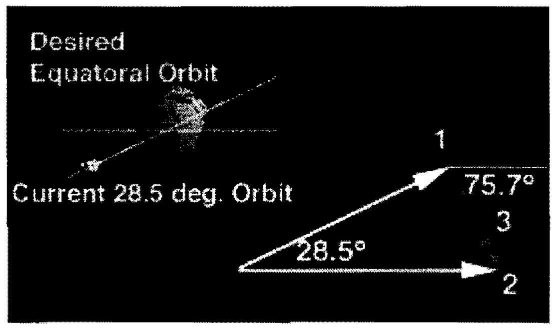

Figure 2: Vector math for a plane change burn

The *Vis-Viva* equation is below

$$V^2 = \mu\left(\frac{2}{r} - \frac{1}{a}\right) \qquad (0.1)$$

It tells us that the square of the speed at a distance r from the center of the earth in an orbit with semi-major axis axis determined by this simple formula.

Suppose we are given a launch from Cape Canaveral on a Delta IV Heavy and are taken to 150km perigee by 39500 km apogee. The apogee will occur near the equator for its sub-satellite point. The semi-major axis is

$$a = (\text{distance from earth center at apogee} + \text{distance from earth center at perigee})/2$$

$$= ((6378+150)+(6378+39500))/2 \text{ km} \qquad (0.2)$$

$$= 26203 \text{ km}$$

At apogee the distance r is 45878 km so the speed at apogee derived from (1) is about 900 $\frac{\text{km}}{\text{sec}}$. The formula for a plane change at a point in the orbit is derived easily from the simple vector arithmetic in Figure 2.

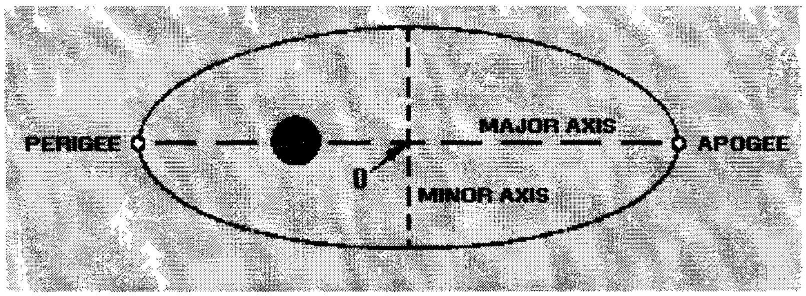

Figure 3: Elliptical orbit about earth

We do not want to change the shape of the orbit, only its plane. So when we are done, we want to have exactly 900 $\frac{km}{sec}$ but in the new plane and we want the shape (eccentricity) to be the same. So the formula easily derived from the geometry of Figure 2 is

$$\Delta V = 2V_{Apogee}\sin(\tfrac{\theta}{2}) \qquad (0.3)$$

Since θ is 28.5 degrees, this means that we require $\Delta V = 1800\frac{km}{sec}\sin(\pi\frac{28.5}{360}) \cong 860\frac{km}{sec}$! This is not a change in velocity we are going to get with a low thrust or cold gas motor with small total delta-V. We need to do it quickly while apogee is still over the equator or we will wait years to repeat the opportunity! Some launches from Cape Canaveral provide for a change of inclination from the default inclination of Cape Canaveral. These launches typically have a final inclination of insertion for the spacecraft around 17°. This would alter the requirements months to be $\Delta V = 1800\text{km/sec}\sin(17\pi/360) \cong 266\,\text{m/sec}$. This is still too much change of velocity for a cold gas motor.

3 Stability Requirements for a Useful Successful Motor Burn

For a large thrust motor to provide for a successful burn, the spacecraft must be spun around its major spin axis to provide for stability during the burn. If there were absolutely no errors in the positioning of the rocket thrust and we could have complete and perfect control over the thrust vector we could use the rocket without worries about stability entering our minds given the old Eagle design. But because we are unable to provide for a perfect alignment of the thrust vector through the center of mass of the spacecraft and it is unlikely it will be parallel to the actual spin axis, we must provide for minimizing the effects of our imprecision. To the extent that our rocket motor is not parallel to the spin access and the thrust vector does not aligned itself with the spin axis or pass through the center of mass of the spacecraft this is called thrust vector misalignment. In many spacecraft, and in all AMSAT spacecraft where a rocket motor was used, this is overcome to the extent possible by spinning the spacecraft.

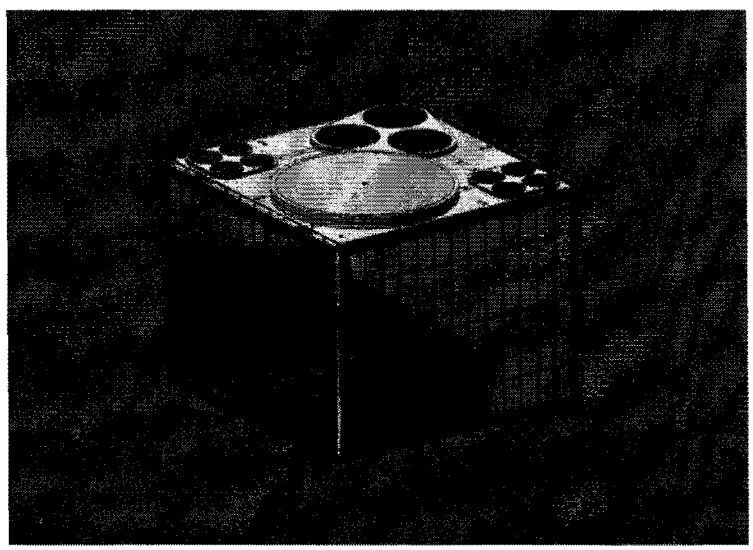

Figure 4: Old Eagle Concept Before Motor Firing

Figure 4 shows the previous Eagle concept. The thing to notice about this design concept is that it is nearly a cube. Think of spinning this cube on the tip of a pencil. You are attempting to spin it fast enough that the imperfect nature of your holding the pencil will not cause it to topple off the pencil.

With a 200 Newton motor and as small as a 0.01 degree offset would have almost 0.04 Newtons of thrust applied along the perpendicular to the spin axis. This would cause the thrust vector to move away from the intended line and the spacecraft would begin to "cone" or precess around the intended thrust vector making the burn both inefficient and possibly dangerous. With the cube, the actual moments of inertia and the ratio of moments of inertia will determine the overall stability of the spinning and motor firings. The necessary numbers in almost any small modification of this cube is too small to guarantee unconditional stability for all of our operations.

4 Antennas Needed, Part I

The AMSAT vision statement, the corporate goals for our future, led to a set of desired communications goals to be attempted in our new Eagle spacecraft. We want to provide a usable set of voice and data services to those who have to live with antenna restrictions. We wanted to minimize the required antenna and power to be generated by the ground stations. In addition, it is our desire to have a slow speed text messaging service.

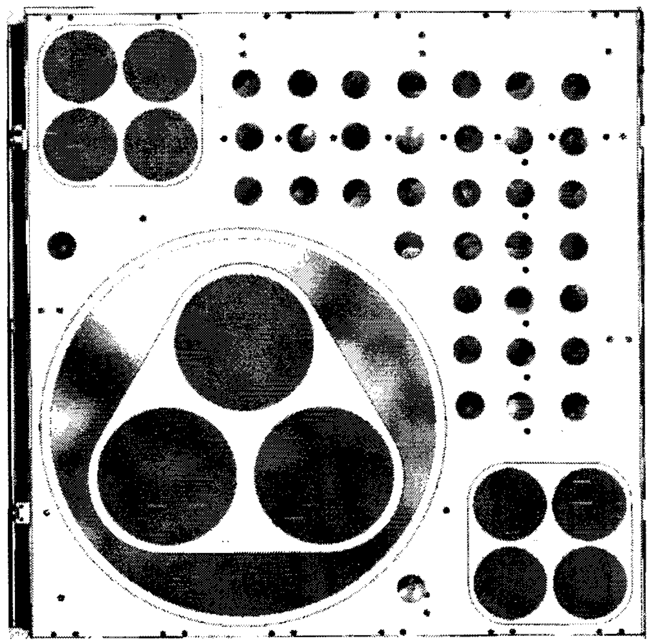

Figure 5: Old Eagle Antenna Concept

The first Eagle spacecraft design had very limited space for antennas. The cramped space required us to stack three 1269 MHz patches on top of a single 435 MHz patch. We also envisioned flying two 2401 MHz transmitters each with a set of patches. Tom Clark, K3IO proposed that we do our Advanced Communications Package (APC) using C band as the uplink and the downlink since we have a earth-to-space allocation in the 5 GHz band that is nearly 200 MHz away from the 5 GHz downlink. The modified patch array is seen in the upper right hand corner of figure 5 is for CC-Rider. Notice there is no 2 meter antenna.

5 Power Needed, Part I

One of the most irritating aspects of the phase 3 program to users and spacecraft operators has been the seasons and off pointing angles. The P3 designs to date only had solar cells around the perimeter of the tri-star as shown in Figure 6. This causes several problems when faced with the realities of charging your batteries using solar arrays.

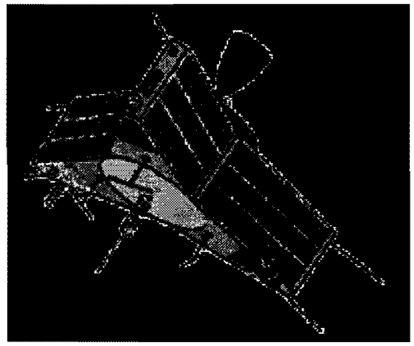

Figure 6: AO-13 (courtesy AMSAT-DL)

The most important of these considerations is that you cannot power the spacecraft and charge the batteries if the sun is not illuminating the solar panels!

Facing this problem forces the control stations to adjust the attitude of the spacecraft to illuminate the panels. This in turn means that the high gain antennas needed to have usable communications links do not point at the earth at apogee which is the design point for the antennas on the Phase 3 spacecraft. Figure 7 (A G3RUH diagram) diagrammatically shows the squint angle problem that should be familiar to many of our readers.

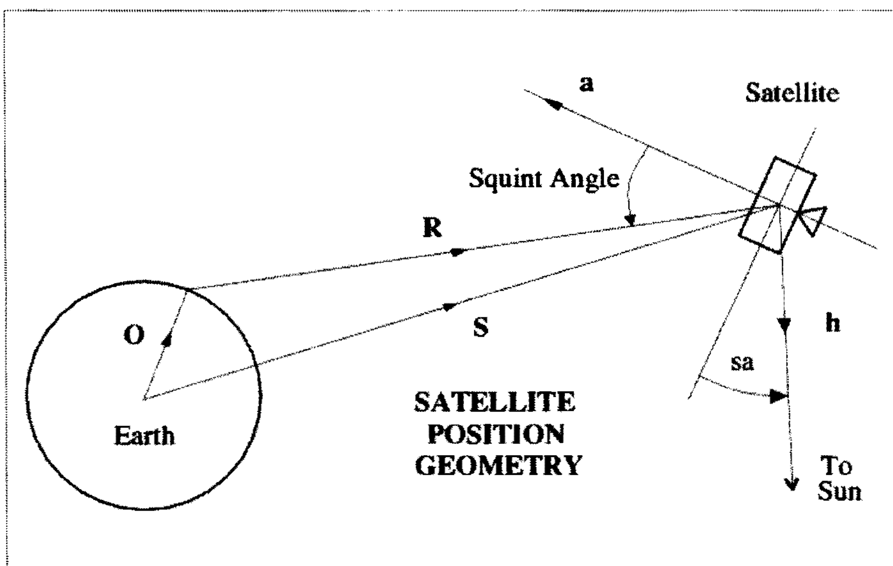

Figure 7: Squint Angle Geometry (courtesy G3RUH)

Dick Jansson, WD4FAB, proposed a new approach to this problem. How can we alleviate this problem to a large extent? In Figure 8 we will allow a picture to replace a thousand words.

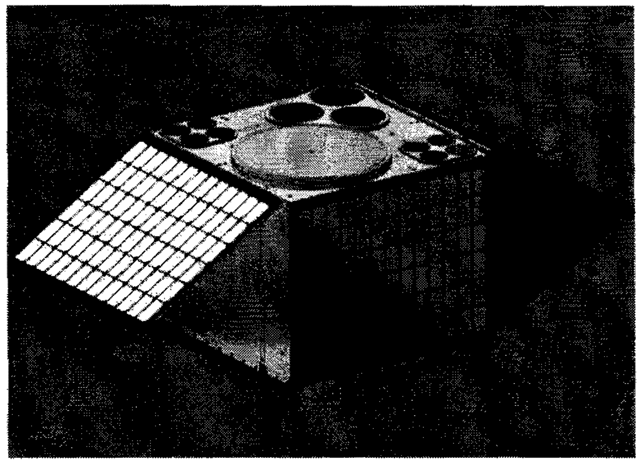

Figure 8: Old Eagle Solar Panels Deployed

The thing to notice in figure 8 is that it does not matter where the sun is in the celestial sphere. The solar panels will receive illumination. The only time we would not receive illumination is during those times of year when we experience solar eclipses and are in the earth's shadow. This means two things, no seasons and no squint angle problems caused by seasons. This does NOT solve the squint angle problem due to the elliptical orbit. We will return to this later.

6 And then there was Bob

In October of 2005, the AMSAT-NA board of directors settled on the author as the vice-president for engineering. After about a month, we began asking hard questions while proceeding with some important foundational work. We decided to question the hardware design, the ability of the spacecraft to support any serious operational requirements, and the entire approach to the spacecraft engineering. It was clear that people were proposing widgets and we had the publication of a functional requirements document which was little more than a list of widgets. I love widgets but what were they to do?

We have some of the most fantastic volunteers doing technical work for this organization that you can possibly imagine. The collective technical talent we have working for us is awe-inspiring and many continue to do it year after year. But before October 2005, we were not asking ourselves to face the question: "What services do we wish to provide?". That question leads to engineering answers because you need to develop ***systems*** to accomplish the tasks. The functional requirements document should be a list of functions (thus the title) and not a list of toys.

After some internal discussions and the beginnings of a white paper on a HEO design, it became clear that we needed to fill out this set of functions or services. They needed to be based solidly upon information theoretic and communications systems analysis. It took eight months to get everyone needed all together to define and design the communications functions or services we wanted to and believed we could deliver on Eagle.

In late June 2006, this meeting was held in San Diego, CA and it was hosted by Franklin Antonio, N6NKF (author *Instantrak)* at his workplace.

Figure 9: N6NKF with N4HY, N2MJI in background (San Diego)

Figure 10: Matt Ettus, N2MJI and Phil Karn, KA9Q (San Diego).

Matt Ettus, N2MJI presented us with a preliminary design for an advanced communications package. The assembled design team did a detailed analysis of the link budgets to sustain the kind of communications services we wished to provide and an analysis of the impact it would have on the spacecraft systems needed to support them. I will not repeat all of the conclusions of the communications design effort as they will be covered by Matt in another paper and talk. I will concentrate on the impact of these design elements on the spacecraft structure.

7 Antennas and Power Needed, Part II

Let's combine these two elements to get to the bottom line since they lead to exactly the same outcome. In San Diego, we did a high level design of the actual communications systems and did approximate power budgets to run all of the spacecraft systems.

We analyzed the kinds of antennas we could build on this spacecraft. We added to our design the requirement that we greatly increase the percentage of the orbit the advanced communications package or payload (ACP) and the linear transponders would be usable. The design goal is to have the ACP usable at least over 70% of the orbit. We need to do this to meet the AMSAT vision of having a small fleet of satellites, including P3E that would provide communications seven days a week, 24 hours a day, 365 days a year.

The first thing we decided is that we cannot fly CC Rider. We do not believe the filtering system needed to make CC Rider work is compatible with the demands of putting the large filters needed in a spacecraft EVEN IF they could be built (which many of us doubted). Paul Wade, W1GHZ, undertook a serious design effort and reported that all of his first attempts failed. Coupled with the larger mass and volume the filters would require, and the need to put all of them on one end of the spacecraft, we rejected CC Rider.

This leads inexorably to two bands for ACP and if so, which two? We tried doing a combined dual band antenna array and other things but other factors propel us to a new direction.

Because the impact of power budget and other considerations on such experiments as RUDAK in the past, we demanded of ourselves that we be able to run both the ACP and one of the linear transponders simultaneously at all times.

Both the antenna and the power requirements, coupled with the poor stability of the original Eagle cube for rocket motor use lead you to one place. We had the wrong design. The antenna area is not large enough. The solar arrays are not powerful enough to deliver the power we needed. We wanted to give ourselves the option of launching on any rocket in the world that would go to geostationary transfer orbit and from anywhere but possibly Kourou we must have a rocket motor.

8 How Do We Get in Phase?

How do we get in phase with the antenna requirement that would allow us to use the satellite over 70+% of the orbit and yet still have sufficient gain to close the links on the ACP. We have looked at the two options that are open to us. We use the spacecraft as an antenna rotator. This is called three-axis stabilization. The spacecraft would have to be rocked back and forth in the orbit to accommodate the elliptical orbit and we would have to use the magnetic attitude control systems much more often (high power consumer) to keep this system usable since it would depend on momentum wheels to do this antenna rotator.

The sensors needed to control a three axis stabilized spacecraft are simply outside of the engineering reach of our volunteers to build in the basement or even their workplace and we do not have the budget to have a unique, one-off design of this built for our spacecraft at this time.

The last remaining option that we could see as usable by us would allow us to not do three-axis stabilized spacecraft. We can continue to spin stabilize the spacecraft as we have all other P3 birds. We decided to attempt to use phased arrays for the ACP. This means that we will steer the antennas electrically and not by using a mechanical rotator. Given the nature of the phased arrays, we are inevitably pushed to use microwaves because of the gain, number of amplifiers, and myriad other factors.

The communications engineers at San Diego assure us we can easily build these phased arrays and our volunteers living in San Diego have a fantastic design and testing facility at their work place and have made it available to us to perfect the phased arrays. The operator of the antenna facility has assured us that we can do this phased array and we believe it. This electrical steering will allow us to achieve the 70% orbit usage. Should we fail, the antennas will revert to being usable in the period around apogee so we have a graceful fall back to failure of this system.

We also decided that we could not do the text messaging service on the ACP because it would consume in excess of 50% of the available power. But we can have a very creditable small hand-held service inside the U/V and L/S transponders. But these transponders need real antennas and real power to make this happen. It was decided they will get much more than we were capable of doing on the older Eagle concept.

9 What Does it Look Like Now?

Since we needed a new physical structure, one that would accommodate larger and more antennas and larger solar array area, we just took the plunge. We also wanted to keep the spacecraft structure to around "four feet" across and light enough that three people can pick the thing up when it is not fueled.

Last January, Matt Ettus, N2MJI, Frank Brickle, AB2KT, and I traveled to Reno to work with Eric Blossom, K7GNU who is GnuRadio project leader, Eagle team member, and one of the San Diego designers. We were working on the foundations of many of the things we will need to construct the ACP and the ground station equipment to use it.

Matt asked me could we change the shape and he suggested a shape. It was immediately clear to me from a small set of calculations that we could put better antennas, larger solar panels, and improve the stability of the frame for use of a rocket motor. I drew up a rough design and asked Dick Jansson, WD4FAB, to produce a quick picture of the beast. Dick had it done in an hour.

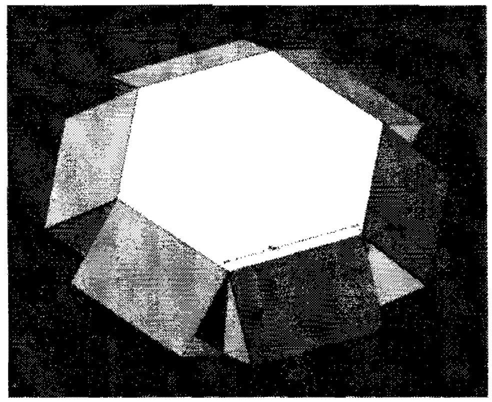

Figure 11: New Eagle Concept (N2MJI and N4HY)

This basic concept solves all of the known problems facing us. We will fly with the panels folded in to have a smaller envelope and these moving parts do worry us but we will test them and the design of them until we are absolutely certain that they will deploy. The space in the gaps will be used for sensors and more. Our analysis shows that should we fail to deploy, the mission will be compromised but not ended.

10 Antennas and Power Needed, Part II

With the basic design in figure 11, we can generate more power than we can use when the sun is facing the edge. When the sun is looking down on top of the spacecraft or at the bottom (motor) end, we will generate ample power to run all the communications packages. The advance in solar cell technology to *triple-junction GaAs* has achieved efficiencies in the mid-20's percent conversion efficiency. We hope to use the excess power available during just under half of the year to power "paying customers" in This Space For Rent modules (TSFR) and while running everything we have at full speed. This might wind up being one of the two linear transponder transmitters rather than one but one will always run.

We need a phased array for 3.4 GHz for uplink. We need a phased array for 5.8 GHz on the downlink. They both need to be 18 dBi gain to illuminate the earth at apogee and minimize the power heating up space. We need usable antennas for 2 meters, 70cm, 23cm, and 13cm to provide for the U/V, L/S linear transponders as well as the L input for the ACP. Can we do it with the new structure? We can. See Figure 12.

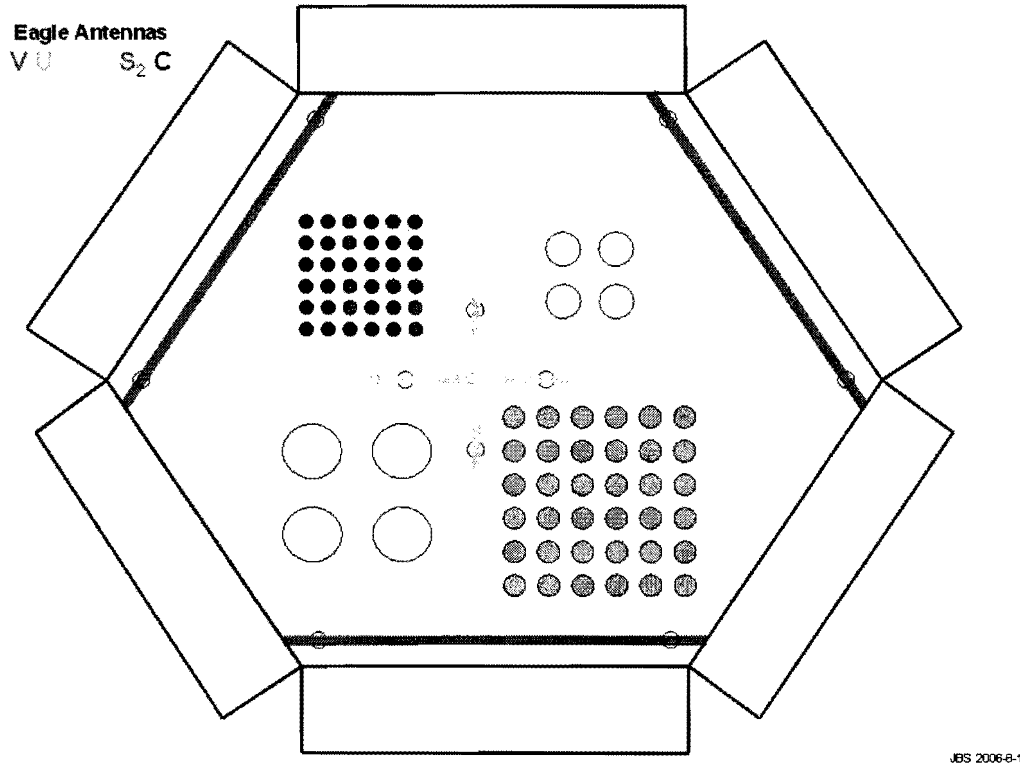

Figure 12: Antenna concept for Eagle (KD6OZH)

Thanks to John Stephensen, KD6OZH, we have an outstanding receiver design for 70cm. Thanks to Marc Franco, N2UO, we have an outstanding amplifier design we will be testing for 2 meters. Stephen Hendricks, a senior engineering student at TCNJ and employee of Al Katz, K2UYH, has an outstanding S band amplifier design and one which was awarded an honorable mention in an amplifier contest by the internationally known power amplifier expert, Steve Cripps.

Howard Long, G6LVB, Lyle Johnson, KK7P, Frank Brickle, AB2KT, and I have been working steadily towards the design of the software defined transponder. It will provide for a "per signal" AGC as a major advance over LEILA which was flown on AO-40. This already functions in a prototype. We have tested the transponder digital signal processor and hardware similar to that proposed for the SDX mixers at Dayton. Tom Clark, K3IO and the author assembled and tested a working SDX system at Dayton. The RF horror show at Dayton could not collapse or even interfere with the SDX operations.

KD6OZH has given us a beautiful high dynamic range, high IP3 70cm receiver design which will provide for the best ever immunity from PAVE PAWS radar since we will be using similar clipping techniques to those developed by Karl Meinzer, DJ4ZC for earlier Phase 3 birds but because of the high dynamic range receiver, many of the pulses will not result in clipping. These will be additionally mitigated by "pulse subtraction" algorithms running in the SDX DSP.

The SDX will provide for the best possible HELAPS (high efficiency amplifier) given the current state of technology because we will be able to do smart things in the DSP to aid HELAPS have better intermodulation distortion at a very small sacrifice in efficiency. However, modern devices are getting huge efficiencies in comparison to the old transistor technology used in earlier Phase 3 spacecraft.

Matt Ettus is designing the ACP along with other DSP types. Frank Brickle is designing the SMS text like service. We have a spacecraft concept.

11 Conclusions

We have spent a year doing a complete rework of the Eagle spacecraft concept. We are ready to begin building real hardware for engineering analysis and proof of concepts. We have stepped up to the plate and hit a grand slam in the author's opinion. We need your emotional and financial support to make the coming year a major success.

12 References

- Report of the San Diego Communications Package Design meeting: http://www.amsat.org/amsat-new/eagle/EaglePedia/index.php/San_Diego_Digital_Meeting
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- CC-Rider concept: http://www.amsat.org/amsat-new/eagle/EaglePedia/index.php/C-C_Rider_Introduction, K3IO
- SDX first noise: ftp://ftp.cnssys.com/pub/amsat/Eagle_SDT_1st_Contact.mp3, W2GPS

Amateur-Satellite Spectrum

Presented by

Paul L. Rinaldo, W4RI

Abstract

This paper reviews the Amateur-Satellite radiofrequency spectrum, its origins, the status of allocations and possibilities for improvement.

The Amateur-Satellite Service allocations ranging from 1260 MHz to 10.5 GHz are in trouble. Each band has a different story. This paper documents the situations in each of the Amateur-Satellite bands and, where possible, provides conclusions and recommendations. It shows the international allocations as they appear in the International Telecommunication Union *Radio Regulations* along with footnotes related to Amateur-Satellite Service allocations. The relevant texts from the IARU Spectrum Requirements document are included. Known threats to each band are shown.

About the Author

Paul Rinaldo, W4RI, is Chief Technology Officer of the American Radio Relay League (ARRL), the national association for Amateur Radio. He is also an Expert Consultant of the International Amateur Radio Union (IARU). His duties include U.S. Government relations on domestic and international Amateur Radio matters, including work with the International Telecommunication Union (ITU) and the Inter-American Telecommunication Commission (CITEL). He was elected to the Board of Directors of the United States ITU Association (USITUA). He is a member of the IEEE-USA Committee on Communications and Information Policy. He was first licensed in 1949. Rinaldo came to work for ARRL in 1983 as Manager of its Technical Department. He went on to become the Publications Manager and Editor of *QST*.

He currently serves as Chairman of ITU-R Working Party 8A Working Group 1, which is responsible for technical studies related to the amateur and amateur-satellite services. As such, he was responsible for studies on 7 MHz and revision of Article 25 leading to the 2003 World Radiocommunication Conference (WRC-03). He has participated in two ITU Plenipotentiary Conferences, six WRCs, all Radiocommunication Assemblies since the early 1990s, numerous Working Parties and Task Groups, and related U.S. preparatory meetings.

He served as Chairman of the ARRL Digital Committee, responsible for development of the amateur packet radio standard AX.25. He has participated on a number of ARRL committees, including the Technology Task Force and has been responsible for the Digital Voice, High Speed Multimedia and Software Defined Radio Working Groups.

He studied Radio Engineering at Valparaiso Technical Institute in Indiana, and is a Life Senior Member of the Institute of Electrical and Electronics Engineers (IEEE). He is President of the Amateur Radio Research and Development Corporation (AMRAD) and is AMSAT LM-36.

1 Origins of the Amateur-Satellite Spectrum

Amateur-Satellite Service frequency allocations originate from the International Telecommunication Union (ITU). The First International Telegraph Convention signed in Paris, in 1865, established the International Telegraph Union (ITU). In 1906, the First International Radiotelegraph Conference was held in Berlin. This Conference established the first regulations governing wireless telegraphy. Subsequently, numerous radio conferences revised what became known as the *Radio Regulations.*

The 1932 Madrid Conference combined the International Telegraph Convention of 1865 and the International Radiotelegraph Convention of 1906 to form the International Telecommunication Convention, and changed the name to International Telecommunication Union.

The 1947 Atlantic City Conference was held with the aim of developing and modernizing the organization. The ITU becomes a UN specialized agency. The Table of Frequency Allocations, introduced in 1912, is declared mandatory.

In 1959, the ITU established a study group responsible for studying space radiocommunication.

In 1963 (Geneva), the ITU held an Extraordinary Administrative Conference for space communications to separate space services from terrestrial services and allocate frequencies to the space services. The 1963 World Administrative Radio Conference (WARC-63) created a footnote, reading: "In the band 144-146 MHz, artificial satellites may be used by the amateur service." The 1971 Space WARC created the Amateur-Satellite Service and made frequency allocations to the new service.

Generally speaking, the Amateur-Satellite Service bands are a subset of the bands allocated to the Amateur Service on a primary or secondary basis. In some cases, there are allocations to the Amateur-Satellite Service by footnote subject to not causing harmful interference to other services; neither can it claim protection from harmful interference caused by the other service or other stations in the same service.

- International uses of the radio spectrum are regulated by the International Telecommunication Union (ITU), via the *Radio Regulations*. They constitute an International Treaty on Radiocommunications covering the use of the radio-frequency spectrum by Radiocommunication Services.
- The International Table of Allocations is Article 5 of the Radio Regulations.
- Countries are sovereign regarding their use of the radio spectrum. Within national borders countries do not have to follow the International Table of Allocations. While domestic allocations can be used for the Amateur (terrestrial) Service, they do not offer a basis for Amateur-Satellite Service allocations, which are international by their very nature.
- The interests of the Amateur-Satellite Service are represented to the ITU by the International Amateur Radio Union (IARU). The IARU participates in relevant Working Parties, Task Groups, Conference Preparatory Meetings and World Radiocommunication Conferences.

2 Present Amateur-Satellite Service Allocations

7000-7100 kHz (40 m) - 24890-24990 kHz (12 m)

These HF bands are allocated to the Amateur-Satellite Service. They are not presently in use in any amateur satellite.

Allocation to services		
Region 1	**Region 2**	**Region 3**
7 000-7 100	AMATEUR AMATEUR-SATELLITE 5.140 5.141 5.141A	
14 000-14 250	AMATEUR AMATEUR-SATELLITE	
18 068-18 168	AMATEUR AMATEUR-SATELLITE 5.154	
21 000-21 450	AMATEUR AMATEUR-SATELLITE	
24 890-24 990	AMATEUR AMATEUR-SATELLITE	

28-29.7 MHz (10 m)

This 29.3-29.510 MHz segment is presently used in some amateur satellites.

Allocation to services		
Region 1	**Region 2**	**Region 3**
28-29.7	AMATEUR AMATEUR-SATELLITE	

144-146 MHz (2 m)

The segment 145.8-146 MHz is heavily used by amateur satellites.

Allocation to services		
Region 1	**Region 2**	**Region 3**
144-146	AMATEUR AMATEUR-SATELLITE 5.216	

435-438 MHz (70 cm) - 5650-5670 and 5830-5850 MHz (5 cm) (C band)

The band 435-438 MHz and 1260-1270 MHz are heavily used by amateur satellites.

<table>
<tr><th colspan="3">Allocation to services</th></tr>
<tr><th>Region 1</th><th>Region 2</th><th>Region 3</th></tr>
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AMATEUR
RADIOLOCATION
Earth exploration-satellite (active) 5.279A
5.138 5.271 5.272 5.276
5.277 5.280 5.281 5.282</td><td colspan="2">432-438
RADIOLOCATION
Amateur
Earth exploration-satellite (active) 5.279A
5.271 5.276 5.277 5.278 5.279 5.281 5.282</td></tr>
<tr><td>1 240-1 300</td><td colspan="2">EARTH EXPLORATION-SATELLITE (active)
RADIOLOCATION
RADIONAVIGATION-SATELLITE (space-to-Earth) (space-to-space)
5.328B 5.329 5.329A
SPACE RESEARCH (active)
Amateur
5.282 5.330 5.331 5.332 5.335 5.335A</td></tr>
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FIXED
MOBILE
Amateur
Radiolocation
5.150 5.282 5.395</td><td colspan="2">2 300-2 450
FIXED
MOBILE
RADIOLOCATION
Amateur
5.150 5.282 5.393 5.394 5.396</td></tr>
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5.149 5.429 5.430</td><td>3 300-3 400
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Fixed
Mobile
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RADIOLOCATION
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5.149 5.429</td></tr>
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Mobile
Radiolocation
5.431</td><td colspan="2">3 400-3 500
FIXED
FIXED-SATELLITE (space-to-Earth)
Amateur
Mobile
Radiolocation 5.433
5.282 5.432</td></tr>
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MOBILE except aeronautical mobile 5.446A 5.450A
Amateur
Space research (deep space)
5.282 5.451 5.453 5.454 5.455</td></tr>
<tr><td>5 725-5 830
FIXED-SATELLITE (Earth-to-space)
RADIOLOCATION
Amateur
5.150 5.451 5.453 5.455 5.456</td><td colspan="2">5 725-5 830
RADIOLOCATION
Amateur
5.150 5.453 5.455</td></tr>
</table>

Allocation to services		
Region 1	**Region 2**	**Region 3**
5 830-5 850 FIXED-SATELLITE (Earth-to-space) RADIOLOCATION Amateur Amateur-satellite (space-to-Earth) 5.150 5.451 5.453 5.455 5.456	**5 830-5 850** RADIOLOCATION Amateur Amateur-satellite (space-to-Earth) 5.150 5.453 5.455	

5.282 In the bands 435-438 MHz, 1 260-1 270 MHz, 2 400-2 450 MHz, 3 400-3 410 MHz (in Regions 2 and 3 only) and 5 650-5 670 MHz, the amateur-satellite service may operate subject to not causing harmful interference to other services operating in accordance with the Table (see No. **5.43**). Administrations authorizing such use shall ensure that any harmful interference caused by emissions from a station in the amateur-satellite service is immediately eliminated in accordance with the provisions of No. **25.11**. The use of the bands 1 260-1 270 MHz and 5 650-5 670 MHz by the amateur-satellite service is limited to the Earth-to-space direction.

10.45-10.5 GHz (3 cm) (X band)

Allocation to services		
Region 1	**Region 2**	**Region 3**
10.45-10.5	RADIOLOCATION Amateur Amateur-satellite 5.481	

24-24.05 GHz (1.2 cm) (K band)

Allocation to services		
Region 1	**Region 2**	**Region 3**
24-24.05	AMATEUR AMATEUR-SATELLITE 5.150	

5.150 The following bands:

... 24-24.25 GHz (centre frequency 24.125 GHz) ...

are also designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within these bands must accept harmful interference which may be caused by these applications. ISM equipment operating in these bands is subject to the provisions of No. **15.13**.

47-47.2 GHz (6 mm) (V band)

Allocation to services		
Region 1	**Region 2**	**Region 3**
47-47.2	AMATEUR AMATEUR-SATELLITE	

76-81 GHz (4 mm) (W band)- 241-250 GHz (1 mm)

Allocation to services		
Region 1	**Region 2**	**Region 3**
76-77.5	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-satellite Space research (space-to-Earth) 5.149	
77.5-78	AMATEUR AMATEUR-SATELLITE Radio astronomy Space research (space-to-Earth) 5.149	
78-79	RADIOLOCATION Amateur Amateur-satellite Radio astronomy Space research (space-to-Earth) 5.149 5.560	
79-81	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-satellite Space research (space-to-Earth) 5.149	
134-136	AMATEUR AMATEUR-SATELLITE Radio astronomy	
136-141	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-satellite 5.149	
241-248	RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-satellite 5.138 5.149	
248-250	AMATEUR AMATEUR-SATELLITE Radio astronomy 5.149	

3 Challenges to Amateur-Satellite Service Allocations

Most threats to Amateur-Satellite Service allocations are the result of actions by individual administrations to allocate spectrum to other users. An exception is the band 1260-1270 MHz, which is within the frequency range used by the European Galileo radionavigation satellite system.

3.1 1260-1270 MHz (23 cm) (L band)

There are a number of documents regarding Galileo frequencies available on the Web.[1] Unfortunately, the band 1260-1270 MHz is in the Galileo E6 frequency band that occupies the band 1260-1300 MHz. The German administration decided that the band 1247-1263 may not be used by automated stations and that the EIRP is limited to 5 W, which will make it impractical for German amateurs to use these frequencies.

ITU studies have concentrated on the potential interference from Galileo to terrestrial radars. These studies have not assessed potential interference to the Galileo system from Amateur-Satellite Earth-to-space transmissions.

3.2 2400-2450 MHz (13 cm) (S band)

This band is occupied by Industrial, Scientific and Medical (ISM) devices including microwave ovens and low-power emitters in the band 2400-2483.5 MHz. The low-power devices include a prolific number of IEEE 802.11b/g local area networks. Cordless phones still operate in this band. There has been a migration to 5 GHz as the 2.4 GHz band has been heavily used.

3.3 3400-3410 MHz (9 cm) (S band)

Radio Regulations footnote 5.282 permits amateur-satellite operation only in Regions 2 and 3. The European Table of Frequency allocations footnote EU17 states as follows:

> In the subbands 3400-3410 MHz, 5660-5610 MHz, 10.36-10.37 GHz, 10.45-10.46 GHz the amateur service operates on a secondary basis. In making assignments to other services, CEPT administrations are requested wherever possible to maintain these sub-bands in such a way as to facilitate the reception of amateur emissions with minimal power flux densities.

However, EU17 does not provide a basis for amateur-satellite operation.

There are sharing studies ongoing within the ITU of the band 3400-3700 MHz (and others) for potential use by the 4th generation of mobile cellular telephones known as IMT-Advanced. Use of the band 3400-3410 MHz for cellular telephony may pose difficulties for amateur satellites. This band is also under consideration for wireless access systems.

3.4 5650-5670 MHz Earth-to-space and 5830-5850 MHz space-to-Earth

These bands are subject to growing use by low-power devices.

3.5 10.45-10.5 GHz

In a publication dated 28 June 2006, the UK administration (Ofcom) proposed auctioning the upper 25 GHz. See http://www.rsgb.com for details.

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[1] Hein, et al, *Status of Galileo Frequency and Signal Design*

4 Some Potential Improvements in Amateur-Satellite Spectrum

Improvements in Amateur-Satellite Service allocations need to be made by the ITU on a global basis. New allocations or modifications of existing ones could take as long as about 15 years, so such an effort should not be undertaken lightly. The IARU represents the interests of the Amateur Services to the ITU.

4.1 Possibility of an Amateur-Satellite Allocation at 50 MHz

50 MHz (6 m) has been mentioned as a potential new band for the Amateur-Satellite Service. The Amateur Service has an allocation of 50-54 MHz in Regions 2 and 3. A goal of the IARU is to obtain an allocation of at least 2 MHz in Region 1. The European Common Allocation Table allocates the band 50-52 MHz to the Amateur Service in Europe. This would satisfy only terrestrial amateur uses but not amateur-satellites unless an allocation is made to the Amateur-Satellite Service. It would be less difficult to seek an Amateur-Satellite Service allocation in the Earth-to-space direction than in the space-to-Earth direction because the latter would have more potential for interference to other radio services using the band.

4.2 Study of the Band 1260-1270 MHz

A suggestion has been made to consider an alternative allocation in the 1240-1250 MHz band to avoid Galileo E6 band (1260-1300 MHz). This would require extensive study and consideration of plans of the Radionavigation-Satellite Service (RNSS), and would be subject to a future WRC. A shorter term solution might be to conduct a sharing study with RNSS interests for the continued use of the band 1260-1270 MHz by the Amateur-Satellite Service.

4.3 An Alternative to the Band 3400-3410 MHz

It has been noted that the Amateur-Satellite allocation exists only in Regions 2 and 3. The possibility of extending that allocation to Region 1 or an alternative Amateur-Satellite Service allocation just 3400 MHz could be studied. Either solution would require lengthy ITU studies and action by a future WRC.

4.4 Bands of 5 GHz and above

There do not appear to be opportunities for improvement of Amateur-Satellite Service allocations in bands of 5 GHz and above. These frequencies are highly sought after by other services for satellite and terrestrial applications. Actions of individual administrations to reallocate Amateur and Amateur-Satellite Service spectrum to other uses should be closely monitored.

5 Relevant IARU Documents[2]

5.1 Representation to Administrations

RESOLUTION 86-3
(Revised 1989)

Concerning guarantee of the exclusive right of a member-society to represent the IARU to its government

Resolved by the IARU Administrative Council, Buenos Aires, October 1986,

That no Member-Society, Regional Organization, or the Administrative Council shall communicate with any government department (including the Telecommunications Administration) of a country or territory represented by an IARU Member-Society if this interferes with the exclusive right of that Society to represent amateur radio in that country or territory.

Should there be any doubt about such a communication the opinion of the Member-Society involved shall be respected -- unless the Administrative Council believes that the Society is acting contrary to the interests of amateur radio of the IARU *or* no longer represents the interests of radio amateurs in its country or territory.

5.2 Terms of Reference of the IARU Satellite Adviser

IARU Satellite Adviser
(Adopted 1995; Amended 2001)

General:

An advisory and representational role requiring technical knowledge and good interpersonal skills.

Function:

To keep the Administrative Council informed on all technical and operational aspects of the amateur-satellite service, and to provide advice and assistance to enable the Council to adopt appropriate policies, and also to better inform the satellite community of the IARU.

Appointment:

The IARU Satellite Adviser shall be appointed by the Administrative Council. The term shall be three years. At the meeting of the Administrative Council corresponding to the expiration of the term, the Council may or may not reconfirm the position, its terms of reference, and the appointment thereto.

Tasks:

Report to the Administrative Council, providing information as to all developments in the satellite area, including all planned amateur satellites.

At the request of the Administrative Council, provide technical and operational advice to assist the representation of the amateur satellite service to the ITU.

And attend such meetings of the satellite community as appropriate.

Represent generally the IARU to the satellite community and particularly to new or non-Amsat satellite groups.

To consult with and liaise with the satellite Community as appropriate.

To appoint any assistants that may be required.

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[2] IARU resolutions and terms of reference are available at http://www.iaru.org/ac-respol.html.

International Satellite Frequency Coordination Benefits All Radio Amateurs

Presented by

Hans van de Groenendaal, ZS6AKV

IARU Satellite Adviser

zs6akv@amsat.org

www.amsatsa.org.za

1 Background

Following the increase in the number of organisations building and launching satellites operating on frequencies allocated to the amateur-satellite service, various attempts were made to introduce a coordination system. This led to the appointment of the IARU Satellite Adviser who is responsible to the IARU Administrative Council and charged with the task to work closely with AMSAT and other organisations to provide a coordination facility and a link to the IARU.

Various processes were followed, including the appointment of a Satellite Frequency Coordinator who reported to the IARU Satellite Adviser. This did not work too well as a single person was not always able to take a world view. In addition, the volume of work had grown well beyond the ability of two volunteers to handle it.

Some years back, following recommendations by the IARU Satellite Adviser to the IARU AMSAT International Forum, held in alternate years in conjunction with the AMSAT UK Colloquium and the AMSAT NA Space Symposium, an Advisory Panel was introduced. Over the past four years this panel has developed a transparent process that has greatly enhanced the coordination of frequencies for satellites that operate on frequencies allocated to the amateur satellite service. Credit is due to the unstinting amount of time and effort the Panel has put into it.

Currently the panel is as follows:

Convener
Hans van de Groenendaal, ZS6AKV
Region 1
Graham Shirville, G3VZV
Norbert Notthoff, DF5DP
Region 2
Roy Soifer, W2RS
Art Feller, W4ART
Region 3
Jan King, VK4GEY

Region 3 has been invited to appoint an additional person.

Panel members were chosen for their expertise and experience on recommendation from the regional IARU organisations and AMSAT groups.

2 Changing Environment

At one stage only satellites operating on frequencies allocated by the ITU to the amateur-satellite service were designed, built and launched by AMSAT groups in various countries. Other institutions such as Universities, Technical Colleges and National Space Agencies are now showing a growing interest in small satellites as educational and development projects. Many of these satellites are "scientific birds" used for research into scientific principles that have little or nothing to do with amateur radio, or are "educational birds" primarily intended to train students in satellite engineering, yet they will operate on frequencies allocated to the amateur-satellite service.

Different countries have different views on how amateur frequencies may be used and many encourage educational institutions to do so. In some areas of the world, even projects that border on commercialisation are licensed to operate on amateur frequencies.

This has raised the question of when is a satellite an amateur satellite. There are many different views around the subject. I however believe that the answer can be found in the ITU Radio Regulations:

Here are the relevant definitions from the ITU Radio Regulations:

Article 1

1.56 *amateur service.* A *radiocommunication service* for the purpose of self-training, intercommunication and technical investigations carried out by amateurs, that is, by duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest.

1.57 *amateur-satellite service.* A *radiocommunication service* using *space stations* on earth satellites for the same purposes as those of the *amateur service.*

Certain other regulations are also worth noting as they relate to the purposes for which an amateur station, satellite or otherwise, can be operated:

Article 25

Section I

25.1 Radiocommunication between amateur stations of different countries shall be permitted unless the administration of one of the countries concerned has notified that it objects to such Radiocommunications.

25.2 Transmissions between amateur stations of different countries shall be limited to communications incidental to the purposes of the amateur service, as defined in No. 1.56 and to remarks of a personal character.

25.2A Transmissions between amateur stations of different countries shall not be encoded for the purposes of obscuring their meaning, except for control signals exchanged between earth command stations and space stations in the amateur-satellite service.

25.3 Amateur stations may be used for transmitting international communications on behalf of third parties only in cases of emergencies or disaster relief. An administration may determine the applicability of this provision to amateur stations under its jurisdiction.

Section II

25.10 The provisions of section 1 of this article shall apply equally, as appropriate, to the amateur-satellite service.

It is sometimes difficult to determine whether a particular satellite that is intended to operate in the amateur-satellite segments should be licensed in the amateur-satellite service or as an experimental station. However, that is a matter for the licensing administration. The advisory panel believes that it is appropriate that such satellites be coordinated, since the benefits of doing so outweigh the potential disadvantages.

Whether such satellites are licensed as amateur or as experimental stations is for the authorizing administration to determine. There is no point in attempting to second-guess that determination. In either case, if the satellites are operating in the amateur bands it is desirable that their operation be coordinated in order that their operation is confined to the amateur-satellite allocations and is conducted so as to minimize the possibility of harmful interference to (other) amateur satellites.

The request for coordination of satellite frequencies is by completing the coordination form which is available on www.iaru.org/satellite. The preamble to the form sets out the various conditions. A wealth of other information of interest to satellite builders is available on above URL.

In the panel's interaction with non-amateur organisations building small satellites that operate on amateur frequencies, it became apparent that many had limited knowledge about amateur radio and about amateur radio's involvement in satellite communication and the level of technological expertise that had been developed since the launch of OSCAR 1 in 1959.

Individual panel members are doing a great job interfacing with Universities and the small satellite industry and other interest groups highlighting the AMSAT message: "*Amateurs pioneered the small satellites, industry followed.*"

3 The Frequency Coordination Process

Prospective builders complete a form with as much detail as possible. This is studied by the Panel. Copies of the requests are sent, for comment, to the National Society and the AMSAT organisation in the country where the request originated.

The panel discusses the validity of the request and interact with the various role-players to achieve a common understanding. Where a satellite is strictly non-amateur every effort is made to convince the requester to seek alternative frequencies. This is however not always possible. The coordination process is set into action the panel selects the best possible frequencies and proposes these to the requester.

The process is transparent and regular updates are posted on a website hosted by AMSAT UK. (Linked from www.iaru.org/satellite)

The panel monitors the progress of the project and, where appropriate and offers advice.

Many educational institutions have little or no idea of how the Amateur and Amateur satellite service operates. How radio amateurs do band planning to ensure maximum usage of the allocated frequency spectrum and how limited the resource really is. Often the same frequency has to be coordinated for a number of satellites because there simply is not enough spectrum available. This process is carried out with lots of thought, study of the orbit and the type of usage and ground station location.

4 National Society Support is Needed

Even considering the potential opportunities which educational satellite projects can provide for legitimate amateur satellite activities as well as the role of educational institutions in training and motivating new generations of amateur radio space enthusiasts, the danger of overcrowding amateur frequencies exists.

IARU member Societies have thus an important role to play:

Firstly,
Member Societies should work with those in their country who are responsible for satellite projects intended for operation in the amateur bands to educate them about how appropriate frequency planning will benefit their projects.

Secondly,
Member Societies should work with their national administration to promote the proper use of amateur frequencies in accordance with the Radio Regulations.

Thirdly,
Engage with educational institutions to create an understanding of the amateur service and to encourage prospective satellite project teams to study the IARU paper on "What is an Amateur Satellite".

The Three SSETI Space Missions

Presented by

Graham Shirville, G3VZV

(with acknowledgement to the many SSETI team members)

Abstract

This paper describes SSETI Express satellite which was launched from Plesetsk in Northern Russia during October 2005, identifies the high level of media and student interest and the invaluable support obtained from the many radio amateurs around the world who received the vital telemetry data immediately after launch. It also describes the results of the flight analysis conducted by ESA and SSETI and give first details of the planned "Lessons Learnt" knowledgebase.

The upcoming GTO ESEO mission, which is planned for a late 2008 launch and which will carry a linear U/S amateur transponder, is also discussed and, additionally, brief details of the ESMO moon orbiter plans are provided.

SSETI - The Student Space Exploration & Technology Initiative

About the Author

I have been a licensed amateur for "many" years and claim to have received signals from Sputnik 1 before I was 10 years old. Whether or not I actually detected the signals, the experience has inspired my interest in space and satellites from that time forward. I am presently a committee member of AMSAT-UK and support the IARU satellite frequency coordination team. I am also The IARU Region 1 Satellite Coordinator but my involvement with the SSETI Express and ESEO missions have been my most exciting space experiences so far!

1 SSETI as described at www.sseti.net

The Student Space Exploration and Technology Initiative

The Student Space Exploration and Technology Initiative (SSETI) was created by the ESA Education Department in 2000, in order to actively involve European students in real space missions. The aim is to give students practical experience and to enhance their motivation to work in the fields of space technology and science, thus helping to ensure the availability of a suitable and talented workforce for the future.

The main goal of the SSETI Program is to become a support and facilitation network for all student spacecraft related activity and education throughout Europe, focusing primarily on hands-on involvement of students in real space missions, including micro-, nano- and pico-satellites and various payload opportunities.

From work performed so far, it is clear that high levels of academic expertise in specific space-related fields exist throughout European universities. However, these units currently operate independently of each other and are too small for an autonomous satellite project. The SSETI Program is able to combine these isolated centers of expertise, giving students access to a powerful network, capable of designing, constructing and operating intricate and interesting student spacecraft and payloads.

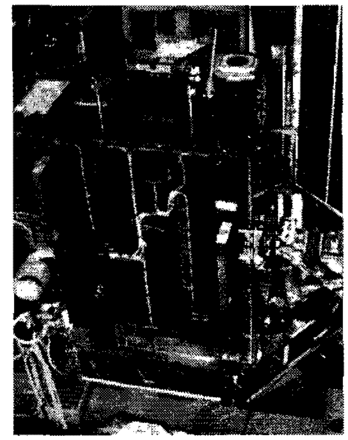
The aim of the SSETI Program is realized through team-based student work on specific satellite projects, in cooperation with the ESA Education Department (which provides technical and managerial coordination) and with support from many ESA and industry experts. A dedicated website has been implemented together with specific Internet-based communication tools, all of which are extremely efficient in facilitating coherence and permanent contact among the student teams.

Since its creation, the SSETI Program has developed a network of students, educational institutions and organizations to facilitate work on the various spacecraft projects. More than 400 European students have made an active, long-term contribution to these spacecraft, either as an official part of their degree or in their spare time. In addition, many hundreds more have been involved with or inspired by SSETI.

The continued interaction of SSETI alumni with the SSETI network will act for the mutual benefit of themselves, ESA, European industry and the SSETI Program. The experience and knowledge gained by the students will ensure a rich and fruitful recruitment ground for ESA and the space sector in general.

2 SSETI Express

This was the first SSETI mission and had the following parameters:

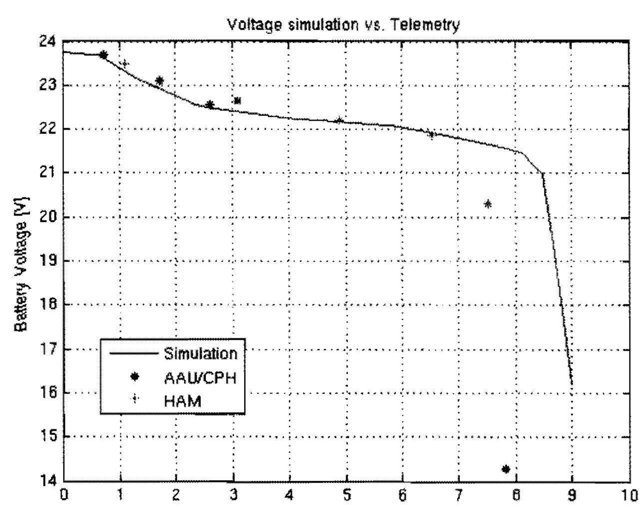


SSETI Express on the launch adaptor

- **Manpower:** Approx. 100 students in 14 university teams
- **Management:** One YGT / Contractor (N. Melville), no prime contractor
- **Project kick-off:** 27th January 2004
- **Flight Readiness:** 27th July 2005
- **Dimensions:** 60x60x70cm, **Mass:** 62 kg
- **Orbit:** 98° Sun-Synchronous, 686 km, ~98 minute period, ~34% eclipse
- **Stabilization:** Quasi-active 2-axis magnetic
- **Communications:** RX/TX UHF @ 437.250MHz, TX S-Band @ 2401.835MHz
- **Groundstations:** Aalborg, Svalsat, Copenhagen
- **Budget:** ~ €1,000,000 (all in)• **Launcher:** Cosmos DMC-3 with SSTL, from Plesetsk (65.5°N)
- **Launch:** 27th October 2005 06:52:26 UTC

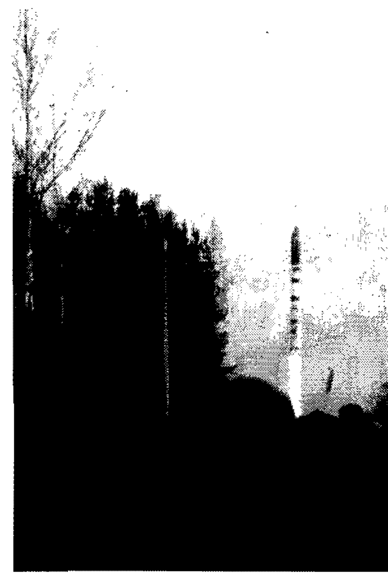
The plan was for the three cubesats to be deployed, the on board camera to be exercised and the pictures downlinked using 38k4 on the S band transmitter, cold gas attitude control thrusters to be tested and a number of experiments completed before using the communications equipment as a FM U/S transponder. The launch was flawless and strong UHF beacon signals were received by numerous stations exactly when expected 100 minutes after lift-off. The command station at Aalborg successfully sent commands to the satellite even though it was still tumbling and it was noted that the battery voltage at 23.7V was lower than expected. The two subsequent passes over Europe showed that the voltage was continuing to drop and after that time the only data coming back was that obtained via radio amateurs in other parts of the world. This was exceptionally strong evidence of the power of our "network". A pass over the command station about 8 hours after launch indicated a battery voltage of only 14 volts and only unconfirmed reports of signals were received after that.

This graph shows the battery voltage readings received from the spacecraft together with the results of a subsequent simulation undertaken on the basis that no power was reaching the battery from the solar array.



Thermal Measurements from the spacecraft during the flight strongly imply that there was significant unexpected heating of the Electrical Power Subsystem (EPS), even though the rest of the spacecraft cooled to sub-zero and was stable.

Laboratory Reconstruction Laboratory reconstruction of the voltage regulator have reproduced the most likely failure, in the excess power dissipation system. Original tests were done in air, but vacuum tests were possible during the Workshop at ESTEC, dramatically increasing the fidelity of the reconstruction.



The Express launch from Plesetsk

Assumptions:

- Full sunlight for 47 minutes before activation
- Negligible power consumption during the coast phase
- In full sunlight peaks of 25W must be dissipated

Result

- One of the MOSFETs on the voltage regulator short-circuited after 43.5 minutes

Probable Failure Scenario

- After separation the EPS hardware timers held the spacecraft off for 65 minutes, as designed, for the safety of the other passengers on the launch vehicle.
- The thermal design of the EPS did not provide sufficient heat flux away from the MOSFETs in the shunt system, causing them to overheat.
- During this time the spacecraft spent 47 minutes in sunlight with the solar arrays sourcing full power, which needed to be dissipated, since the spacecraft was turned off and consuming nothing.

Tests undertaken relevant to the Electrical Power System prior to launchFunctional testing

- Timer functionality for coast phase
- Solar array simulator (current source)
- Solar array illumination tests (mid-power)
- Battery charge regulator and voltage regulator

Thermal Vacuum Testing

- Four thermal cycles with functional checks using a current source solar array simulator
- Timers were skipped to meet the schedule but without simultaneous solar simulation these tests would have been uneventful
- Only a full test involving the timers, solar array simulator and vacuum simultaneously would have exposed the failure. Only a full solar illumination test would have given complete confidence

Specific Lessons Learned

Manpower:

- More manpower is required than a single individual working on both Management and System Engineering Continuity in project management is essential
- More professional support from ESTEC experts is required

Reviews:

- Expedient and focused Critical Design Review should have been performed
- As a minimum a careful peer review should have been performed

Testing:

- Take as much time as it needs, don't cut corners
- Test in FULL context, over all extreme configurations

Components:

- Operational ranges must be scaled appropriately when using non-space-qualified components
- In the preliminary design phase a list of project-suitable component specifications should be defined

Hundreds of lessons learned have been defined and iterated by the project teams and will form the basis of a dynamic, online SSETI Knowledge Base, accessible to future SSETI projects and to the educational space community in general

Subsystem Performance

Subsystem	Source	Mission Rating
Attitude Control & Determination	University of Aalborg, Denmark	*Success*
Camera	University of Aalborg, Denmark	*Untested*
Electrical Power System	University of Naples, Italy	***Failure***
Groundstation (Primary)	University of Aalborg, Denmark	*Success*
Groundstation (Secondary)	Svalsat, Norway	***Failure***
Groundstation (Tertiary)	Eng. School Copenhagen, Denmark	*Success*
Mission Analysis	University of Zaragoza, Spain	*Success*
Mission Control Computer	University of Aalborg, Denmark	*Success*
Propulsion Instrument Control	EPFL, Switzerland	*Untested*
Operations	University of Warsaw, Poland	*Success*
On-Board Computer	University of Aalborg, Denmark	*Success*
Propulsion	University of Stuttgart, Germany	*Untested*
S-Band Antennas	University of Wroclaw, Poland	*Untested*
S-Band Transmitter	AMSAT-UK	*Untested*
Structure	University of Porto, Portugal	*Success*
Telemetry Interface Database	AFTI, France	*Success*
Temperature Control System	University of Stuttgart, Germany	*Success*
"T" Cubesat Deployment Pods	University of Toronto, Canada	*67% Success*
UHF Band Transceiver	AMSAT-DL /TU Vienna, Austria	*Success*
NCUBE-2 Cubesat	Andøya Rocket Range, Norway	*Untested / Failed*
UWE-1 Cubesat	University of Würzburg, Germany	*Success*
Xi-V Cubesat `	University of Tokyo, Japan	*Success*

Mission Achievements

- **Primary Mission Objective**

  To demonstrate the successful implementation of this pan-European Educational initiative and therefore encourage, motivate and challenge students to improve their education and literacy in the field of space research and exploration was completely fulfilled

- **Secondary Mission Objective**

  To carry as passengers, and subsequently deploy, up to three educational CUBESAT pico-satellites was fulfilled

- **Several important milestones were met:**

  - Timely completion and handover of spacecraft
  - Reception of first transmissions, precisely on schedule
  - Establishing two-way communications
  - A significant amount of telemetry was downloaded

  • Many subsystems on-board performed successfully and now have flight heritage for use in future mission

  • Educational benefit, including internship possibilities, and several PhD and Master theses which would not have otherwise been possible.

- **Cooperation with the Amateur Radio community, enabled:**

  - inclusion of flight hardware for mutual benefit
  - extensive educational input to SSETI teams
  - a virtual global ground station (which proved invaluable during the mission)
  - an OSCAR number, "XO-53", was assigned to SSETI Express by AMSAT
  - future, highly beneficial, cooperation of a similar nature (ESEO)

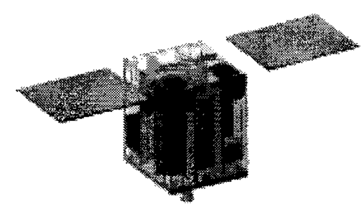
SSETI Express attracted a huge amount of media attention:

- The launch was broadcast on over 100 European TV
- Fourteen national events took place, organized by SSETI students, at which local media was welcomed and direct interaction with the teams was possible
- The student-run SSETI website served more than 1,000,000 hits during the month of October
- During launch day the *Google* search engine reported over 800,000 web pages referring to "SSETI Express"
- Numerous scientific and engineering publications have run features on the SSETI Express project.

So it can be stated that:

Although the flight had a premature end, the project was a very significant success

3 SSETI ESEO – The European Student Earth Orbiter is planned to be the second SSETI mission to be launched into space



Objectives

- ESEO is an educational mission, designed, integrated, tested and operated by students
- ESEO is an Earth satellite to be placed into a geo-synchronous orbit
- ESEO is a test bed for future SSETI missions
- ESEO will provide measurements of radiation levels and their effects throughout multiple passes of the Van Allen belt
- ESEO will take pictures of the Earth and other celestial bodies
- ESEO will provide a Mode U/S linear transponder for radio amateurs

Payloads

- Micro camera (pointed at the satellite)
- Narrow angle camera (down to 50 meter resolution earth pictures)
- Radfets (total dose measurements)
- Radiation effect memory board (radiation effects on memory chips)
- Langmuir probe (radiation strength)
- Inflatable high gain antenna (patch array)
- Thrust vector control with a carbon fiber thruster nozzle

Launch Parameters

The AMSAT-UK ESEO team

Orbit – geo-synchronous transfer orbit
Launch vehicle – Ariane 5 or Soyuz ST
Launch site – Kourou French Guiana
Launch date – Late 2008
Apogee – 35900km
Perigee – between 250 and 500km
Mean motion – 2.289 orbits per day
Decay period – ???
Mission Lifetime - Primary mission – I month minimum, extended mission until de-orbit or failure
Dimensions – 600x600x7010mm – compatible with the ASAP ring
Mass -120 kg
Expected lifetime – primary mission min 1 month, extended mission until end of life
ADS –Sun and horizon sensors, magnetometers and a star tracker
ACS- Momentum wheel, cold gas thrusters and vector control main thrusters
Orbit Control system – Nitrogen gas 18 litres @ 300bar
OBDH – CAN, RS232 & RS422
Telemetry - S-Band 9k6kb/s and 128kb/s – AMSAT S Band – 400bps!
Power – Li Ion batteries 300Wh, 15-25V unregulated bus, 2 deployable sun tracking solar arrays with 150W average and 300 W peak output

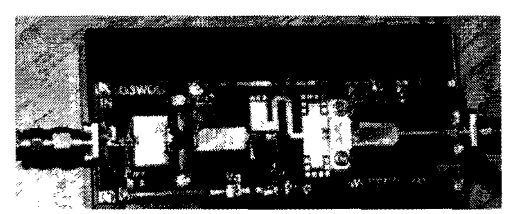
Configuration

Dimensions -600x600x710mm – compatible with an ASAP ring
Mass -120kgs
ADS – sun sensors, horizon sensors and magnetometers
ACS - Momentum wheel and cold gas thrusters
Propulsion - 18 liters nitrogen @ 300bar
On board data – CAN bus, RS232 and RS422
Telemetry – S Band @ 9k6kb/s or 128kb/s plus AMSAT S band @400b/s
Power – 2 deployable sun tracking solar arrays. 150 watt average output
Batteries – LI Ion, 300Wh
Power bus – 15-25V unregulated

Communications Suites

The primary communications package will be an S band unit designed and developed by the SSETI team at the University of Wroclaw in Poland. It will use standard CCSDS protocols and the "commercial" 2.1GHz & 2.2 GHz space allocations. The transceiver will use a number of patch antennas (LGAs) exactly as were developed and built for SSETI Express. It is also intended to deliver power to a single medium gain antenna (MGA) which will be mounted on the earth facing end of the satellite and also an experimental inflatable array of 12 patches.

The AMSAT-UK package is designed to be successful even if the satellite has not reached or looses its stable earth-pointing attitude. This should provide the command stations with a reliable, but slow, telemetry downlink and uplinked telecommand capability. It is also intended to provide a usable U/S linear transponder for radio amateurs. This will have selectable DSP and analogue options. The link budgets indicate that users will need a higher erp on 70cms uplink and a larger dish on S- Band than was needed on AO40 at apogee. The on-board antenna configuration should mean that "squint angle" will not be a factor and that therefore signals will be stronger when the satellite is nearer the earth.



An engineering model 5 watt Class AB 2 stage PA

The AMSAT-UK Redundant TC/TM Transceiver & Transponder

- UHF Receiver and omni linear antennas
- Command decoder / CAN interface to OBDH
- Linear transponder and DSP Transponder function with 50kHz bandwidth
- TC receiver & TLM transmitter
- 400bps telemetry beacon with FEC
- S Band High Power Amplifier (approx 10 watts) and omni linear antennas
- AMSAT module control and protection system

The SSETI -ESEO Project current timetable

Phase B: Detailed Definition
July 2006 Preliminary Design Review

Phase C: Development
Dec 2007 Workshop
Jan 2007 Critical Design Review

Phase D: Manufacture, Integration & Test
Apr 2007 Completion of Eng model modules
Jul 2007 Completion of Eng model
Mar 2008 Completion of Flight model modules
Jun 2008 Completion of Flight model
Oct 2008 Transport to Kourou

Phase E: Launch
Nov 2008

Phase F: Mission Operation
Nov 2008 until ?

4 SSETI ESMO

European Student Moon Orbiter

In March 2006, the Education Department of the European Space Agency approved the European Student Moon Orbiter (ESMO) mission proposed by the Student Space Exploration & Technology Initiative (SSETI) association for a Phase A Feasibility Study. If found to be feasible, ESMO will be the third mission to be designed, built and operated by European students through the SSETI association.

The ESMO spacecraft would be launched in 2011 as an auxiliary payload into a highly elliptical, low inclination Geostationary Transfer Orbit (GTO) on the new Arianespace Support for Auxiliary Payloads (ASAP) by either Ariane 5 or Soyuz from Kourou. From GTO, the 200 kg spacecraft would use its on-board propulsion system for lunar transfer, lunar orbit insertion and orbit transfer to its final low altitude polar orbit around the Moon.

A 10 kg miniaturized suite of scientific instruments (also to be provided by student teams) would perform measurements during the lunar transfer and lunar orbit phases over the period of a few months, according to highly focused science objectives. The core payload would be a high-resolution narrow angle CCD camera for optical imaging of lunar surface characteristics. Optional payload items being considered include a LIDAR, an IR hyperspectral imager, a mini sub-surface sounding radar for polar ice detection, and a Cubesat sub-satellite for precision gravity field mapping via accurate ranging of the sub-satellite from the main spacecraft.

Two different spacecraft designs are being studied in parallel and traded-off by the students during the Phase A: one based on a hybrid solid/liquid propulsion system, and one relying upon solar electric propulsion. The former would allow a rapid transfer to the Moon within a few days, but with a reduced payload, whereas the latter would take up to 12 months for the lunar transfer phase with the benefit of giving greater payload accommodation and wide launch window flexibility.

Other technologies include miniaturized avionics, and lightweight structure and solar array. The mission would need to be supported by a Global Educational Ground Station Network for TT&C, a single large ground station for payload data downlink from lunar orbit, and several student-run Mission Control Centers.

The mission would end in 2012 with a targeted impact of the spacecraft into a polar region at around 2 km/s, and ground-based telescopes would observe the impact ejecta plume for traces of water ice, as recently executed by SMART-1.

Presently we are not planning for AMSAT-UK collaboration with this mission.

5 Conclusion

The opportunity to join the SSETI program has enabled the AMSAT-UK team to provide amateur radio transponder hardware for two missions and also to enable the students to learn about our passion.

It has also enabled us to transfer much of our "knowledge" to them in a friendly and helpful manner. This contribution has been greatly respected and valued by them and by the Education Office at ESA.

The tremendous support given by radio amateurs around the world during the few hours of the SSETI Express mission was a great benefit to that mission and has sown the seeds for ongoing co-operation.

A surprising percentage of the students are already amateurs and a good number of others are taking out licenses – this can only be good for relationships between amateurs and future generations of space scientists.

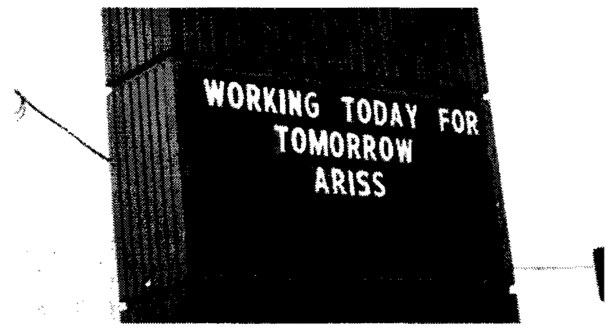
ARISS---Ten Years as a Team and Six Years in Space

Frank H. Bauer, KA3HDO; Gaston Bertels, ON4WF; Robin Haighton, VE3FRH; Keigo Komuro, JH1KAB; Ken Pulfer, VE3PU; Sergey Samburov, RV3DR; Rosalie White, K1STO; Dave Larsen, N6CO; Scott Avery, WA6LIE; and Miles Mann, WF1F

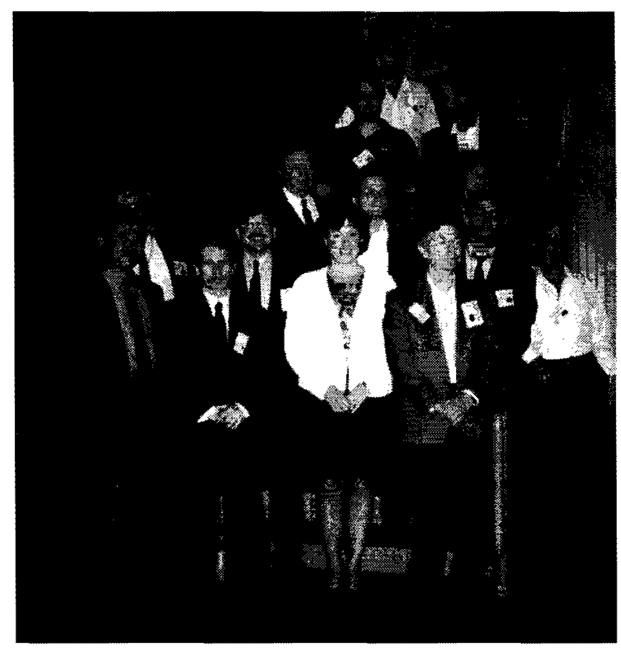
Introduction

It is hard to believe that the ARISS team celebrates its tenth anniversary this year. Ten years of ARISS has raced by, just like a fast-growing sapling that soon turned into a healthy, enormous tree. It was not easy at first. The team needed to learn each other's cultures to thrive. But since then the "ARISS tree" has grown an accumulation of thousands of branches of achievements in the technical field, the educational arena, on-air operations, public outreach events and international goodwill.

In 1996, as the International Space Station neared initial hardware delivery, NASA asked the SAREX working group to spearhead an effort to bring together an international delegation to discuss the future of ham radio on ISS. The reason: to consolidate the many ham radio voices around the world into one voice—a team that would coordinate the development and operations of ham radio on ISS. Invited were representatives from national amateur radio organizations, AMSAT, and other ham radio groups that possessed expertise in ham radio on the U.S. Shuttle and Russian Mir space station. In November 1996, the first ISS ham radio meeting was held at the Johnson Space Center in Houston, Texas. In attendance were members from eight national amateur radio organizations, including Russia, Germany, Italy, Japan, Canada, France, Great Britain, and the USA. This meeting served to initiate the dialog on the development and operations of a permanent amateur radio station on ISS.



Hotel Sign at Conclusion of 1996 Meeting
Figure 1



1996 ARISS Meeting Attendees
Figure 2

Those humble beginnings really impressed NASA. And the rest is history---the working group called ARISS--Amateur Radio on the International Space Station—was formed.

This paper presents a retrospective from many who attended that first meeting in Houston or were pivotal in the development of the ARISS team.

ARISS Accomplishments

Frank Bauer, KA3HDO

What a phenomenal team!! To me, our two biggest ARISS accomplishments are: 1) the team's enthusiasm to learn from each other's culture to become a high performing international team and 2) our ability to demonstrate to the space agencies and the amateur community that the ARISS team can produce results and meet the stringent safety requirements for ISS. These two accomplishments were a requirement for success on ISS. But it was not easy. It took a lot of discussion, arguments, and compromise to make it work. Over the first couple of tumultuous years, we started to gel as a team. Now we are a high performer.

Some specific ARISS accomplishments include:

- The first human spaceflight frequency plan for 2 meters and 70 cm
- Installation of the Ericsson 2 meter radio system and pico-packet for voice and packet in the FGB. This occurred less than two weeks after the first crew arrived (making ARISS the first payload on ISS)
- The development of 4 multi-functional antenna systems that were mounted by 3 EVAs on the periphery of the Russian service module; these support 2 meters, 70 cm, L band, S Band, HF operations and GPS reception
- The installation of a UHF/VHF Kenwood D-700E in the Service Module, near the dinner table and window
- The successful completion of over 253 international schools to date—kudos to the operations team and volunteer mentors on a job well done!
- 13 ISS expedition crews using our radio system to conduct thousands of QSOs with hams on the ground
- Over 15,000 students touched each year
- Millions, worldwide have heard an ARISS connection
- Witnessing students, worldwide, become scientists and engineers as a direct result of the ARISS connection
- The first Spacesuit satellite—SuitSat-1 / Radioskaf deployed from ISS

And many, many other accomplishments too numerous to capture in this paper.

As the ARISS International Chairman, I feel privileged to serve as the leader of this outstanding team. I am proud to know that we have successfully carried out the vision of our good friend, Roy Neal, K6DUE. Roy, before his passing, kept preaching to the team that our primary goal was to see amateur radio become a permanent fixture on ISS. His vision is now a reality.

I look forward to the future, where many more astounding ARISS accomplishments are on the horizon. And I would like to personally thank all who have poured their hearts into this program to inspire school children and inspire our ham radio community through amateur radio.

Looking Back, Looking Forward

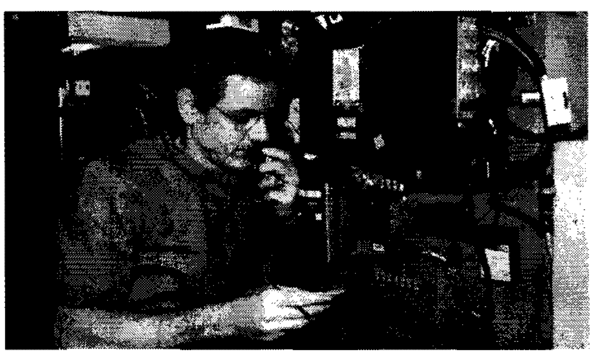
Rosalie White, K1STO

Being in the thick of it as ARISS International Secretary-Treasurer and as one of the US delegates to ARISS, I find it no easy task to point out only a few highlights. I cannot even begin to cover the massive amount of accomplishments on the technical side or the radio side of ARISS, so I will focus on the other fronts.

On-Air Operations

As we assisted with and monitored the first successful ARISS school QSOs and random ham QSOs, we were so very thrilled! We forgot all about the thousands of hours it took to plan, build and develop, discuss, test and so on! As the years passed, the types of on-orbit activities have increased.

We all point proudly to recent records set by Astronaut Bill McArthur who greatly topped the record of school QSOs made during any one ISS Expedition – 39 lucky schools. His other achievement was making a whooping 1,800 QSOs from space! Finally, he earned the ARRL Worked All States award, plus the 2-m and 70-cm Worked All Continents award, and currently, he is compiling QSLs for DXCC.



Bill McArthur, KC5ACR operates the Kenwood D700
Figure 3

How did hams react to all of this on-the-air ARISS activity? One ham sent a very long thank you letter to the ARISS Team and Bill McArthur for his many general QSOs and school QSOs. The ham had erected new antennas and feedlines to regularly track Bill's activity.

This past February, the ARISS International Team contributed another ham "first," the now-famous SuitSat-1. It captured the attention of thousands of people, and 500 hams posted what they heard. It transmitted greetings 3,500 times to hams.

Telling the Amateur Radio and ARISS Story

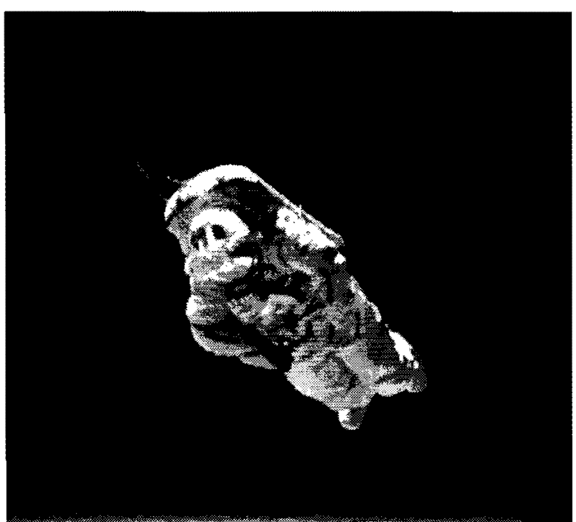
Since Day One, the ARISS Team learned to keep PR in the forefront of our thinking when we were working on something innovative. The ARISS International Team always encourages schools to strive for publicity. Every school QSO results in a great deal of good PR.

Beyond the schools efforts, in the first half of 2006 alone, some publicity hits in the US included:

- NASA set up a presentation of the ARRL WAS award to Bill McArthur, KC5ACR, at a Space Center Houston event.
- 10,000 families visited the Smithsonian's Space Day event, where ARISS was featured as part of an AMSAT booth.
- Team members gave 5 talks about ARISS at Dayton -- at AMSAT's Forum, the ARISS portion garnered a huge audience.
- The ARISS US leaders prepared material for a booklet that NASA published, *Inspiring the Next Generation,* to distribute to schools around the US -- NASA included 3 pages on ARISS and 2 pages on SuitSat-1.
- An Engineering Week QSO in Washington DC had 7,000 people intently listening.
- Our Johnson Space Center team gave a presentation to 100 teachers from across the US at a teacher's conference at Space Center Houston.
- Members of the Titusville ARC hosted a weeklong special event station at Cape Canaveral to celebrate the successful US Space Shuttle Program and talk about ARISS in school.

Students Participating in Engineer's Week
Figure 4

SuitSat-1 was an attention grabber; the SuitSat web site got 10 million hits. NASA videographers were fascinated and let the cameras track SuitSat far longer than they tape other space walk events. The media got lit up over SuitSat! Unprecedented stories about SuitSat and ham radio blazed, worldwide through the media.



SuitSat-1 On Orbit
Figure 5

The US ARISS Team won multiple accolades in 2006, earning PR for Amateur Radio and ARISS. Frank Bauer was one of a few people selected to compete for a national-level Rotary Award; he was honored at a black tie dinner at Johnson Space Center. Rosalie White was recognized by her area club for helping students become interested in Amateur Radio and ARISS. Kenneth Ransom was presented with the most coveted NASA award, the Silver Snoopy, by Astronaut Bill McArthur.

For Our Youth

In 1996 at our first ARISS international meeting, we stressed that "ARISS = Education" for our world's youth. Every delegate from each country agreed to this tenet.

An example follows of how the educational experience gained from a space QSO can stay with a youth through the years. A student who was part of *a SAREX QSO*, in years past, has since graduated from the Air Force Academy. This year she is flying fighter jets, and now, aspires to join the astronaut corps!

ARISS schools integrate ham radio into the classroom in many excellent ways. A typical example from this year is Salt Brook Elementary School (NJ) whose students designed a web page to post their space experiments, ham communications and ISS tracking. Their area high school ham students mentored younger students and were Control Ops during the ARISS QSO.

Looking around the US, for this year alone, we see many wonderful positives as follows:

- An ARISS volunteer demonstrated HF and satellites during a two-day visit to the 5th grade classes at Romeo Elementary School (FL) -- the demo was part of the prep for the school's upcoming ARISS QSO.

- This summer, a parent sent an email after a school's QSO to thank us for spurring her son into taking technology courses.
- Several ARISS schools have been networked to ARRL's Big Project offerings, and teachers are using its technical and space-related lesson plans.
- Every 2 weeks, an Illinois ham team teaches electricity to all 4th graders from a school waiting for an ARISS QSO; the principal and teachers are enthusiastic supporters with some teachers and students planning to join a license class.
- ARRL set up and staffed an exhibit at a national-level teacher conference.
- Astronauts enthusiastically took part in ARRL's Kid's Day and School Club Roundup.
- Students participated in the SuitSat "spacewalk" with their pictures, artwork, and signatures. While SuitSat was on-the-air, student voices from around the world could be heard beaming from this unique satellite.

ARISS is Teeming with International Teamwork

From the first ARISS international meeting in 1996 up to today, one of my definitions of ARISS is this: ARISS is teeming with teamwork. The ARISS International Team is made up of many groups. The US built a team; other ARISS Regions built teams. To meld teams together, committees were set up, and we asked each ARISS Region to name a representative to each committee. We established different types of committees as we saw a need. This practice continues today. Take a quick look at the official minutes from any ARISS international meeting, and you will read summaries of accomplishments made by the many teams and committees. It *does* take a team!

At the first international meeting in 1996, the representatives were strangers from all over the world who gathered together because they were very interested in space-related ham activities. That was amazing, in itself! Even before the meetings ended, we decided we were fellow hams spread around the globe who needed to team up together. As the years added up, we learned to work well with one another, enjoying the camaraderie. Now we are workhorses dedicated to ARISS… but we are strong lifetime friends, as well! And that may be the very best part of ARISS.

Thinking of the Future

In 1996, Roy Neal, Frank Bauer and Rosalie White set up our ARISS international meetings to plan for the future. Since then, every ARISS team member, worldwide, thinks of the future.

Team members in Russia and at Johnson Space Center have always kept their eyes on the future, coaxing astronauts and cosmonauts to develop an interest in ARISS. Currently, Kenneth Ransom and Nick Lance take the lead in teaching Amateur Radio material to the astronauts ready to study for their ham exams, and training them on the ISS radios, as does the Russian team with the cosmonauts. Of the 14 graduates in the latest astronaut class, 11 earned their ham licenses thanks to the Johnson Space Center ARISS Team.

In the first six months of 2006, alone, the Russian Team trained the Expedition 13 crew and ESA astronaut Marcos Pontes, a future civilian ISS visitor, and two US astronauts on how to use our radio equipment. The US Team trained ESA astronaut Thomas Reiter on use of the radios.

Other teams worldwide are beginning to take charge of licensing their countries' ISS crewmembers.

For planning of the distant future (and discussing current issues), Frank Bauer and I networked with Johnson Space Center staff in August 2006. We were happy to hear that the JSC staff was delighted to learn that ARISS is studying ways to move our program into President Bush's initiative for NASA, which he calls *Moon, Mars & Beyond.* The entire ARISS international team has its eyes on the prize: getting ARISS involved in exploration. The team welcomes everyone's ideas for this. It is going to be an exciting trip for the ARISS Team, and you should be along for the ride with us!

ARISS-Japan Accomplishments

Keigo Komuro, JH1KAB

The first Japanese ARISS school contact was successfully completed between Iruma Children's Center, JK1ZAM and NA1SS on 23 November 2001. The mayor of Iruma city, parents and school boys and girls, and citizens directly watched the QSO. This news was televised on NHK TV the next morning and more articles were reported in the news papers. After this contact ARISS-Japan was solidified and all applications from IARU Region 3 countries have been accepted by ARISS-Japan. Since that first contact, 45 applications for school contact have been accepted by ARISS-Japan, of which 34 have been successfully completed.

During this school contact, a sophisticated simultaneous audiovisual translation system for non English speaking countries was developed and used, which works as follows.

1) The questions to astronauts on ISS from the children were fed in parallel to a loud speaker system.
2) The operation room was equipped with a big wall screen on which the PC outputs were displayed.
3) When a question was sent in English, its off-line Japanese translation from the PC was simultaneously displayed. This was quite easy to accomplish because all questions were provided in advance.
4) When the answer in English from the ISS was heard through the loud speakers, a simultaneous, but off-line translation, (English to Japanese) was started. Within minutes, the Japanese translation of the English answer was displayed under the said question displayed on the screen.
5) Simultaneously, the next question was asked by a student. So the children and the audiences were hearing the next question in English and at the same time they were able to watch the answer(s) in Japanese to the previous question(s) on the screen.
6) This system provided no idle time for translation and many student questions were successfully completed.

Lastly, we are very proud that Japanese radio equipment has been successfully operating as part of the second phase ARISS equipment on the ISS. This includes the Kenwood D700 and a soon to be installed Yaesu radio system.

ARISS Contact with Kagawa, Japan
Figure 6

ARISS-Europe

Gaston Bertels, ON4WF

ESA Coordination

When European astronauts began fulfilling missions on the International Space Station, ARISS-Europe started developing solid ties with the European Space Agency. This is an ongoing process.

Presently, we have an arrangement with ESA's ISS Utilisation Strategy and Education Office for setting up School Contacts whenever ESA organizes an educational event. This occurs twice a year, mostly during a mission of a European astronaut. The ARISS "Space Talk" is the top prize for the winning classes of a space oriented educational competition in primary schools.

There are also other occasions for ESA to call for an ARISS contact. The latest occurred July 2006 when the Greek Minister of National Education and Religious Affairs asked for a "Space Talk" with the ISS during an ESA Space Camp in Greece.

Moreover, we often manage to set up more ARISS School Contacts with European astronauts, mostly for high schools in the astronaut's country.

Ham Radio in the Columbus Module

ARISS' European branch also managed to get permission to install amateur radio antennas on the nadir of Columbus, the European Space Laboratory, which will be attached to the ISS, end of 2007.

These patch antennas for L- and S-band, are being developed in Poland by the Institute of Telecommunications and Acoustics, Wroclaw University of Technology.

ARISS-Europe launched a fund raising campaign for these antennas. Donations were collected from individual radio amateurs as well as from societies and institutions. This is an ongoing process, as the final version of the antennas, their certification tests and installation are still to be completed.

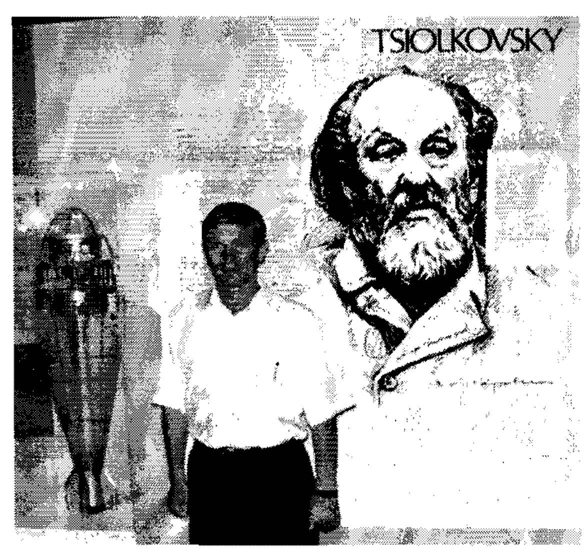
Planned onboard equipment include a linear transponder (L-band up-and S-band downlink) as well as digital amateur radio television (DATV).

ARISS Russia

Sergey Samburov, RV3DR

At a recent ISS Ham Technical Interchange meeting, I pointed out to Frank Bauer that this year is an historic year for ARISS---our 10th birthday! And we are also celebrating 6 years on-orbit. So, the two of us devised this special paper to commemorate these special events.

Another special birthday happens next year (2007)—the 150th birthday of my great-grandfather, Konstantin Tsiolkovsky. As many of you know, he was a philosopher and a father of theoretical rocketry. He once said, "The Earth is the cradle of humanity, but one can not live in a cradle forever!" The ARISS team is doing its best to take ham radio out of Earth's cradle and into the far reaches of the universe! We are doing this first on the ISS. And we hope to expand this to the Moon and beyond.



Sergey Samburov with his Great-Grandfather (U.S. National Air and Space Museum)
Figure 7

The ham radio system is currently in 2 portions of the Russian segment. I coordinate the hardware installation, the crew training in Russia and the development of exciting projects like SuitSat/Radioskaf. I also train the Spaceflight participants—Mark Shuttleworth, Greg Olsen, and most recently Anousheh Ansari. They are all quite interested in using the ham radio. We are all working quite well together, getting the ISS crews excited about using ham radio. And working on inspiring projects developed for hams and school children.

Next year is a special year—the 150th birthday of my great-grandfather, the 125th birthday of rocket pioneer Robert Goddard and the 50th anniversary of Sputnik—the first satellite in space. As is Russian tradition, the ARISS team hopes to have some great commemorative celebrations next year. This may include another SuitSat/Radioskaf, if our space agencies agree.

I thank the ARISS team for all their hard work and dedication. I enjoy your friendship and our common goal.

ARISS Canada

Ken Pulfer, VE3PU

Like others, my recollections of the ARISS founding meeting are fond ones.

I stumbled into ARISS by accident, because I happened to be visiting one of my sons and his family in Houston that month. The chance to revisit JSC once again after not seeing it since some of the first shuttle and Canadarm flights in the early 80's was something I could not resist.

The result has been 10 very rewarding years as a delegate, a host of new friends, and a feeling of satisfaction in a job well done, although my contribution has been minimal. I take pride in having brought several Canadian volunteers to the ARISS team, including Daniel Lamoureux VE2KA on the School selection committee, Steve MacFarlane VE3TBD as a mentor and contributor to the Operations committee, and Wayne Harisimovitch and his team with the Discovery web site and IRLP distribution. Of course Robin Haighton and his time with AMSAT has been the anchor of the Canadian effort.

My big disappointment is my failure to get more Canadian astronauts as licensed hams. So far, only Bob Thirsk has taken the plunge, and that on his own initiative. Steve MacLean, who was a luncheon buddy for several years, will hopefully be flying in the next week or two but the CSA has never made the time to get him his ticket.

ARISS Canada

Robin Haighton, VE3FRH

Canada has been an active part of the ARISS program since its foundation 10 years ago and its "divorce" from the shuttle "SAREX" program.

The particular area of interest for the Canadian Participation in ISS is the Donation by Canada of the "Canada ARM" which is used extensively in constructing the ISS. The principle difference between the new arm and the former "Shuttle Arm" are the manipulating "fingers" which permit detailed work to be carried out. Now that construction has once more commenced, the Canada Arm will be put to use again in the final development of ISS.

Canada is pleased to have participated at many levels in ARISS including Publicity, technical committees, and administration and between the Canadian Delegates we have covered most, if not nearly all, of the monthly teleconferences.

Many thanks must go to the Radio Amateurs of Canada (RAC) for hosting the ARISS website for several years. The Canadian AMSAT representatives to ARISS and the US AMSAT representatives are very closely integrated and as such both groups promote ARISS within the AMSAT organization.

MIREX and MAREX Teams

Miles Mann WF1F, Dave Larsen, N6CO and Scott Avery, WA6LIE

In November 1996, there were several teams supporting ham radio in space. The Mirex team was one of those groups with three teams, led by Sergey Samburov, RV3DR in Russia, Thomas Kieselbach, DL2MDE in Germany and Dave Larsen and Miles Mann in the US. At the time, there were three ham radio projects on board the Mir Space Station, including a repeater, packet and SSTV. When we arrived in Houston, we were meeting space industry Amateur radio enthusiasts from many countries for the first time face to face.

After 2 long days and nights a Memorandum of understanding was generated, creating ARISS.

The international team also hammered out the foundation for developing and installing new Amateur Radio projects, including plans for getting feedthroughs in the Service module. A plan was also developed to re-use navigation antennas in the FGB for Amateur Radio usage, after the FGB docking had been completed.

As a direct result of creating ARISS, we now have 5 different coax cables connected to multiple antennas, for a total of 12 externally installed Amateur radio antennas on the International Space Station.

Once the Mir activities were complete, the US-based team adopted the name Marex and worked aggressively to develop an SSTV system for ISS. In July 2006, the SpaceCam Imaging project was activated. Now the crew of ISS can "see" the faces of the people they are talking to through SSTV.

We would like to thank all of the volunteers of ARISS for making ARISS very successful. We would especially like to thank Lou McFadin, W5DID, who was instrumental in developing the hardware interface to integrate SpaceCam to the ARISS hardware system and Sergey Samburov for all his support as the Russian segment lead. And we wish to thank all of the ARISS delegates for supporting our efforts in these very valuable education projects.

SSTV Picture from ISS
Figure 8

Conclusions

The ten years that the ARISS team has been together has resulted in some marvelous achievements for ham radio and school children around the world. We now have a permanent ham radio system in space. And we are looking at moving away from our "cradle"—Earth and to the Moon, Mars and beyond. We hope you will all work with us as a team as we make this happen!!

Dedication

The ARISS team would like to dedicate this paper to three founding members of ARISS that have poured out their support to ARISS but have since died. Specifically, we would like to dedicate this paper to Pam Mountjoy from NASA, Thomas Kieselbach, DL2MDE, from the ARISS-Europe team and Roy Neal, K6DUE from the ARISS USA team.

Pam was the vision behind making ARISS a one ham radio team into the space agencies. As an educational outreach executive at NASA, she was instrumental in getting NASA behind the ARISS and getting initial funding for SAREX and ARISS.

Thomas' excitement for hardware development was infectious. His guidance in the early years was pivotal in the development of the antenna design. His idea and excitement for a digitalker on ISS was a primary reason why the student voices were on-board SuitSat-1. He gave us great ideas and pushed the team hard.

Roy was a key moderator and leader within the ARISS team. When things got rough or contentious, he would always remind us of our primary objective—to make ham radio a permanent fixture on human spaceflight vehicles.

The legacy of these three individuals is the success we have all shared these past 10 years.

Thanks!!

A New Approach To Satellite Power Systems

Presented by

Louis W. McFadin, W5DID

Abstract

Since the first satellites have been built, all have used batteries to store the energy during the time they are in the sunlight for use while they are in eclipse. Much effort has been spent trying to develop reliable battery systems that carefully manage the batteries in order to extend their lifetime as much as possible. The fact remains that they are all based on chemical reactions that are mostly reversible. The bottom line is that these chemical reactions cannot be 100% efficient neither are they 100% reversible. It is a well known fact that the primary cause of the demise of satellites is battery failure. This paper looks at these problems and explores methods of reducing the probability of failure.

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About the Author

Lou McFadin, W5DID, was licensed in 1959. He earned his BS degree in Electrical Engineering from Oklahoma State University in 1963. He worked for NASA at the Johnson Space Center, from 1967 until his retirement in 1995. While there, he served as the Principal investigator for the Shuttle Amateur Radio Experiment (SAREX) among other NASA duties. After retiring from NASA, Lou has served AMSAT as the P3D integration manager and P3D laboratory manager. He currently is the ARISS U.S. Hardware manager, as well as a member of the Eagle Power Systems team and the Eagle Sensor Systems team.

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1 Previous Approach

Usually a battery system is designed around a buss voltage that corresponds to an integral number of battery cells. In the case of AO-10, AO-13, and the planned P3E, that is 14 VDC or 10 cells. In the case of AO-40, it was 28VDC or 20 cells. The cells are then wired in series and connected to the power buss and a charger regulator is connected between the solar panels and the buss. In this scheme, it is imperative that the batteries be carefully selected to match in capacity and voltage. This screening is necessary because all the cells are in series and the failure of any cell usually means the entire system has failed. This battery screening and matching process is often very elaborate and tedious.

A typical satellite power system diagram is shown in Figure 1.

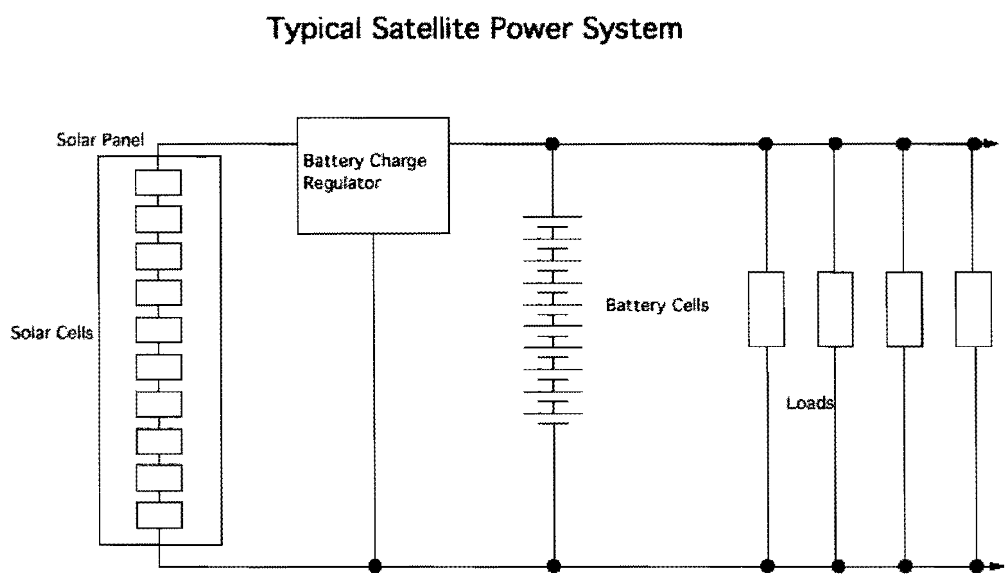

Figure 1. Typical Satellite Power System

As can be easily seen from this diagram there are many single point failures that can occur in such a system.

The Battery Charge Regulator (BCR) could fail, any of the solar cells could fail, or any of the battery cells could fail. While this failure mechanism can be mitigated by paralleling the solar panels isolating them with diodes, and using relays to separate battery strings, the system is still basically a series system where a single failure constitutes a major problem and significant reduction in capability when a failure occurs.

2 Proposed Approach

What we are proposing for Eagle is a re-thinking of this topology. If we can somehow change the system from being a series system to a parallel system with sufficient isolation, the overall reliability can be increased many fold.

With the recent development of microcontrollers and high reliability power Field Effect Transistors (FET)s and surface mount components, the tools exist to achieve this goal. The recent development of Super Capacitors using Aerogels has provided capacitances as high as 2600 Farads, which introduces additional possibilities for energy storage that heretofore were not possible.

We are proposing a system with at least six solar panels positioned such that at least one is always exposed to the sun if the satellite is not in eclipse regardless of the satellite's orientation. These six solar panels would be connected to a minimum of three BCRs. Since the panels on opposite sides of the spacecraft would not be exposed to the sun at the same time, they can use the same BCR without conflict. The BCRs can be designed as Maximum Power Point Converters (MPPC). In this concept the microcontroller constantly adjusts the current pulled from the solar panel in order to keep the solar panel delivering the maximum power to the satellite. This is achieved by monitoring the voltage and current being drawn from the panel. As the current increases, there is a certain point where any increase of current causes the voltage to drop and thus reduces the amount of power delivered. Typical curves are shown in Figures 2and 3. (Reference 1).

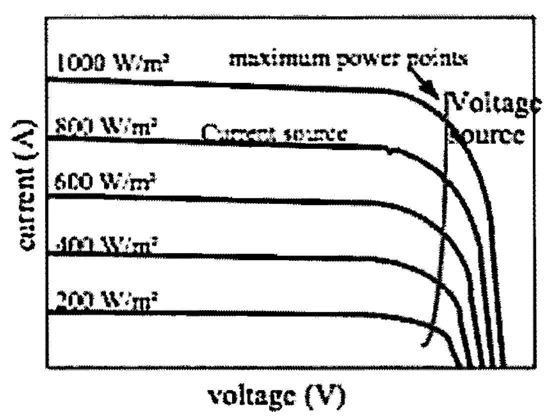

Figure 2 Typical I-V curves

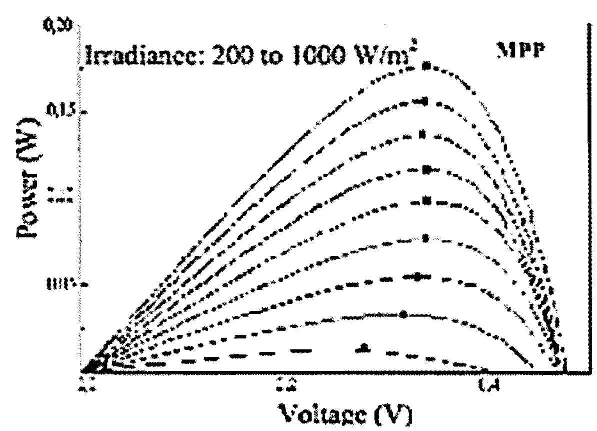

Figure 3 Typical MPP vs Irradiance curves

Systems for achieving this have been well described in the literature and have been built and are in service today.

Figure 4 shows a diagram of a boost converter designed to provide this function.

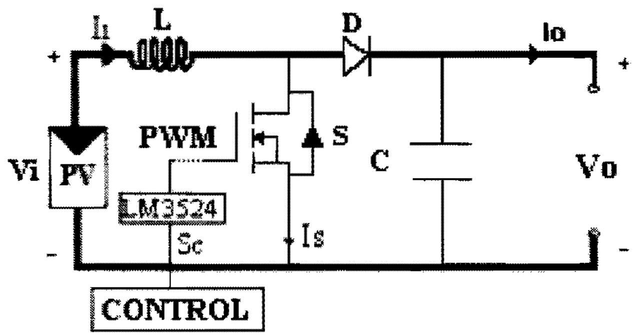

Figure 4 Typical Boost Converter.

The major difference in this proposal is that the system would also be designed to monitor the buss voltage and cut back on the power taken from the panels once the buss is above a certain pre determined set point. This would result in the excess energy being radiated from the panels by thermal radiation. In other words, they would heat up. Adding dumping resistors has been a source of failure in some satellites and therefore is to be avoided.

The other part of this new proposed system is the energy storage system. In this system it is proposed that the energy storage system be a group of parallel subsystems.

A simplified diagram of the proposed system is shown in Figure 5.

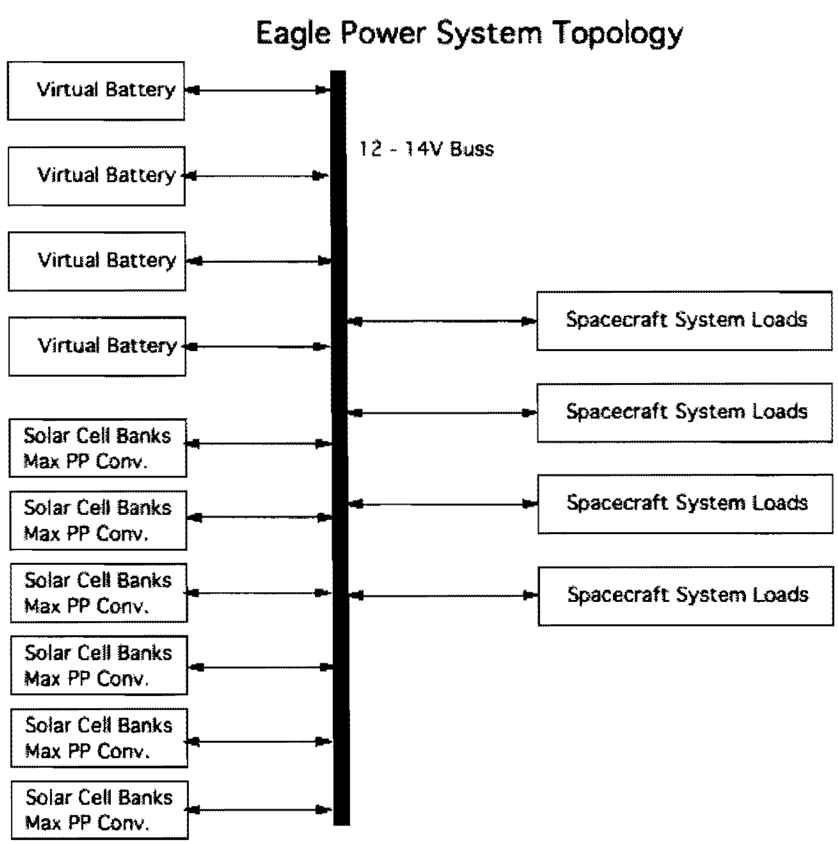

Figure 5 Proposed New Power System

The key to this systems' success is the Virtual Battery (VB) System. This system uses a switchable up-down converter. The Virtual Battery system monitors the buss and controls the charge and discharge of the storage system based on demand from the buss.

A simplified block diagram of the system is shown in Figure 6.

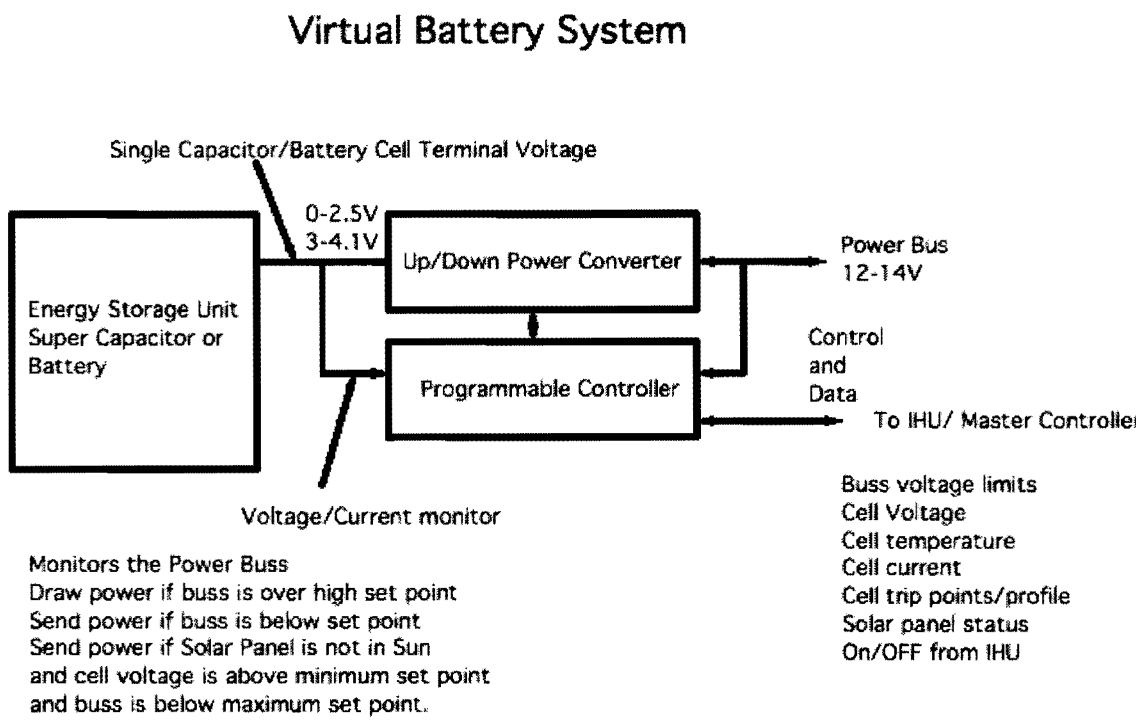

Figure 6 Virtual Battery System

You will probably notice that the energy storage device has not been specifically identified in this diagram. There is a reason for that. Since the behavior of the charge/discharge system is controlled by a microprocessor, the characteristics can be tailored to several different types of energy storage devices. Examples include Lithium Ion batteries, Nickel-Metal Hydride, Nickel-Cadmium and Super Capacitors. All of these are in the same voltage range and could use the same circuit board with only firmware changes according to the requirements of the storage device. The Super Capacitor has the advantage of virtually unlimited charge discharge cycles and an unambiguous energy vs voltage curve. The Lithium Ion battery has the advantage of the highest energy storage density with the disadvantage of a more complex control algorithm We have built a prototype of the Super Capacitor system with the total circuit board size no larger than two square inches. These are the benefits of technological development.

Figure 7 shows the schematic of the prototype Super Capacitor system.

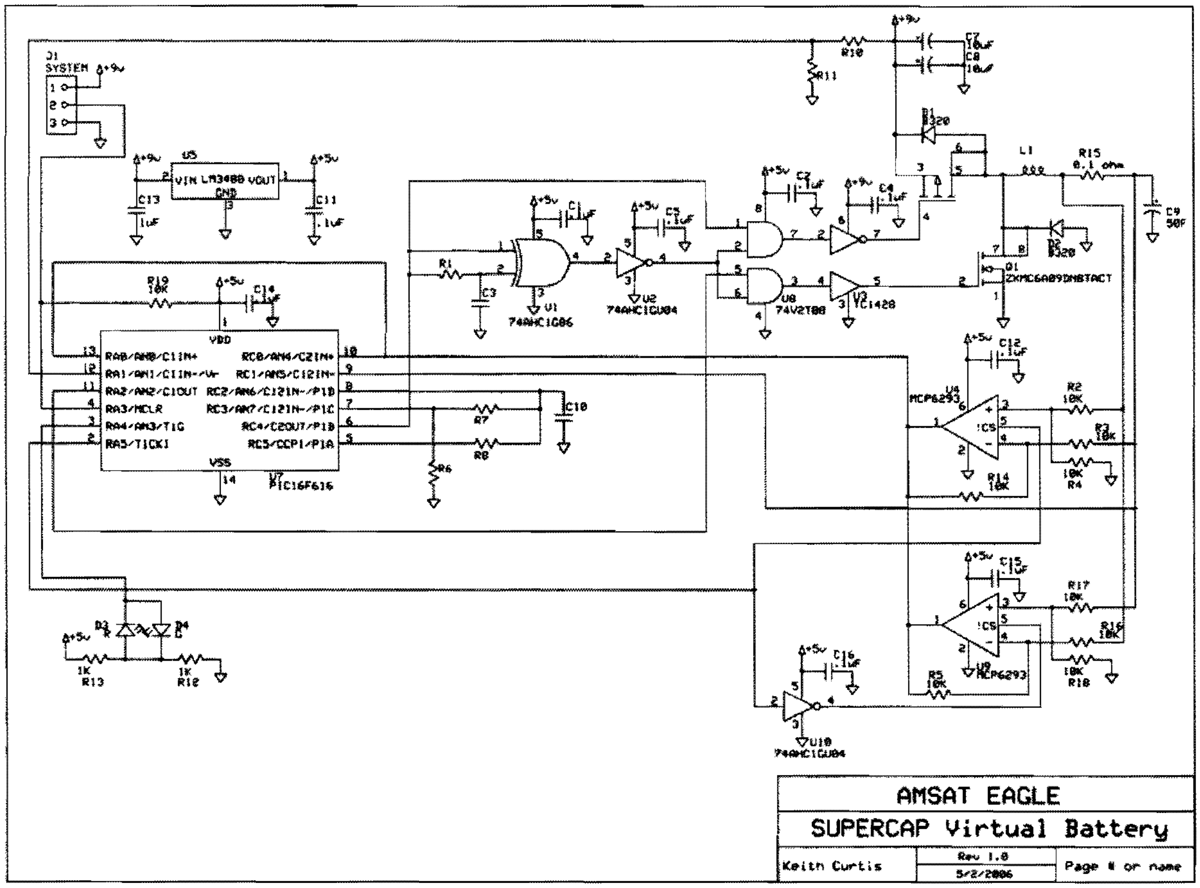

Figure 7 Super Capacitor Prototype Schematic

The features of this system include:

- A highly redundant system of parallel storage devices.
- Parallel energy conversion devices in the MPP converters for the solar panels.
- A de-centralized control system.

The spacecraft computer can modify the buss voltage setting by communicating with the MPP Converters and the Virtual Batteries, but the default settings will bring the power system up without outside supervision.

The system will start on its own from a zero power condition as soon as the solar irradiation increases above a minimum value. If one of the converters fails, others will still function.

If one of the parallel storage systems fails, others will still function. In other words, systems will fail gracefully.

3 Conclusion

What we are proposing here is a new approach for the energy conversion and storage for future satellites. This system will increase the overall reliability of satellites so that they should outlive their builders.

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Amateur Radio and the CubeSat Community

Presented by

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Abstract

This paper explores the relationship between the AMSAT and CubeSat communities, including gained educational experiences, collaboration on an International Ground Station Network, and future Amateur Radio payloads on CubeSats.

1 Introduction

CubeSats are a class of picosatellites built primarily within a university setting to get students interested and educated in the science of building small satellites. Multidisciplinary teams of students work on designing and fabricating the satellite structure, electronics, communication system, and payload. Formal procedures for building and testing satellite components are written by students and used throughout the process. While some schools choose to outsource aspects of fabrication, such as milling the structure and fabrication of PC boards (due to time constraints or lack of adequate equipment), most of the building and assembly of the satellite is done in house.

One of the greatest concepts within the CubeSat project is the very short conception-to-operation time, usually two to three years. This allows first and second year students the opportunity to be involved with the satellite from the planning stages to operation of their satellite while it is orbiting this planet.

CubeSats are defined by a very simple specification: 10cm on a side with a total mass of less than 1 kg. There are other specifications in the standard, such as separation springs and deployment switches, but those two are the main ones. The CubeSat standard was started by Bob Twiggs at Stanford University in 1999, but was fully developed and kept up-to-date by students at Cal Poly.

The common CubeSat standard was designed so that satellites can be loaded into a CubeSat deployer, such as a P-POD, T-POD, or XPOD, and launched into space on a whole range of launch vehicles. A CubeSat deployer is used as the interface between the launch vehicle and CubeSats, to protect the primary payload from our satellites and provide a common set of mounting holes for the launch vehicle. A deployer also allows CubeSats to switch launch vehicles if the situation should arise.

Currently, there are 4 CubeSats working in orbit right now (Table 1), with another 6 not functioning in orbit. University designed and built CubeSats typically have a 60% success rate of turning on when deployed into space. While this success rate may seem extremely low, remember that the primary purpose of this project is education. The objectives of the project have been fulfilled whether the satellite works in space or not.

Satellite	School	Launch	Frequency	Payload
XI-IV	University of Tokyo	30 June 2003	437.490 MHz	Camera
QuakeSat	Stanford/Quakefinder	30 June 2003	436.675 MHz	VLF receiver
XI-V	University of Tokyo	27 October 2005	437.345 MHz	Camera
CUTE-1	Tokyo Institute of Technology	21 February 2006	437.505 MHz	Attitude determination

Table 1: Operational CubeSats as of September 2006

One might comment on how much space junk we are adding to space. While this has been true in the past, due to the FCC's new orbital debris mitigation plan [1], things are changing. Methods to de-orbit spacecraft are being developed and tested; these ideas will be discussed later in this paper.

As can be seen in Table 1, most CubeSats operate in the 70cm Amateur band. Simplex systems are used to decrease complexity and reduce required frequencies. Most CubeSats uplink codes are not published, and therefore can't be used by the general public, although Japanese Amateur Radio operators can use XI-IV to take and download pictures.

2 Collaboration between AMSAT and CubeSat Communities

If regular Amateur Radio operators cannot uplink to a CubeSat, then what could possibly be the benefit to the Amateur Radio community? There are numerous benefits to the community, among them the education of another generation of satellite builders and users, and the ability to work satellites with new and interesting payloads.

Education is the reason why this program was started. Students working on CubeSats are already interested in satellites, and with a little push many of them get their Amateur Radio license. At Cal Poly, more than three-quarters of the students working on the CubeSat project have their Amateur Radio licenses. About half of the team has talked with XI-IV, and about a quarter of the team has talked on regular AMSAT satellites.

These students are the future of AMSAT, and will one day be building and designing the next generation of Amateur satellites. The complex problem solving they learn in the lab will help them with the new technologies.

The CubeSat community thrives off of interaction with experienced satellite builders. Students in these programs need mentors to help them with the complexities of building an object destined to orbit this planet. The AMSAT Area Coordinator list is great place to begin looking for mentors around a particular university.

Another area where the AMSAT and CubeSat communities work together is trying to find the CubeSats just after launch. Each university wants to know as quickly as possible whether their satellite is working or not, but there are many obstacles. For example, the first pass over the earth station might be several hours after deployment, NORAD can't differentiate between individual CubeSats in the days after deployment (so they are just going to release one Keplerian element for multiple satellites), or the elements might be slightly wrong. The Amateur community can help out with all of these problems, and has done so in the past.

The SSETI Express mission is a great example of the help that Amateur Radio operators are willing to give the CubeSat community. SSETI Express was a 62 kg satellite, with 3 CubeSats inside, that was launched in October 2005. Unfortunately, the satellite failed just 14 hours after launch, but the Amateur community provided crucial data to the SSETI Express team when the satellite was out of range of the primary and secondary earth stations [2].

3 Ground Station Network

A ground station network is a collection of earth station networked together for the purpose of sharing data. The main benefit of this approach is it dramatically increases amount of data that can be downlinked or uplinked to a satellite, as well as increasing control of operations for satellite owners. While there are some legal issues that still have not been resolved, using other earth stations to uplink commands to your satellite allows events to take place around the world and owners to react to potential problems quickly.

Currently, there are two independent ground station networks. One is the Mercury Ground Station Network [3], designed by James Cutler of Stanford University. At the height of its use, there were several stations in California and one in Alaska that were connected to the network. However, the network is no longer being actively used or maintained.

The second ground station network is the Ground Station Network built by various technical universities in Japan. While currently there are 13 Japanese universities using the Ground Station Network [4], there are plans to expand the network to include users outside of Japan within the next year. Currently, the Japanese Ground Station Network is only dealing with digital data packets, but there is no reason why it could not be adapted to use VoIP or similar protocols for voice.

A great benefit of linking earth stations is that more data can be downloaded. While this may not seem very beneficial to the average voice satellite operator, this can be helpful for hams that use store-and-forward or BBS satellites.

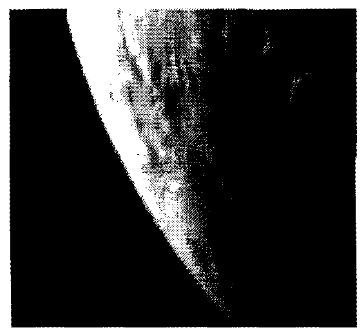

Figure 1: Picture downloaded from XI-IV in 7 hours

A test conducted on 26 April 2006 between the University of Tokyo and Cal Poly San Luis Obispo demonstrates just how much more data can be downloaded with just two stations [4]. The test, using the Japanese satellite XI-IV (Figure 2), was to download a full 32kB picture as fast as possible. Normally, it takes 1 day at Cal Poly to download a picture (or a little less than 10kB per good pass), and 1-2 days at the University of Tokyo. It takes them the extra time because of local RF interference on their Amateur bands. During this test, it only took 7 hours to download a full picture. About one-third of the picture was downloaded at Cal Poly, and the rest was downloaded at the University of Tokyo. The picture was stitched together by students at the University of Tokyo, and can be seen in Figure 1.

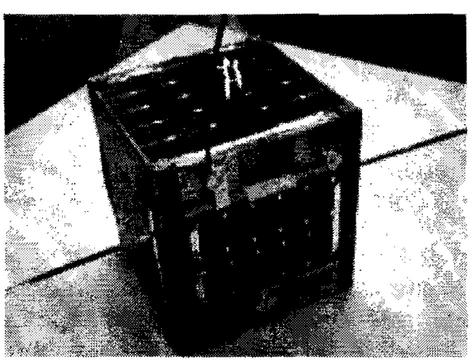

Figure 2: XI-IV satellite

During the beginning of August 2006, a test was conducted [5] between earth stations at Cal Poly San Luis Obispo, University of Tokyo, and Luleå University of Technology in Kiruna, Sweden. This test used both the CUTE-1 and XI-IV satellites. The main purpose of these experiments was to test an arctic ground station on the network. The station at Kiruna, Sweden is at 67.7° north, and can communicate with satellites in polar orbit almost every pass. Another test was to see how the satellites would react to very frequent transmissions (large power load), and also see how much data could be downlinked from both satellites. The earth stations involved with this test were too far apart for true handoffs.

During the test with CUTE-1, approximately 2.2kB of temperature, voltage, accelerometer, gyro, and current data was downloaded during one pass over each earth station. The transmitter was on for 25 minutes, and the battery voltage stayed above 3.75 volts, which is slightly below nominal voltage for their particular Li-Ion batteries but well within the acceptable range. CUTE-1 can be seen in Figure 3. The test with XI-IV yielded 60.3kB of data downlinked to earth stations.

There are many legal aspects to think about when using an internet-based ground station network. However, they may not be as large as one might anticipate. On the receive side, there is no problem at all; a station does not even need any Amateur Radio involvement to receive satellite signals and put them on the internet. However, on the transmit side, the situation becomes more complex.

Domestically, there should not be any legal problem for transmitting through a ground station network because both Amateur Radio operators fall under FCC rules and regulations. Also, the FCC does not care where the data being transmitted originates; it is up to the control operator of the station that actually transmits the data to monitor the data and ensure it follows the rules [6]. This is no problem for unencrypted communications, but most satellite commands are encrypted and cannot be inspected by a control operator. Legally, satellites uplink commands can be encrypted (§97.211), but the transmitting control operator might not like this idea.

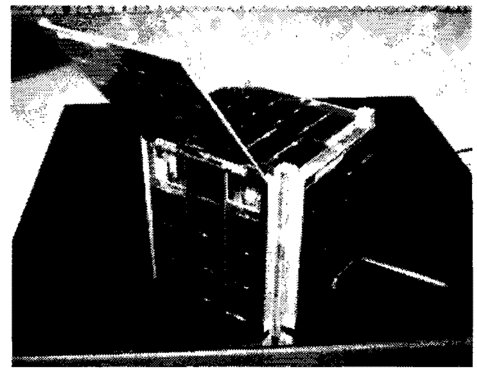

Figure 3: CUTE-1 satellite

A good example of transmitting on RF using another Amateur's station can be found within the Echolink system. Within this system, any Amateur Radio operator with a computer and microphone can talk on Amateur Radio repeaters across the country. This system is used all the time and currently has the backing of the FCC [7].

Bigger legal issues occur when the Ground Station Network goes international. While the same principles still apply (the FCC only cares about the station), some heads might turn if a station from a country without a reciprocal licensing agreement started transmitting from the middle of this country. The International Ground Station Network community will need some legal help (from AMSAT and the ARRL) in this regard before the system can be fully deployed.

4 Future

The future is looking bright for the CubeSat community. There are several CubeSat launch opportunities in the near future, and many new schools and companies are starting CubeSat programs. There is also real science being developed by these universities.

As for future launches, there is another Dnepr launch of 7 CubeSats from Kazakhstan this winter, organized by Cal Poly. In November 2006, GeneSat, with E. coli bacteria aboard, is scheduled to be launched aboard a Minotaur. The University of Toronto is organizing a launch of 5 CubeSats from an Antrix PSLV on 30 June 2007. Cal Poly is in talks with SpaceX and Space Access Technologies for launching CubeSats aboard their launch vehicles.

Universities are also flying interesting experiments on their CubeSats. Delft University of Technology, in their Delfi-C^3 mission, is performing tests of thin-film solar cells, internal wireless networks, and high-efficiency power amplifiers [8]. It will have a Mode U/V linear transponder for use when the science mission is complete.

Experiments are also being flown to flight qualify de-orbit mechanisms, in response to the FCC's recent guidelines [1] requiring that satellites de-orbit themselves within 25 years of end of life. These de-orbit devices range from tethers to balloons to deployable panels. Future AMSAT satellites will need to incorporate a de-orbit device.

5 Conclusions

While CubeSats may seem small and uninteresting to the average AMSAT member, they are a growing force within the satellite community. These CubeSat programs are enabling a whole new generation of satellite builders and operators to learn about systems integration, Amateur Radio, orbital mechanics, and communications systems. Both communities work together to track CubeSats during their first few days, and AMSAT mentors are always needed guide students through the design and build process, and to teach the art of Amateur Radio.

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Emerging Launch Opportunities for Small Satellites and Secondary Payloads – 2006 Update

Presented by

Lee McLamb, KU4OS

Abstract

Finding opportunities to launch is a primary challenge faced by AMSAT and as well as the entire small satellite community. This paper will review additional capabilities that are emerging in the form of new launch vehicles, new launch sites as well as new multiple and secondary payload adapters for existing vehicles.

About the Author

Lee McLamb first became interested in radio after constructing a AM broadcast crystal radio set from a kit in the third grade. That interest led to getting a first FCC license, the Commercial 3rd Class Radiotelephone with Broadcast endorsement, at the age of 14. By high school graduation Lee held the Commercial First Class Radiotelephone license and later received the additional endorsement for radar. It was while working with fellow broadcast engineers that he was finally encouraged to get his first amateur license in 1980. Lee was introduced to amateur satellites in 1982 by way of UO-9 and was immediately hooked. Amateur satellites have been his primary ham radio interest ever since.

In his current job as a Superintendent of Range Operations at Cape Canaveral AFS, Lee leads a team to plan and execute the communications, radar, telemetry and command support required for launches. As a volunteer for AMSAT, Lee has filled the roles of Executive Vice President, Director of Industry Relations, AMSAT News Service Editor and a mentor for several university satellite projects involving amateur radio. He has written articles published by The AMSAT Journal, CQ VHF and other AMSAT groups around the world.

Introduction

There has been a revolution building in the space community over the last few decades. Small satellites have proven to be useful tools for accomplishing real-world missions as well as serving educational, research and development missions. As a result an entire industry has now grown up around small satellites. Some studies[1] have identified hundreds to potentially thousands of small satellites that could be launched if inexpensive access to space became available. Each of the Future Small Launch Vehicles in Table 1 was described in last year's paper[2]. This paper will focus on new or updated information that has become available since October 2005.

New Rockets

One means to satisfy the growing demand for access to orbit is with new rockets specifically tailored for that mission. Several companies are building entirely new rockets and others are adapting existing technology for new uses.

Table 1 shows the capabilities of some existing launch vehicles as well as those currently in development.

One of the first questions asked is how likely is it that these future rockets will actually ever exist? Fortunately it appears that several have enough history behind them by being based on components from other vehicles or are already far enough along that they have a very good chance of existing as something more than a PowerPoint presentation.

Table 1: Existing and Future Small Launch Vehicles

	Sun-synchronous (98 deg inclination)	
Existing Small Launch Vehicles	**Mass (kg)**	**Altitude (km)**
Athena I	320	600
Athena II	1080	600
Minotaur	380	600
Pegasus XL	250	600
Falcon I (Space X)	430	700
Taurus	600	600
Future Small Launch Vehicles		
RASCAL	75	500
Scorpius Sprite Mini-Lift	150	741
Super Strypi	181	370
Falcon 5 Falcon 9 (Space X)	4,100 * 9,300 *	185 185
QuickReach	453	"LEO"
Streaker	Not	Given
K-1	1750	600
* 9 Degree inclination		

Falcon - SpaceX

The Falcon I by Space Explorations Technologies Corporation[3] (SpaceX) was planning their first launch from Vandenberg AFB, CA for the summer of 2005. Because the Falcon flight path would over-fly the Titan IV launch pad, delays in launching the final Titan IV, caused SpaceX to delay that mission and pursue making their first launch from an entirely new Kwajelean Atoll launch site in the Pacific Ocean. The first Falcon I launch occurred on March 24, 2006. Unfortunately, corrosion lead to a fuel leak and engine fire which resulted in the loss of hydraulic pressure. This loss of pressure then caused the first stage engine to shut down just 34 seconds after lift-off.

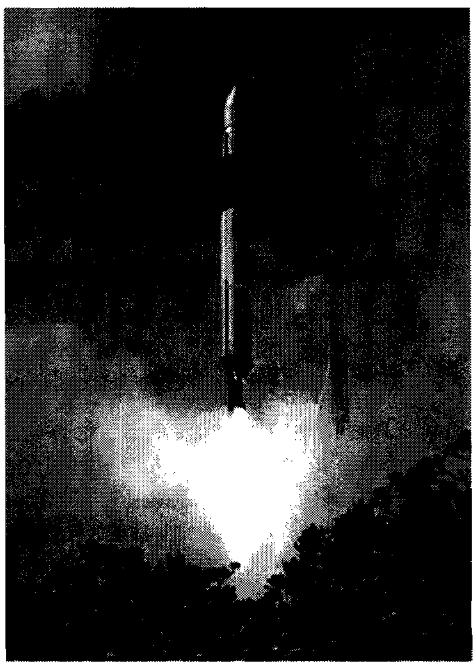

Figure 1 Falcon I maiden launch from Kwajelean Photo Credit: SpaceX

SpaceX is also developing a family of larger rockets called Falcon 5 and Falcon 9. The Falcon 5 will feature over ten times the capacity to a Sun-synchronous LEO as well as being able to lift 1,050 kg to a Geo-Transfer Orbit (GTO). The Falcon V uses five engines on the first stage to provide the capability to still achieve orbit should an engine fail. With the Falcon 5, SpaceX will also introduce their "half-bay" launch option to allow launch sharing for payloads that don't need the full 7.9m x 3m interior volume of the Falcon 5 payload fairing. The Falcon 9, which utilizes the same first and second stage tank structures as the Falcon 5 will provide an option for a larger 5m fairing as well as an increased 3,400 kg capability to GTO..

Currently there are thirteen flights contracted for the Falcon I and Falcon 9 launch vehicles through 2009.

QuickReach – AirLaunch LLC

The QuickReach small launch vehicle is designed to be a highly responsive vehicle targeting the placement of small satellites into LEO. As part of the DARPA/FALCON Small Launch Vehicle (SLV) Program, the goals include launching 453 kg to LEO within 24 hours notice with a launch cost of less than $5 million USD.

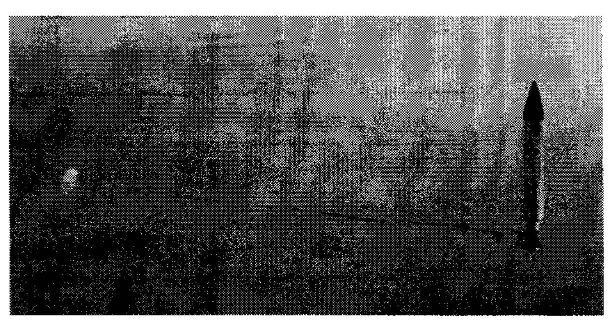

Figure 2 QuickReach drop test Photo Credit: AirLaunch LLC

QuickReach is a two-stage vehicle using a combination of Liquid oxygen and propane for propellants on both stages. The rocket stands 66 feet tall, is 7 feet in diameter and weighs 32,659 kg. The rocket is carried to its airborne launch point between 30,000 and 35, 000 feet above sea level on an unmodified Air Force C-17A or other large cargo aircraft. Extraction from the aircraft is accomplished using a combination of gravity and a standard 15 foot drogue chute to pull the rocket out through the large rear cargo door. Use of an airborne launch platform potentially has many advantages over a ground launch from a fixed launch site including simplified operations, reduced weather delays, fewer schedule conflicts, and enables launch to a wider range of potential orbits. Use of the C-17 as a launch platform also provides a great deal of flexibility. The C-17 can take off and land on runways as short as 3,500 feet (1,064 meters) and as narrow as 90 feet (27.4 meters). The Air Force originally programmed to buy a total of 120 C-17s, with the last one being delivered in November 2004 – current budget plans involve purchasing 180 aircraft[4].

Secondary Payload Adaptors

Another area which is showing increased activity is developing new structures for mounting multiple secondary payloads on a single launch. Existing secondary payload adapters have also continued to grow and evolve over the years.

ESPA

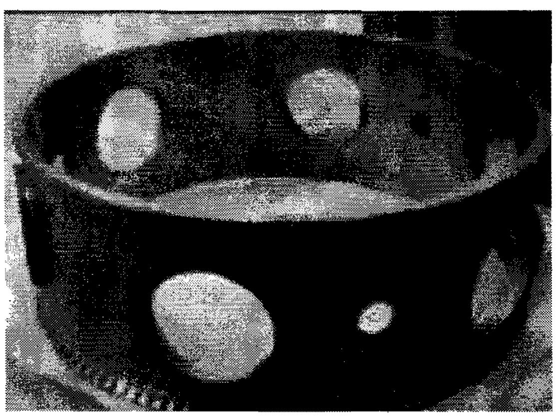

Figure 3 ESPA Ring Photo Credit: CSA Engineering

In the United States two new rockets have recently been developed as part of the Department of Defense (DoD) Evolved Expendable Launch Vehicle (EELV) program. These two EELV launchers are more commonly known as the Delta IV by Boeing and the Atlas V by Lockheed-Martin. As these rockets were being developed it was noticed that there were large unused payload margins expected on most DoD missions. In almost every case this excess margin was greater than 1360 kg and in many cases approached 5000 kg. To take advantage of this excess margin an EELV Secondary Payload Adapter (ESPA) has been developed. ESPA takes advantage of this unused payload margin by deploying up to six secondary payloads.

ESPA is an aluminum ring that is roughly 157 cm in diameter by 61 cm tall. Individual satellites can be mounted on one of six standardized secondary payload mounting locations on the perimeter of this ring.

Each satellite can have a maximum mass of 181kg and a dynamic envelope of 61 cm x 61 cm x 96 cm. ESPA is installed between the EELV payload attach fitting and the primary payload. Currently the first flight of and ESPA ring will be the STP-1 mission.

STP-1 is currently scheduled to launch on an Atlas V late in 2006.

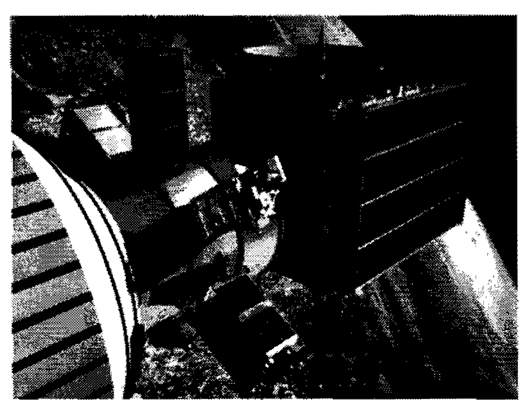

Figure 4 STP-1 Mission Credit: Lockheed-Martin

Atlas V Internal Payload Carrier (IPC)

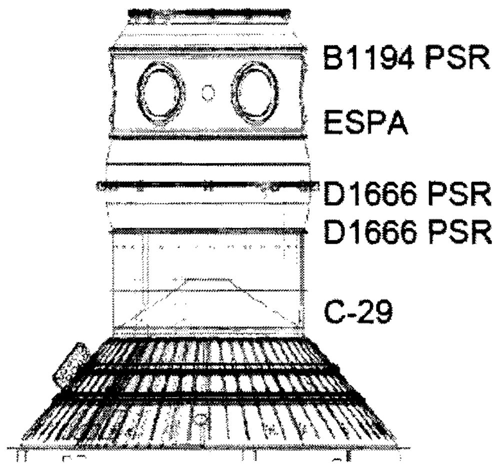

Figure 5 Atlas V IPC Credit: Lockheed-Martin

During the CubeSat workshop in Logan, UT this year, Lockheed-Martin[5] presented several options which are under development to support additional options for secondary payloads. Six different configurations were shown based primarily on existing combinations of hardware. One example is shown in Figure 5, which includes an ESPA ring with a payload separation ring (PSR) below. By separating the ESPA, the internal volume of the combined ESPA and C-29 adaptors are then exposed allowing deployment of an additional payload. This internal volume would accommodate a payload of 48" (121 cm) O.D. x 60" (152 cm) height.

Poly Picosatellite Orbital Deployer

A part of the on-going CubeSat[6] program between Cal Poly and Stanford Universities is the Poly Picosatellite Orbital Deployer (P-POD). Each P-POD can carry up to three standard 10 cubic cm , 1 kg CubeSats or a combination of "single-", "double-" or "triple-" cubes. This greatly reduces the development time for satellite develops by providing a standard physical interface. The P-POD also handles all the interfaces with the launch vehicle and is designed for maximum flexibility by providing mounting surfaces near all edges. The P-POD weighs only 2.25 kg empty. With the P-POD fully loaded with three CubeSats, the total system mass amounts to a mere 5.25 kg.

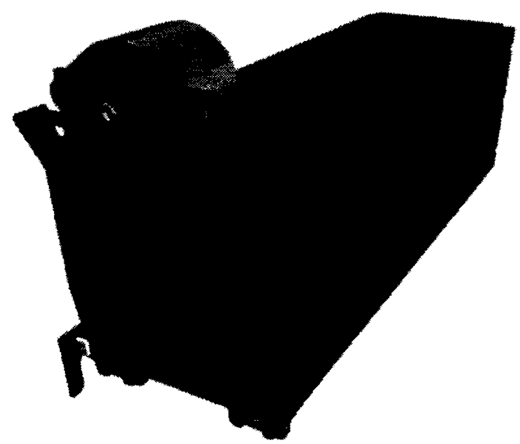

Figure 6 P-POD Credit: Cal Poly

Not only does each P-POD provide an opportunity for multiple satellites to be launched, but because of the low masses and volumes involved some missions are also able to accommodate multiple P-PODS. An example is the DNEPR launch in June of 2006 which carried five P-PODS containing thirteen satellites. Unfortunately a launch vehicle failure resulted in the complete loss of that mission. However, another DNEPR mission is scheduled for late 2006 carrying three P-PODS and seven satellites. Also in 2006, the Minotaur/TacSat-2 mission includes a P-POD carrying NASA's GeneSat-1 satellite.

Falcon Rideshare Adapter

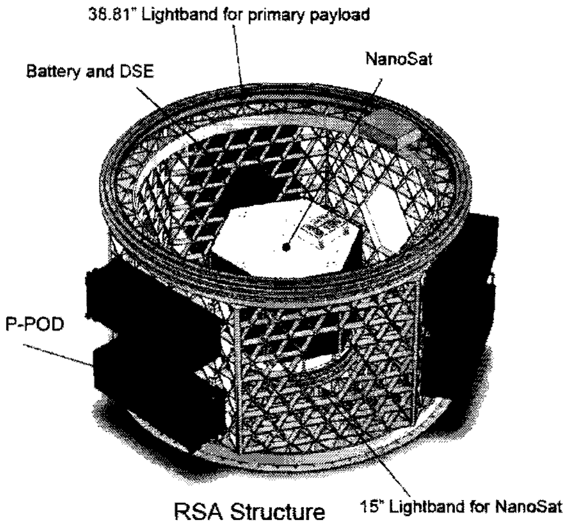

Figure 7 Falcon Rideshare Adapter
Credit: Space Access Technologies

The Falcon Rideshare Adapter (RSA) was developed under a contract from Space Access Technologies and in partnership[7] with Astronautics Technologies SB (ATSB) and SpaceX. The RSA provides a ring shaped mounting structure beneath the primary payload which allows the integration of secondary payloads both within the RSA and around the outside circumference.

Using the standard Falcon I payload fairing as a baseline, mounting the Primary Payload on top of the RSA allows for Primary volume envelope of 122 cm O.D. x 91 cm height, with a mass of up to 200 kg.

Within the RSA a secondary payload up to 24" (60.96 cm) x 24" x 19" (48.26 cm) with a mass of up to 90 kg could be accommodated. This would represent an "Half ESPA" sized satellite. Another potential candidate for the interior mounting location would be the AFRL/NASA sponsored University "Nanosats". These nanosats are actually fairly large by amateur satellite standards, measuring 47.5 cm O.D. x 47.5 cm height with a mass of 30 kg. Multiple satellites could also be supported within the RSA. Two of the Air Force Academy 20 kg, 14" (35.56 cm) cubic "FalconSAT" satellites would fit within the interior volume. Very small payloads such as P-PODs containing CubeSats can also be mounted around the exterior of the RSA. Enough volume and mountings location exist on the RSA to include up to eight P-PODS.

K-1 Small Payload Adapters

The development of the new, reusable K-1 launch vehicle by Kistler Aerospace Corporation is also resulting in the introduction of two new payload adaptors for that vehicle[8]. The K-1 Multiple Small Payload Adapter-1 can fly up to three "minisatellites", with each satellite having a mass up to 500 kg. For smaller payloads Kistler is also offering the K-1 Multiple Small Payload Adapter-2. This adapter, which features a shelf below the primary payload similar to Ariane's ASAP, can fly up to eight microsatellites, with masses up to 125 kg each.

Kistler plans to offer rideshare opportunities to small satellites as an integral component of their launch services. Since Kistler expects to recover the cost of their launch vehicle over just ten missions, Kistler's "Ticket-to-Orbit" approach will eventually become similar to the airlines – customers may buy "seats" on K-1 missions, using standard interfaces and services.

Conclusion

AMSAT now has an active and on-going project to continually seek out, identify and evaluate new launch opportunities. Some may turn out to be suitable for HEO spacecraft such as Eagle while others are limited to LEO missions. Eagle is a small satellite by almost all measures. In fact, by some definitions, Eagle would be classified as a microsat. Which rocket will eventually carry Eagle to orbit is still unknown. What is clear is that there will be more options and opportunities in the future for all types of amateur radio satellites to be placed into orbit.

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