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TABLE OF CONTENTS

SECTION A: Satellite Construction and Launch

SECTION B: Satellite Operations and User Ground Station Equipment

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October 24, 2008

Dear AMSAT Member:

Welcome to the 2008 Harry Yoneda, JA1ANG, AMSAT-North America Space Symposium and Annual Meeting. Last year's Symposium in Pittsburgh was exciting and I expect this year's meeting here in the Atlanta area will be equally so. I hope you will take advantage of this opportunity to visit sites in Atlanta during your stay. There will be a Sunday outing to the Georgia Aquarium, billed as "the World's Largest and Most Engaging Aquarium."

We have made progress toward obtaining a launch and in defining the nature of the Eagle payload for that launch. As information has matured we have had to adjust our design to fit the parameters of the flight opportunity. You will see presentations that reflect this ongoing design planning and a technology demonstration to show you what kind of system we will be flying.

This past year has also been one of challenges to our infrastructure and leadership. The Engineering department was overwhelmed by rapidly changing circumstances that has led to a restructuring of the department and a re-tasking of the engineering teams. The AMSAT Lab, which was moved to Pocomoke City Maryland in January 2007, will now need to be moved again. Progress on the P3E satellite continues at a slow pace due to U.S. ITAR concerns and the lack of a launch opportunity. You will be hearing more on these difficult topics and AMSAT's plans for overcoming these problems during the Symposium.

AO-51 and other satellites continue to perform very well thanks to a dedicated and highly capable Operations Team led by AMSAT's VP-Operations Drew Glasbrenner, KO4MA. You might want to thank him when you see him at the Symposium.

The coming year will again be one dedicated primarily to completing the SuitSat II project and to getting the Eagle project designed based on the launch opportunity at hand while also preparing for future missions. Another issue is development of new software for AO-51. There are also many other areas of importance to AMSAT in the area of member services, such as improving our Web site, Internet store, and electronic communications capabilities. We continue to look for capable volunteers to help us improve on these areas as well as participate in our satellite development projects.

AMSAT's initiatives are forward looking and challenging. To accomplish them we need you, the dedicated members of the Amateur Radio community, to step forward and contribute your time and resources.

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Richard M Hambly

Richard M. Hambly, W2GPS
President

Ron Parise, WA4SIR, 1951 – 2008

Dr. Ronald A. Parise, WA4SIR, passed away on May 9 after a long and courageous battle with cancer. His accomplishments were many, including space explorer, astrophysicist, avionics and software expert, ham radio operator, pilot, inspirational speaker and motivator, student satellite mentor, husband, father, and friend.

Ron flew as a payload specialist on two space shuttle missions: STS-35 on the space shuttle Columbia in December 1990 and STS-67 on the space shuttle Endeavour in March 1995. These two missions, called Astro-1 & 2 respectively, carried out ultraviolet and X-ray astronomy observations. He logged over 614 hours and 10.6 million miles in space. Ron and his crewmates on Astro-1 became the first astronomers to operate a telescope in space, observing 135 targets including comet Levy, the planet Jupiter and supernova 1987A in the Large Magellanic Cloud. His personal contributions to these two missions have provided scientists with an unprecedented view of our universe, expanding our understanding of the birth, life and death of stars and galaxies.

Ron participated in flight hardware development, electronic system design and mission planning activities for the Ultraviolet Imaging Telescope, a major component of the Astro payload. Astro-1 was originally scheduled to be launched in 1986 on the next space shuttle mission following the STS-51L Challenger accident and was delayed nearly five years as a result of that tragedy. It was finally launched on the STS-35 mission on December 2, 1990. Failure of a payload computer system onboard Columbia required significant manual intervention by Ron and his crewmates to point the telescope at its targets and acquire the scientific data necessary for a successful mission. Ron's second flight with the Astro-2 payload in March 1995 was highlighted by the detection of primordial helium in intergalactic space. This discovery provided confirmation of a prediction of the Big Bang theory on the formation of the universe.

Ron was the ultimate ham radio operator in space and on the ground. First licensed when he was 11 years old, Ron kept the amateur radio hobby at the forefront of everything he did including his operations from space. During his two Space Shuttle flights, he talked to hundreds of hams on the ground, giving new meaning to the phrase "ultimate DX-pedition". He was instrumental in guiding the development of a simple ham radio system that could be used in multiple configurations on the Space Shuttle. As a result, his first flight on STS-35 ushered in the "frequent flyer" era of the Shuttle Amateur Radio Experiment (SAREX) payload. He was the first ham in space to operate packet radio and his flight pioneered the telebridge ground station concept to enable more schools to talk to Shuttle crew members despite time and orbit constraints. In his two shuttle flights, he inspired countless students to seek technical careers and he created memories at the schools and communities that will never be forgotten.

Ron's love for the amateur radio hobby and his love of inspiring students continued well beyond his two Shuttle flights. During the formation of the Amateur Radio on the International Space Station (ARISS) program, Ron was a tremendous resource to the newly forming international team. In many instances Ron's wisdom and sage advice was instrumental in helping the international ARISS team resolve issues when they reached critical technical or political roadblocks. He was a key volunteer in the development of the ham radio hardware systems that are now onboard ISS. The ARISS team is deeply indebted to WA4SIR for his leadership, technical advice and tremendous vision.

Ron worked hand-in-hand with the students at the US Naval Academy and Embry-Riddle Aeronautical University on the development of their student satellites. He helped develop Radio Jove, a student educational project to listen to the radio signals emanating from Jupiter. He also spoke at numerous schools over the years, inspiring students to pursue careers in science, math and technology.

"To leave our home world and look back at it from space is a most incredible experience," he said in 1998 in reply to the original Ask An Astronaut website. Ron Parise was--and continues to be--an inspiration to countless students, ham radio operators, and friends the world over.

Ron had a B.S. in physics from Youngstown State University, and M.S. and PhD degrees in astronomy from the University of Florida. He is survived by his wife Cecelia and children Nicholas and Katherine. He was 56. His family has established a scholarship in his memory at Youngstown State University.

The Ultraviolet Imaging Telescope: Instrument and Data Characteristics

http://arxiv.org/PS_cache/astro-ph/pdf/9704/9704297v1.pdf

Far Ultraviolet Imagery of the Edge-on Spiral Galaxy NGC 4631

http://arxiv.org/PS_cache/astro-ph/pdf/0009/0009138v1.pdf

Haruo Yoneda, JA1ANG, 1919 - 2007

Many AMSAT members will remember JA1ANG as a regular attendee at AMSAT-NA Annual Meetings and Space Symposia over the years. Haruo Yoneda, (Harry as we all called him) was an AMSAT-NA Board member from 1980 to 1988. His long-time support of AMSAT-NA is demonstrated by the fact that he held AMSAT-NA Life Membership Number 14. As well as being an avid supporter of AMSAT-NA, Harry co-founded the Japanese brother organization, JAMSAT,

Haruo Yoneda was born June 15, 1919 in London, while his father was assigned to the British Capital as a representative of a Japanese trading firm. Four years later the family moved to Australia. Young Haruo attended a private British school during the 20s and then went to Japan when his family retuned to their home country in 1929. During the voyage, the ten-year-old became fascinated by the Morse Code emanating from the vessel's radio room. This ignited the desire to become a ham and spend the rest of his life in pursuit of the hobby. Harry's first call in 1936 was J2NG, with which he became a well known DXer and member of the First Class Operators Club. Later, he was issued JA1ANG.

Harry graduated from the Department of Communication Technology of Osaka Imperial University in 1942, and spent the next four years in the Japanese army. After the war, he became a director of JARL. Later with his column on QSOing for the magazine CQ Ham Radio, he promoted the use of the English language among Japanese amateurs. He also published a very popular book on the subject in 1969. Single sideband suppressed carrier was coming on the scene in the late 1950s and JA1ANG was one of the promoters of this mode in Japan.

In 1951, Harry came to the U.S. to take graduate work at the University of Kentucky, Ohio State University and Columbia University from which he earned a masters degree. Retuning to Japan in 1953, he worked for the Tokyo Broadcasting System in that firm's television studio and later joined Dentsu, a worldwide advertising company.

In 1955, Yoneda San married his life's partner, Yoshi, who is still living. Daughter Yuri was born a few years later.

Traveling widely in connection with his employment with Dentsu, Harry was particularly effective on the international amateur satellite scene, serving as a link between the various AMSAT groups around the Globe.

Bitten by the satellite bug about the time of Australis OSCAR -5, Harry began actively promoting that branch of Amateur Radio by participating in the founding of the Japanese satellite organization, JAMSAT in addition to his active role in AMSAT-NA as a Board member. Harry also held the U.S. call, N3AMW and was often heard on the AMSAT 2 meter FM repeater which operated in the Washington DC area during the 1970s. It was always a pleasure to hear Harry's pleasant voice on the repeater and know that he was in town.

JA1ANG became a silent key on October 8, 2007, marking the final chapter in Haruo Yoneda's enthusiastic support of Amateur Radio, especially amateur satellite activities.

Our friend, Harry will be sorely missed.

Howard (left) with Owen Garriott, W5LFL (right)

Howard Ziserman, WA3GOV, 1952 – 2008

Dr. Howard Ziserman, WA3GOV, passed away suddenly on July 31. For many years, Howard served as an Amsat Area Coordinator for Maryland and Virginia. He volunteered to staff the Amsat table at every hamfest in this area, sometimes traveling over 100 miles. He had a love for the space program and worked at the NASA Bioprocessing and Pharmaceutical Research Center in Philadelphia in the early 1980's. When he moved to Maryland in 1989, he combined his love of education and space, working as a technical mentor for the SAREX payload on Space Shuttle Mission STS-64 and later on the ARISS program. For this work he received the NASA Group Achievement Award.

Howard had a B.A. in Chemistry from Cornell University, a B.E. in Electrical Engineering from Johns Hopkins University, an M.S. in Chemistry from the University of Maryland and a PhD in Biochemistry from The University of Oklahoma Health Sciences Center. He was 55.

RNA polymerase II bypass of oxidative DNA damage is regulated by transcription elongation factors

http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1679758

Taking EAGLE to new heights

A Strawman Design for a Geostationary Amateur Satellite

Tom Clark, K3IO

Background – Phase-3 Satellites: AMSAT has provided the amateur community with 3 High Earth Orbit (HEO) Phase-3 satellites: AO-10, AO-13 and AO-40. The Phase-3 era has been defined by elliptical orbits with apogee at ~40,000 km high. AMSAT-NA has announced a goal of providing full 24/7 coverage of the earth. To accomplish this goal, three HEO satellites will be required. The first is planned to be AMSAT-DL's P3E now nearing completion in Germany. AMSAT-NA has planned on the EAGLE series of satellites and the *ad hoc* EAGLE team has been planning on such a mission for 3+ years.

Unfortunately, launch opportunities for suitable GTO "piggyback" rides have all but dried up. Any opportunities that AMSAT-DL and AMSAT-NA have identified come with a price tag in the $2,000,000 to $10,000,000 range. No cheaper alternatives have been identified, and no way to raise such funding for an amateur satellite has been uncovered.

All the Phase-3 satellites have shared many common elements. The satellites have been piggybacked on launches to Geostationary Transfer Orbit (GTO) with a low (<500 km) perigee and ~40,000 km apogee. All the satellites are equipped with hypergolic kick motors to modify the GTO by raising perigee to a height > 1,000 km and changing other orbital parameters to make the satellite be more suitable for the users. To raise the perigee, the motor needs to be fired at apogee in a direction aligned with the velocity vector.

After the motor has achieved the desired orbit, the spacecraft is re-aligned by ~90° to direct the "antenna farm" towards the earth at apogee. In order to make these changes, the satellite's spin is changed with electromagnets that torque the spacecraft around perigee, where the earth's magnetic field is strongest. The orientation of the spin axis must be determined with an attitude determination system to an accuracy of better than ~5°.

In order to accomplish all these steps and to be a useful radio platform, the satellite must have a number of subsystems that work properly:

1. All the RF hardware including high gain antennas,
2. The apogee kick motor with all the associated fuel tanks, fuel, plumbing, valves, etc,
3. Attitude determination hardware to figure out which way the satellite is pointing in order to fire the kick motor in the proper direction and to point the antennas,

4. Magnetic Torque hardware to control the spin axis (used only while the satellite passes thru perigee),

5. All the solar panels and batteries needed to produce 100+ watts average power,

6. And finally, a real-time, multi-tasking control computer (called the IHU) to make all these widgets play together.

Of these, only Item 1 can be thought of as “real ham radio”. Items 2-6 fall into the category of “rocket science”. When combined with the need for proper testing, documentation needed to secure permission (see Bill Ress, N6GHz’s paper on ITAR for a discussion of just one type of documentation needed), team management, logistics, fund raising, etcetera, you can understand why it is often said “***Amateur Radio is <10% of the difficulty of building an amateur satellite.***”

New -- Geostationary Satellite Possibilities: Since suitable GTO launches for Phase-3 satellites have virtually dried up, AMSAT put Lee McLamb (KU4OS) onto the job of looking for alternate opportunities; by attending “***Rideshare***” and “***SmallSAT***” conferences on AMSAT’s behalf, Lee has identified a possibility of a “***Hitchhiker***” ride attached to a commercial Geostationary Orbit (GEO) satellite.

In this concept, an AMSAT payload would stay attached to the GEO host. In addition to the ride to GEO, the host would supply an earth-pointing platform stable to ~1-2° plus electrical power at levels of several hundred watts. On learning of this possibility, it was immediately obvious that such a ride immediately erased requirements 2 thru 6 from the list above. Instead of “Rocket Science”, we can finally work in the areas of receivers, transmitters, antennas and computers that can be thought of as “Ham Radio” ! ! !

GEO-EAGLE – a Strawman Design : In order to examine the suitability of this opportunity, I decided to think about the architecture of a “strawman” AMSAT GEO payload derived from the thinking done by the EAGLE team. Having such a design lets us explore the Hitchhiker concept. I want to stress that the design presented in this paper is my own. It has been neither reviewed nor accepted by AMSAT-NA’s Board of Directors, Officers, or other members of the EAGLE design team. Blame me, not them !

In our preliminary discussions about details of the host interface, we were told of a couple of launches favoring the USA and Canada, about the physical size constraints, and about blockage limits imposed by their antennas. It became obvious that we would have to split our package into two boxes, each with a footprint in the range 35-65 cm (14-26 inches). It was logical to consider one box as the receive box and the other as the transmit box.

After considering the frequencies they use (~6 GHz uplink & ~4 GHz downlink, plus Ku-band frequencies in 12-15 GHz range), it appears that we would be best served with the 20

MHz wide C-band uplink allocation (5650-5670 MHz). Given the large number of 802.11a, cordless telephones, WiMax and other Part 5 devices, this means that we will occupy the 5cm amateur band with transmitters that can be a “stake in the ground” to help establish our rights as a licensed service.

It appears that our primary downlink should make use of the 9cm S2 allocation available in Regions 2&3 (covering the Americas and the Pacific Basin) from 3400-3410 MHz. Hopefully we will have enough occupancy to keep this band reasonably free from terrestrial RFI. I have also considered the possibility of using S1 (2400-2402 MHz) as either an uplink or downlink.

At these microwave frequencies, the spacecraft can use small, fixed dish antennas covering the entire visible disk of the earth. From GEO, the earth fills an antenna beam with a full width ~18.3°; this implies that a full-earth beam will have a directivity ~22 dBi, which in turn indicates a dish antenna ~6-8λ in size, corresponding to dishes with a diameter ~30-40 cm @ C-band and ~54-72 cm @ S2. These sizes are quite compatible with the box sizes suggested to us.

The user on the earth will be able to use a dish antenna in the 0.6-1M in diameter, i.e. antennas like are commonly used for Ku-band satellite TV. Because the satellite’s position will be quite stable, the user will be able to fix the dish pointing. The FCC has established a rule that satellite antennas 1M and smaller are exempt from local CC&R limitations, but they specifically state that the rule does not apply to amateur antennas. However, since the dish antenna looks exactly like a TV dish, we hope that amateurs in areas where restrictive zoning is in force will be able to sneak by as in a “stealth” mode.

In considering the design of the RF links, it has become obvious that we should make use of the full available bandwidth. I will discuss a satellite RF & DSP implementation that will allow part of the uplink band (20 MHz@C-band), allowing simultaneous linear “bent-pipe” operation in some frequency segments, and a fully error-corrected digital uplink (probably FDMA+TDMA). On the downlink band (10 MHz@S2), a part of the passband would be available for “bent-pipe” linear transponder users, and a different part to high speed digital links with “fresh” FEC applied (probably CDMA). The digital links will support the ACP functions identified in the EAGLE designs.

In the symposium presentation I plan to discuss the conceptual design in more detail and include details of the hardware needed both on the spacecraft and on the ground. A preliminary version of this paper was presented at the TAPR/ARRL DCC in Chicago in late September.

CAVEAT: I again caution the user that this presentation is a discussion of a preliminary design which has not been reviewed within AMSAT. I invite inputs & comments from all on these ideas – remember YOU are AMSAT and your inputs are needed !

ITAR and AMSAT
(And other export control rules)

Presented by

Bill Ress – N6GHz
N6GHZ@amsat.org

Background

AMSAT-NA is facing a critical crossroad in its attempts to support international development of Amateur satellites due to the implications of various export control rules, primarily ITAR. If we can't get an acceptable 'handle' on ITAR issues, there seems to be a reluctant acceptance that AMSAT-NA may indeed be forced to 'go it alone' in terms of developing satellites. This is certainly regrettable, but it may be our only option.

In the past, AMSAT-NA has been attempting to assist AMSAT-DL with the development of their P3E Amateur satellite. Most notably, P3E's integrated housekeeping unit (IHU) function was to use the IHU-3 developed by AMSAT-NA technical volunteers.

When it was realized that Amateur satellite development activity could fall under the export control of a document called ITAR, the International Traffic in Arms Regulations, (and to a lesser extent, the Export Administration Regulations (EAR), implemented by the U.S. Department of Commerce), the efforts to support AMSAT-DL ground to a halt as the AMSAT-NA volunteers did not want run afoul of ITAR and its often severe penalties. This then started the spread of what I'll call, "ITAR paranoia" throughout all phases of AMSAT-NA satellite development. Since AMSAT-NA had little or no experience or guidance to offer in ITAR matters, many decided to quit working on AMSAT-DL projects. It became imperative that AMSAT-NA understand these export control rules and provide guidelines for AMSAT-NA members working on our satellites.

Prompted by the concerns of these members and the desire to support the AMSAT-DL P3E project with the AMSAT-NA IHU-3, Rick Hambly, AMSAT-NA President, along with others have spent considerable effort for almost two years to understand and work with the constraints demanded by ITAR, develop the appropriate documents and to provide member guidelines.

ITAR Satellite History

Prior to 1992, all items related to military satellite manufacturing were controlled by the State Department as munitions and were subject to ITAR approval. Between 1992 and 1996 debate occurred over who should have jurisdiction over commercial satellites, and after much wrangling, in 1996 commercial satellite jurisdiction was transferred to the Department of Commerce.

Then two launch failures of the China's Long March rocket would once again bring change to US export policy. In January 1995, the failed launch of the Long March 2E rocket carrying Hughes-built Apstar 2 spacecraft and in February 1996, the failed launch of the Long March 3B rocket carrying Space Systems/Loral-built Intelsat 708 spacecraft caused new U.S. Congressional scrutiny on how commercial satellites were exported.

The satellite manufacturers and China worked together to create an analysis of the failure of both these launches. This analysis was required to fulfill insurance requirements and was reviewed by the Department of Commerce. Commerce determined that the export of the analysis to the insurers and China fell under the license Commerce issued in February of 1994 and allowed its transfer to China. This decision caused a firestorm of political and government interdepartmental squabbling. As a result of what was determined to be severe export violations, Congress in 1999 passed ITAR authority from the Department of Commerce to the Department of State.

In January of 2002, Space Systems/Loral agreed to pay the US government $20 million to settle the charges of the illegal technology transfer and in March of 2003, Boeing agreed to pay $32 million for the role of Hughes (which Boeing had acquired in 2000) in the export violation. In addition to that, the company has had the export of its satellite, Chinasat-8, blocked for launch in China from 1998 to the present day.

Effects of ITAR

On the positive side, ITAR has routinely uncovered and prosecuted many violations of ITAR export controls. On the State Department web site, the violations are routinely posted. So ITAR is working to prevent the unauthorized export of sensitive munitions and technologies.

On the negative side, quoting from
http://en.wikipedia.org/wiki/International_Traffic_in_Arms_Regulations :
"There is an open debate between the Department of State and the industries and academia regulated by ITAR concerning how harmful the regulatory restrictions are for U.S. businesses and higher education institutions. The Department of State insists that ITAR has limited effect and provides a security benefit to the nation, which outweighs any impact that these sectors must bear. However, many companies and institutions within the affected areas argue that ITAR is stifling U.S. trade and science. Companies argue that ITAR is a significant trade barrier that acts as a substantial negative subsidy, weakening U.S. industries' ability to compete."

"U.S. commercial firms expend significant resources to prove that their products should not be classified as ITAR controlled technology. As a recent example, concerns over connections between the Boeing 787 and the B-2 Spirit stealth bomber prompted Boeing to take elaborate steps cleansing the commercial jet of any military technology. The issue arose when Boeing engineers, fearing indictment and penalties, refused to sign forms declaring that the 787 was 'ITAR-free.' As a result Boeing conducted extensive research on the source of technology implemented on the 787. They removed all military technology and either found a commercial source for the same technology or replaced it with technology derived from a commercial source."

Concerns For AMSAT-NA

You probably wonder, "But we're designing and building satellites just for Amateur use on authorized ITU Amateur satellite bands. Why are we affected?" The simple answer is that we are involved in designing satellites and their components, which ITAR considers a "defense item", which are regulated by the US Government if exported. I have emphasized export because our primary concern is with the export of satellites and satellite technology and components. So if AMSAT-NA designs and builds satellite components and satellites by U.S citizens and has them launched by US launch companies from the US, the impacts of the export laws, such as ITAR, do not apply.

Ah, but wait. Are we really in the clear? The answer is "not necessarily." To find out why not, we have to learn more details about U.S. export control laws and the term "deemed exports."

More Ominous Export Issues for AMSAT-NA – Deemed Exports

As if what we just discussed isn't enough of a concern for AMSAT-NA, we have another ITAR category of exports – deemed exports.

The definition of an export is not limited to sending goods overseas; it also applies to the release of technical data to foreign nationals. It can occur simply by mailing data to or engaging in a conversation with a foreign national. Foreign nationals are defined as those persons that are not US citizens, do not hold Green Card status and are not under asylum in the United States. This transfer of data can take place entirely within the United States and still be considered an export. This is called a "deemed" export as the transfer can be expected to result in export.

It's here that AMSAT-NA volunteers can inadvertently run afoul of ITAR. An example would be the email dialog between AMSAT-NA and AMSAT-DL volunteers on getting the IHU and the IHU software operational. But this problem can be mitigated by obtaining a State Department approved Technical Assistance Agreement (TAA) between the parties needing to exchange defense item information.

What Key U.S. Export Control Laws Affect AMSAT-NA?

U.S. export control laws that protect national security and trade are the International Traffic in Arms Regulations (ITAR), implemented by the U.S. Department of State, and the Export Administration Regulations (EAR), implemented by the U.S. Department of Commerce.

The EAR covers the export of "dual-use" items. These are typically commodity items, which could have military applications, or be modified to have a military application. An example would be a microwave amplifier device that is designed to operate above 31 GHz. To export this item you would need an export license from the Department of Commerce. More details can be obtained at the Department of Commerce EAR website[i].

The Department of State Directorate of Defense Trade Controls (DDTC)[ii] administers ITAR. ITAR covers the export of items that have intended military applications. An example would be a surface to air missile. ITAR doesn't say you CAN'T export that surface to air missile but it does say you must receive an export license from the Department of State, using well-documented procedures.

What AMSAT-NA Satellite Items Are Covered Under ITAR?

ITAR controls defense items such as satellites and all specifically designed or modified systems or subsystems, components, parts, accessories, attachments, and associated equipment for satellites as well as many dual-use technologies such as software, integrated circuits, computers, electronics and security-related information systems that are vital for satellites and launch vehicle technologies.

ITAR defines defense items as either "significant military equipment (SME)" or "non-significant military equipment." SME items are obvious. Non-SME items are often unclear and in need of clarifications. Most, but not all, of what AMSAT-NA will do falls under the Non-SME category.

ITAR 121.1 describes "The United States Munitions List." Category IV under this Munitions List, covers LAUNCH VEHICLES, GUIDED MISSILES, BALLISTIC MISSILES, ROCKETS, TORPEDOES, BOMBS AND MINES. Of interest to AMSAT-NA is "Launch Vehicles." Under this category, all specifically designed or modified components, parts, accessories, attachments, and associated equipment for the launch vehicle require export approval. For AMSAT-NA this would include the satellite adapter ring that we would fabricate to bolt the satellite to a launch vehicle. This category also includes any technical or manufacturing data or procedures associated with the adapter ring. While considered a Non-SME item, it still has stringent export rules. Also covered are orbit modifying propulsion systems, such as the rocket motor on AO-40.

ITAR Category XV of the Munitions List covers SPACECRAFT SYSTEMS AND ASSOCIATED EQUIPMENT. Under this category, our satellites are considered as Non-SME items but still under export controls.

Because our satellites or satellites systems in this category are not clearly defined, we must have the Department of State, using their clearly defined procedures, make a determination on a case-by-case basis, and define the requirements for export.

An example could be the proposed export of our IHU-3 or a 70cm command/transponder receiver along with any detailed design, development, and manufacturing or production data.

Under Category XI—MILITARY ELECTRONICS, computers specifically designed or developed for military application and any computer specifically modified for use with any defense article in any category of the U.S. Munitions List come under ITAR export control. Our IHU-3 could also fall under this category.

Presentation of Papers at an AMSAT-NA Symposium

Recently, the issue was brought up about AMSAT-NA members making technical presentations at the AMSAT Symposium and violating ITAR.

ITAR has a section on “Public Domain”; Section 120.11. It defines permitted “public domain” technical exchange as the following:

(a) Public domain means information which is published and which is generally accessible or available to the public:
(1) Through sales at newsstands and bookstores;
(2) Through subscriptions which are available without restriction to any individual who desires to obtain or purchase the published information;
(3) Through second class mailing privileges granted by the U.S. Government;
(4) At libraries open to the public or from which the public can obtain documents;
(5) Through patents available at any patent office;
(6) Through unlimited distribution at a conference, meeting, seminar, trade show or exhibition, generally accessible to the public, in the United States.

So under (6) above technical papers can be presented at an AMSAT Symposium, even with the presence of a foreign national as long as it isn’t the clear intention of the presenter to circumvent ITAR.

What Actions Must AMSAT-NA Take To Comply?

The first thing we must do is not view export control rules, such as ITAR, as the “vial curse” to AMSAT-NA activities. We need to work within the framework defined by ITAR and EAR. Companies do it successfully every day. A good example is Space Quest who supported AMSAT-NA’s AO-51 (Echo) and continues to be involved in satellite components and satellites.

Both the Department of Commerce (EAR) and the State Department (ITAR) have clear procedures for working with them and for resolving questions. We have started that dialog by following the procedures they provide.

First, AMSAT-NA is currently registered as a “manufacturer and exporter” with the Department of State – the first step required by State to start any export issue dialog with them.

Commodity Jurisdiction Determination

Then we will ask the State Department to make a “commodity jurisdiction determination” for the IHU-3. This action by the State Department will identify their view of the potential export status of the IHU-3 to AMSAT-DL. Because of the information that we will supply to State for this determination they will be formally introduced to AMSAT-NA and its history with Amateur satellites.

Clearly, U.S. Munitions list items fall under the ITAR; however, many other items also fall under ITAR that are not specifically listed. If we can show that the product has predominant civilian applications and that it has a performance equivalent to products used predominantly in civilian applications, then we can possibly avoid the more restrictive ITAR determination. However, the State Department has considerable discretion in determining whether a product falls under ITAR

Technical Assistance Agreement

The next action we might take will be to revisit the drafting of technical assistance agreement (TAA) on the IHU-3 between AMSAT-NA and AMSAT-DL with an attempt to develop a document acceptable to all parties. If this process is successful, it could lay the foundation for TAAs with other AMSAT organizations.

But even if there is a TAA in place, there are subsequent documentation and reporting rules regarding administration of the TAA that can be just as onerous as the basic tenant of ITAR. This includes documenting/logging all foreign communications (voice communications, e-mails, file transfers, etc.), maintaining visitor logs at locations where work is being done (e.g. the basement where the IHU-3 is being tested), etc. Prosecution can occur for failure to maintain proper administrative procedures as well as the inadvertent violation of transferring technical information. The potential implications of administering ITAR are something that AMSAT-NA will need to address.

Our basic dilemma with TAA's is that the basis for this document places the foreign nationals under US law. That is, the TAA places the same restrictions on the foreign nationals for subsequent responsibility for limiting distribution of information that they receive under the TAA as US citizens. For example, if the IHU-3 were to be subsequently provided by AMSAT-DL to another AMSAT organization that does not have a TAA with AMSAT-NA, then the volunteers within AMSAT-DL could be subject to US criminal prosecution.

AMSAT Compliance Guideline

AMSAT-NA will then continue work on a formal “AMSAT-NA ITAR/EAR Compliance Guideline” to be made available to all AMSAT-NA members. It is planned to be a do’s and don’ts document for our volunteers.

Conclusion

One can argue that ITAR has caused countries that were once our space industry's customers to develop their own space/satellite industry. Some say we are losing our technical edge in space to the newly forming foreign competition[iii],[iv],[v],[vi].

Whatever complaints one puts forth about export control rules such as ITAR and EAR, the simple fact is they are here, they can apply to us and they must be adhered to. Understanding, following and working within the export control rules must be an on going activity for AMSAT-NA if we are to continue our joint satellite development efforts with other AMSAT organizations.

References

[i] Bureau of Industry and Security - U.S. Department of Commerce - EAR
http://www.bis.doc.gov/

[ii] U.S. State Department – Directorate of Defense Trade Controls – ITAR
http://www.pmddtc.state.gov/regulations_laws/itar_official.html

[iii] Europeans begin funding development of alternatives to U.S. satellite components by Peter B. de Selding. Space News, v.16, no.6, 14 February 2004, p.1.

[iv] U.S.-built components banned from Galileo Program: Blaming export laws, Europeans start replacing trusted hardware suppliers by Peter B. de Selding. Space News, v.14, no.13, 31 March 2003, p.3.

[v] Arabsat credits tough U.S. export rules in decision to choose EADS by Peter B. de Selding. Space News, v.14, no.41, 20 October 2003, p.1.

[vi] Thales Alenia Space will be building an "ITAR-free" satellite, Palapa-D, so that it can be launched on a Chinese Long March rocket

P3E's Software Defined Transponder (SDX)

Presented by

Howard Long, G6LVB

Abstract

Over the past few years, the rapid development of Software Defined Radio (SDR) techniques has led to these technologies becoming into mainstream use. Although the large dynamic range and flexibility afforded by SDR facilitates many benefits for space applications, the environmental considerations of space have considerable affect on the design of P3E's SDX.

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 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. 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. More recently, his business has expanded into providing business processing solutions for the international wholesale insurance markets.

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 groundstation hardware and software for ESA's SSETI Express project 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 next door to the Science Museum, and when not nailing down problems with London's stock trading systems or working on his latest amateur satellite project, he collects wine from around the world and writes restaurant reviews.

1 Introduction

The term Software Defined Transponder (SDX) was originally coined around July 2005, when separately AMSAT-NA and AMSAT-UK were coincidentally working on very similar technologies as an extension to the use of Software Defined Radio (SDR). The reasons for switching to this technology were clear: not only does SDR afford a large dynamic range, it also allows much more egalitarian use of available passband and the possibility to improve the efficiency of transponder transmitters.

At the 2005 AMSAT-UK Colloquium, the author demonstrated the prototype for automatic frequency selective notching technology (Satellite Transponder and Equalizing Level Limiting Adapter, STELLA) on a PC with an I/Q modem that could be either a plug in replacement or optional transponder payload for existing 10.7MHz IF transponders.

Since that time, the demand for such a device, from being a simple proposal, has become widely accepted as the future of linear transponders, in particular for High Earth Orbit satellites.

More recently, a great deal of work has been done to engineer the design for space use. Of particular concern for reliability are the considerations of thermal design, radiation mitigation and component choice.

2 SDX overview

The primary design of any linear transponder is to receive signals on one frequency passband and retransmit a facsimile of those signals on another frequency passband. For Phase 3 satellites, typically the uplink passband is downconverted to a 10.7MHz IF where an AGC limits the entire passband, and subsequently the signals are upconverted to the desired downlink passband frequency.

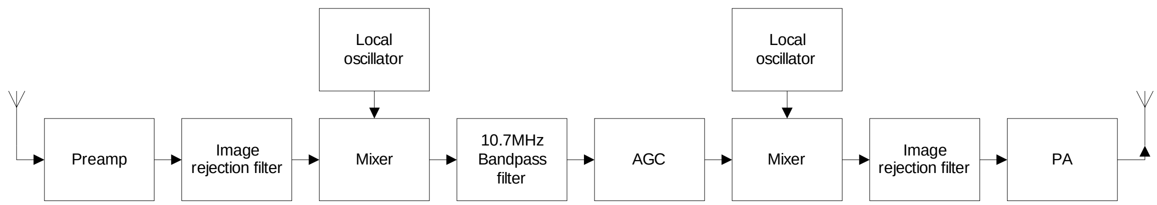

Figure 1: Typical Phase 3 transponder design

The original concept behind the SDX was to replace the AGC component and replace it with a software defined transponder comprising of a 10.7MHz downconverter, A/D converter, DSP processor, D/A converter and 10.7MHz upconverter, making it plug compatible with the existing AGC.

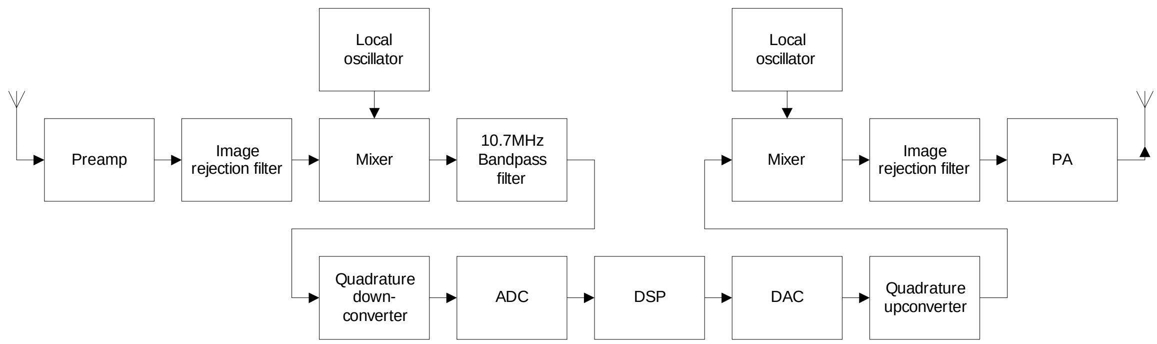

Figure 2: Original SDX proposal, replacing the AGC

Originally, up and downconversion was to be performed by digital up and downconverters, but the power consumption of these devices is too high to be considered for this application. Not only is there power budget to be considered, but also the difficulty of dissipating the heat in a vacuum environment. Finally, the design switched to using quadrature sampling detectors and exciters for the function, together with quadrature local oscillators. Although dissipating less power, a disadvantage of using QSD/QSE is that baseband image rejection is dependent on very tight component tolerances. It is however possible to correct for this using software methods.

A further consideration when using zero IFs is that noise proportional to 1/f means that resolving signals at, or very near, the LO is not possible. So rather than even attempting to do this, at the LO frequency a standard 400bps BPSK beacon is placed on the downlink and the corresponding uplink around this is notched by the DSP.

A departure from the QSE is in the V band exciter. For this stage, a direct conversion quadrature upconversion is performed to 145MHz to provide the constant envelope phase, and the baseband envelope is provided separately. This allows for a more direct HELAPS interface.

The prime motivator for the SDX was STELLA, or Satellite Transponder with Equalizing Level Limiting Adapter. This has been covered in detail in other texts, and in précis the functionality of STELLA is to be able to provide a level playing field for all stations. Traditional AGC technologies use the strongest signal as the basis for their level limiting. Thus, one single strong signal can attenuate other, more well behaved signals. STELLA resolves this by automatically detecting strong signals, implementing adaptive notches on those signals without disrupting other service users.

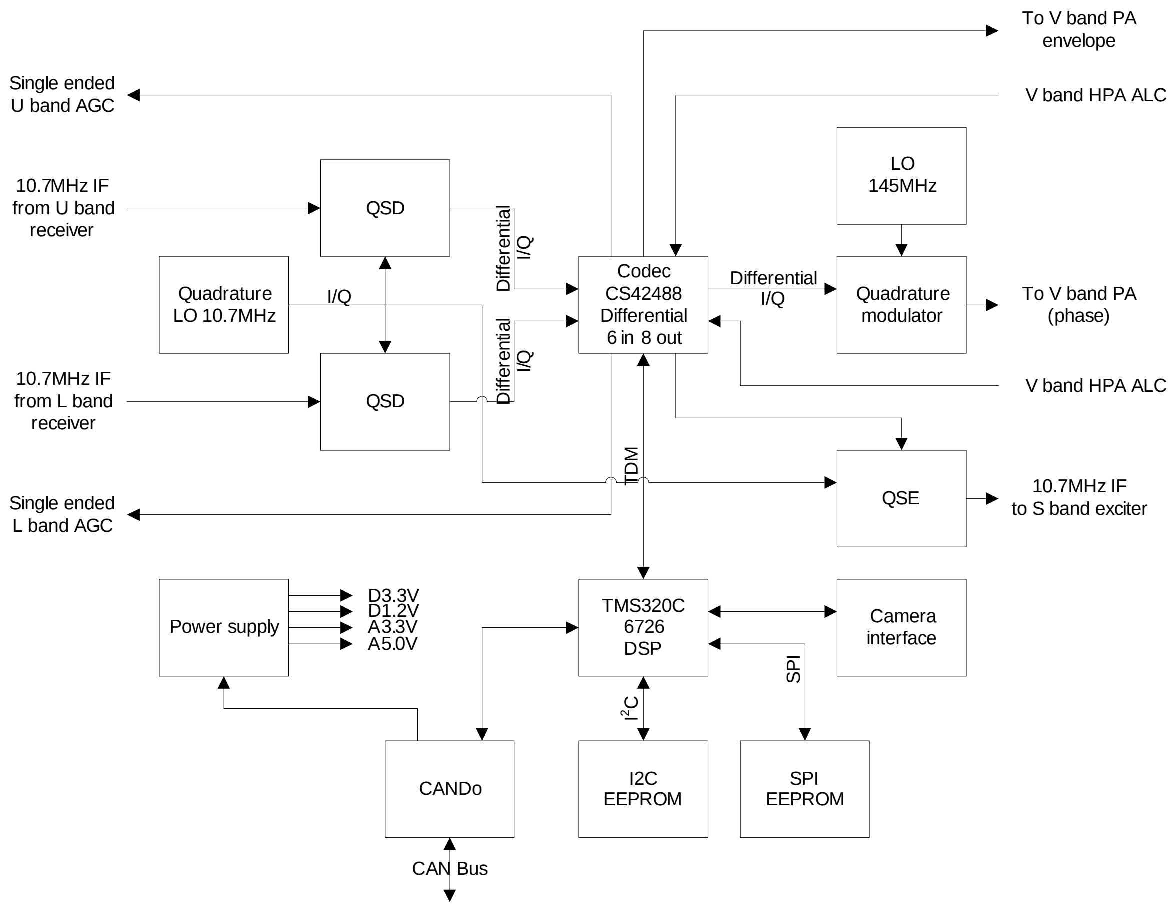

Figure 3: P3E's SDX

Furthermore, the ability of the SDX to detect strong signals also allows it to detect and minimize the effect of radar signals such as PAVE-PAWS. Once the signal can be modeled, it is possible to minimize the impact on certain modes, particularly analog voice and CW. With non-error correcting digital modes, it is more difficult to remove the impact of such interference.

Already, firmware and hardware for the SDX has been demonstrated covering FEC and non-FEC 400bps beacons, notching of the passband around the beacon, a CW beacon, the linear transponder and STELLA.

From peer review, it has become clear that mitigations against the harsh environment of space are essential.

3 Component selection

When designing terrestrial devices, certain problems are low on the priority list during parts selection. Sometimes, a completely opposite choice of part will be made for a terrestrial application, such as the choice of RoHS parts.

The choice of parts for use in space is a difficult one for many reasons. Although there are often space qualified parts available, often these devices are from limited production runs and modeling their failure modes with such a small sample can often lead to a less reliable device than a COTS (commercial off the shelf) device. There are also the considerations of both limited availability and selection of parts, and the inevitable cost premium of using space qualified parts.

Frequently, when considering what constitutes a part as “space qualified” thoughts turn to the thermal, packaging and radiation concerns.

More and more frequently nowadays COTS parts are rated to -55ºC to +125ºC, and where available these parts are chosen over the standard commercial range of 0ºC to 70ºC.

The plastic encapsulation of devices is often considered bad practice for use in vacuum due to outgassing. Obtaining the right part with, for example, a ceramic package, is invariably both difficult and extremely expensive. Care must be taken when placing and soldering plastic parts to ensure that the part is not contaminated (for example grease from fingers), and that it is uniformly heated to minimize the possibility of cracks occurring on the package.

Larger integrated circuits nowadays often have the chip die mounted on an exposed tab on the underside of the device. Not only does this provide further low impedance paths to ground, but it also has significant thermal use. Frequently manufacturers provide land patterns for use on PCBs, and attention must be paid to how the heat may be further dissipated not only using the PCB's ground plane, but also provision for the insertion of a low thermal resistance to the chassis underneath the PCB, bearing in mind the thermal impact of operation within a vacuum.

The choice of capacitors is often difficult. Although it is quite common to use tantalum rather than standard electrolytic parts, the failure mode of a tantalum device can be catastrophic particularly when used for power supply decoupling. It is thus very common to derate the voltage rating by a significant amount, typically at least 50%. For this design, AVX TAJ and TPS tantalum capacitors are used extensively, and these are the same devices that SSTL have used historically.

On occasion tantalum capacitors cannot be used as a direct replacement in certain situations, in particular timing and power supplies. For long term timing purposes, the leakage of a tantalum capacitor may be excessive, in which case a ceramic capacitor may be used, although care in the selection of dielectric must be used (eg, X7R) in order to maintain relatively acceptable constant value over a large temperature range. For power supply applications, it is not uncommon for regulator data sheets to include *minimum* ESR specifications.

The choice of 1% C0G/NP0 capacitors for all baseband filters allows closer I/Q channel matching (thus reducing the baseband image) as well as providing a zero temperature coefficient. Parts are accurately matched prior to installation. It is often difficult to source 1% C0G capacitors in larger values, and so individual package sizes for certain values vary dependent on the availability or parts. Similarly 0.1% resistors are used for baseband filters.

Resistors are also commonly derated for power dissipation purposes.

Satellite power budget also makes some big demands on designers during part selection. For example, when designing the QSE/QSD, the amplifiers used were chosen for their low noise, low voltage, single supply, rail to rail operation. Low noise, for the QSD in particular is of prime concern, but also a wide dynamic range is needed. This is at odds with our low power and therefore low voltage considerations. In terrestrial SDR, QSE/QSD amplifiers operating at +/-15V provide a spectacular dynamic range, but at the cost of almost 1W per amplifier: catastrophic to power budget and thermal considerations. Using low voltage rail-rail I/O differential amplifiers can make an enormous difference on power while limiting the effect on dynamic range.

Power budget also dictated the use of a single multiple channel CODEC for ADC/DAC operation rather than the use of several duplicated devices.

The choice of devices that are not lead free is also preferred. Tin whiskers are a phenomenon that can have disastrous effects, and leaded parts are significantly less susceptible to such incidents of failure. Unfortunately increasingly it is becoming more difficult to source leaded COTS parts.

4 Schematic design

Predominantly, thermal, vacuum, shake and radiation are our main considerations when designing for space. Once the parts have been chosen, bearing in mind these concerns, it is mitigation against radiation that is foremost when designing the schematic.

Although it is possible to extend the life of parts due to total ionizing dose and reduce the chances of single event effects (SEE) with shielding, it is not possible to completely guarantee against SEE particularly when a satellite is in GTO, traversing the inner Van Allen belt regularly.

SEEs may cause simple memory bit flips. This may cause the firmware to crash or produce undefined behaviour. This can be mitigated against by using a short term watchdog timer so that the entire device is powered down for a few seconds and then brought back on line. In this design, there is an autonomous 10 minute timer.

It is also possible that an SEE may cause a direct short across the power supply. In order to attempt mitigation for this, several current detection devices are provided throughout the design, and the power is immediately severed to the entire SDX for several seconds, allowing decoupling capacitors to discharge. This is not fail safe: it is possible that a device may burnout short before the power can be completely removed.

The camera subsection of the SDX is independent of the DSP, and as such is isolated from the DSP in the event of an overcurrent condition in this segment. The DSP can operate independently of the camera section.

If there has been no ground command received for three days, the entire SDX is power cycled.

During a power down, the SDX is isolated from the CAN Do interface.

Each time a non- complete power cycle occurs, the SDX cycles through its next DSP ROM. There are four DSP ROMs, two on an SPI bus and two on an I2C bus. ROM0 is selected if the SDX is specifically powered down from the CAN Do interface. The CAN Do interface can also specify a particular ROM to boot from. As long as there is power, the SDX can run autonomously.

There is a handshake between the camera and DSP, and it is possible for the camera to demand a complete power cycle. Similarly, the DSP can power cycle the camera on demand.

More generally speaking, the design now has the option of using a single oscillator source to derive all clocks in an effort to reduce the possibility of unwanted products. Although thus far this has not been a problem, during peer review it was recommended to follow this as best practice.

To allow for correction of I/Q imbalance on the uplink, a low power DDS is included, injecting a signal into the SDX front end. Correction for I/Q imbalance on the downlink is less problematic as the typical 40-50dB image rejection for the hardware in the design would be difficult to detect on the ground.

5 Conclusion

The design of the P3E SDX has undergone several revisions over the past two years, integrating additional functionality and integrating many features to enhance its reliability for space following peer review. The author welcomes comments to further help in its design.

6 Appendix

The P3E SDX block diagram is shown in figures 4-6. The schematics are shown in figures 7-18.

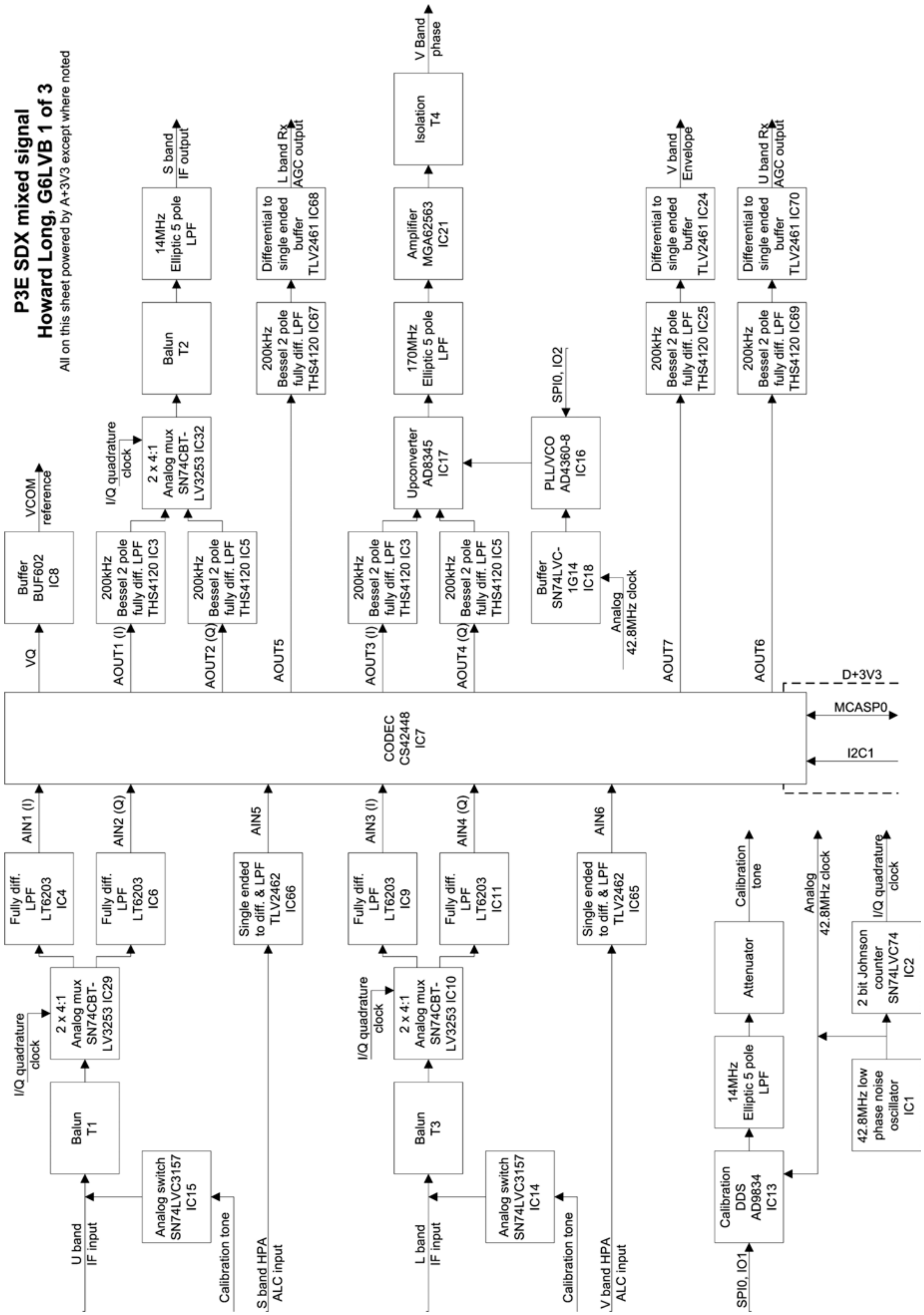

Figure 4: P3E block diagram - mixed signal

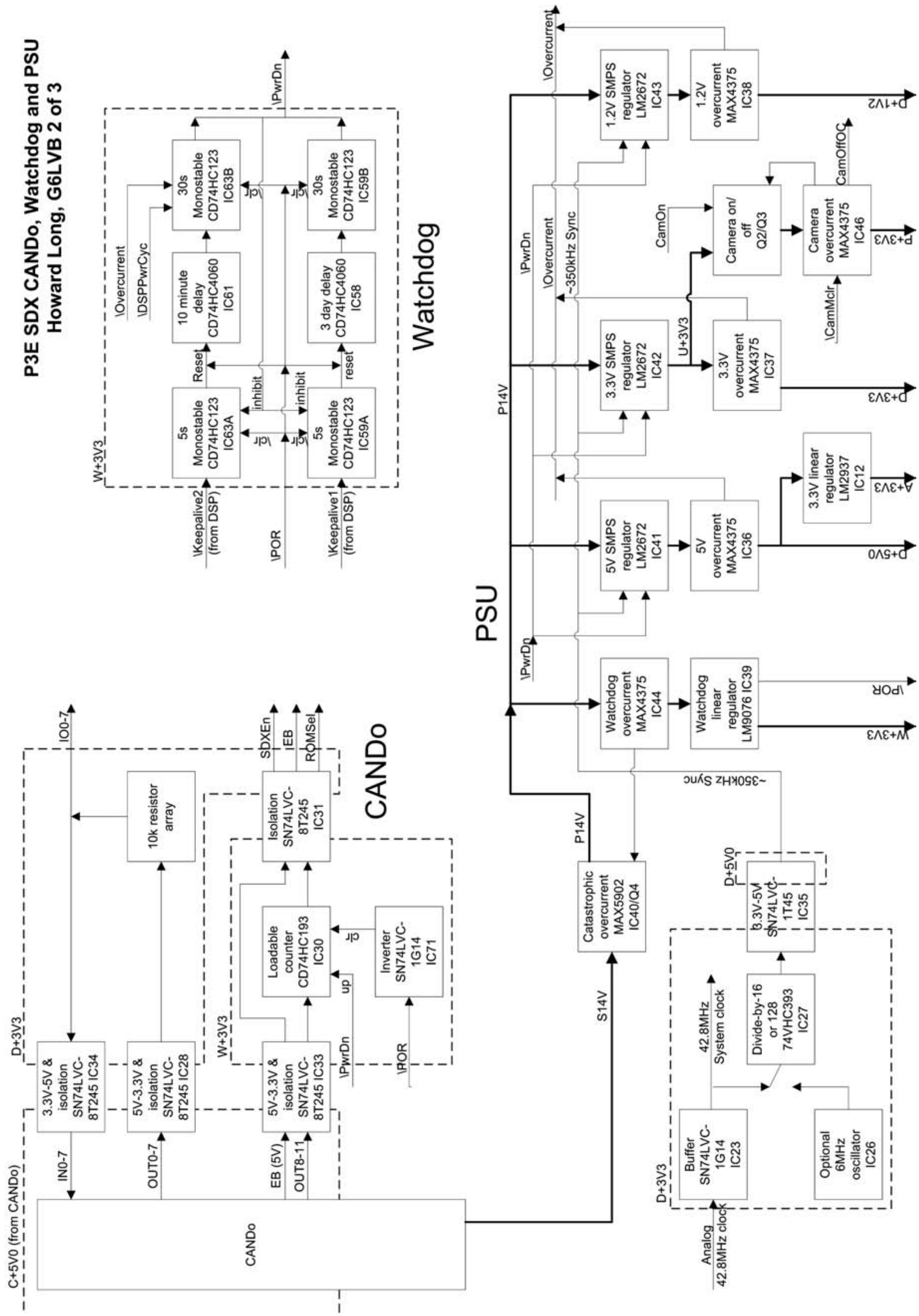

Figure 5: P3E block diagram – CANDo, watchdog and PSU

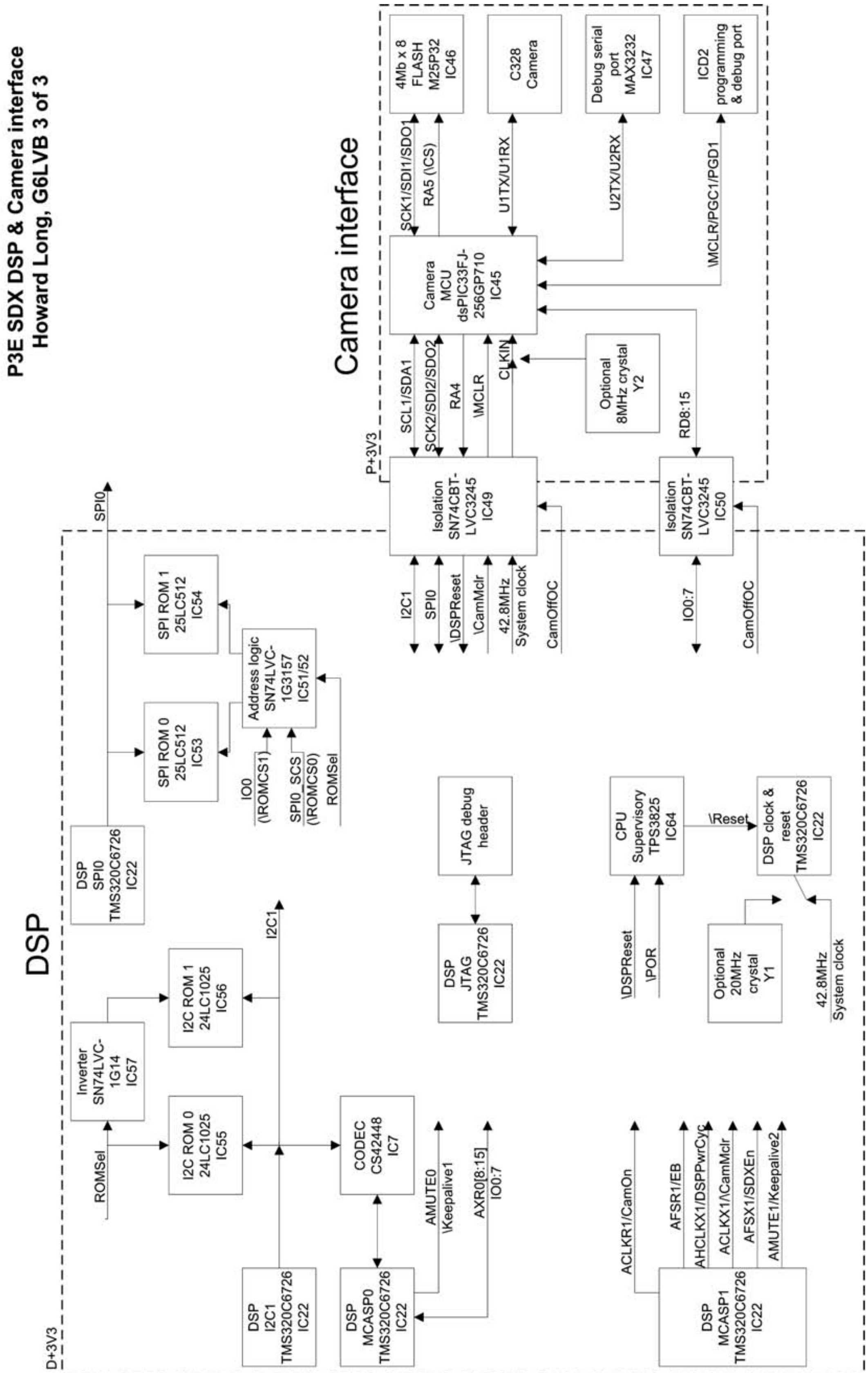

Figure 6: P3E block diagram – DSP & camera interface

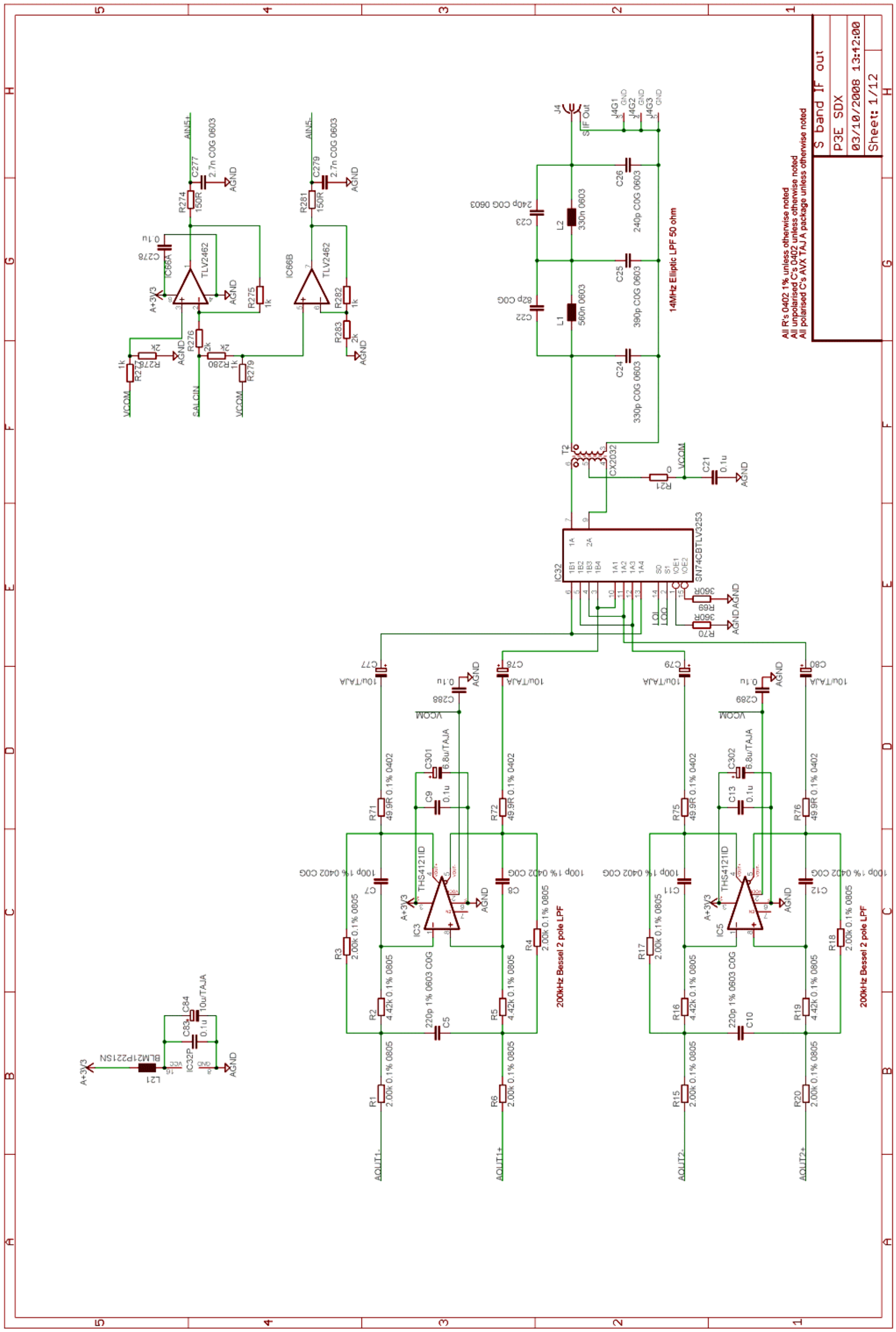

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Figure 7: P3E SDX schematic - S band IF out

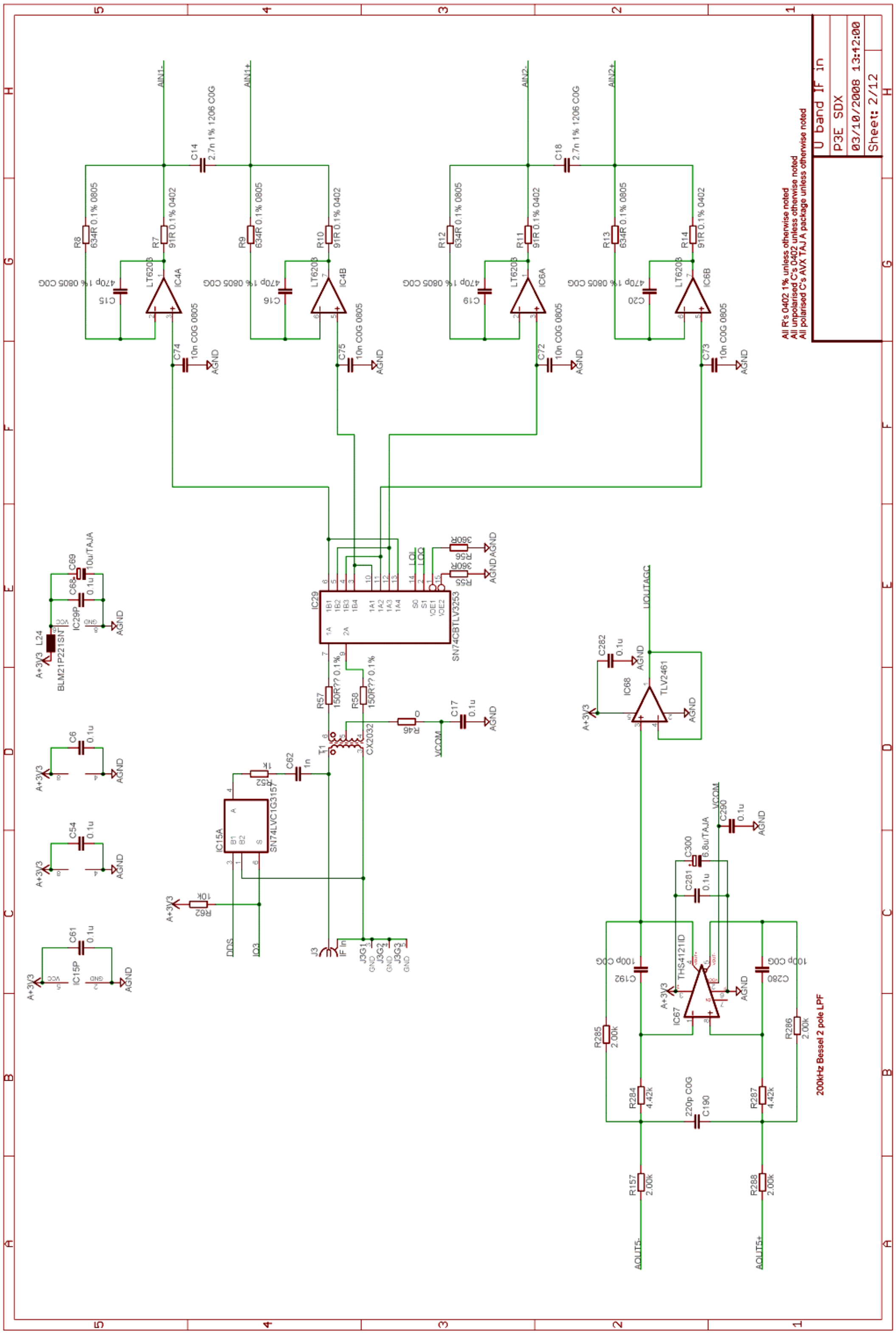

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Figure 8: P3E SDX schematic - U band IF in

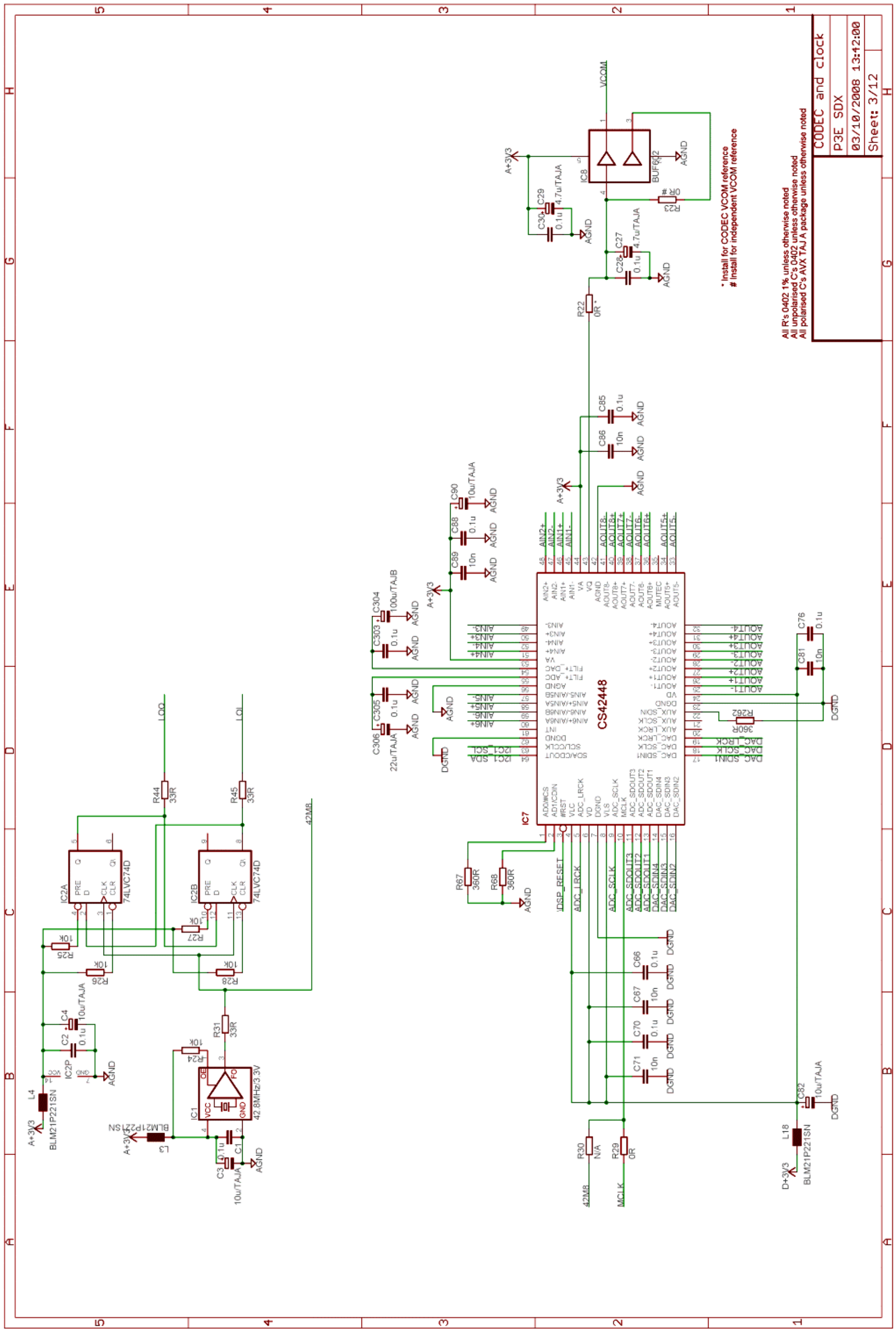

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Figure 9: P3E SDX Schematic - CODEC and clock

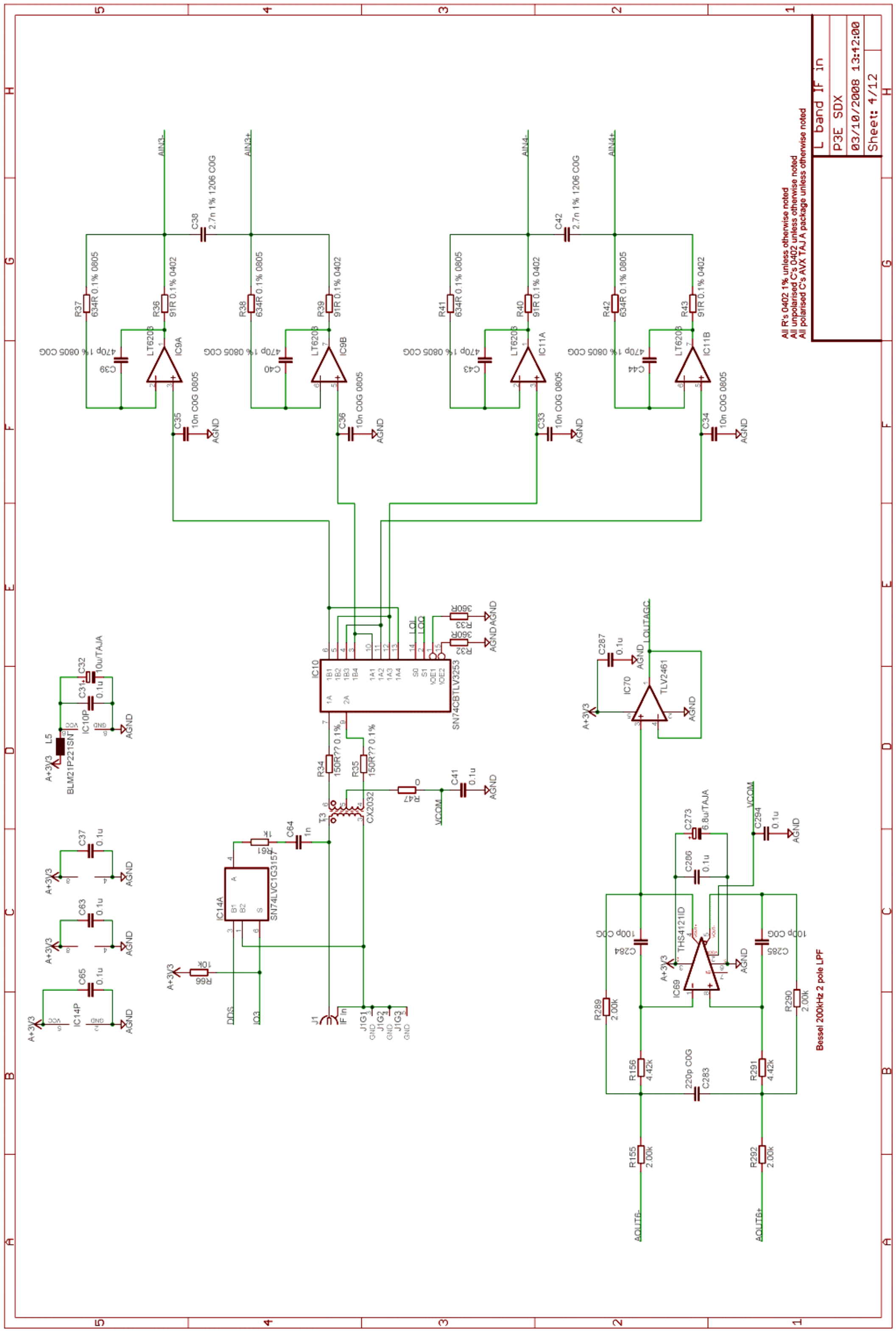

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Figure 10: P3E SDX Schematic - L band IF in

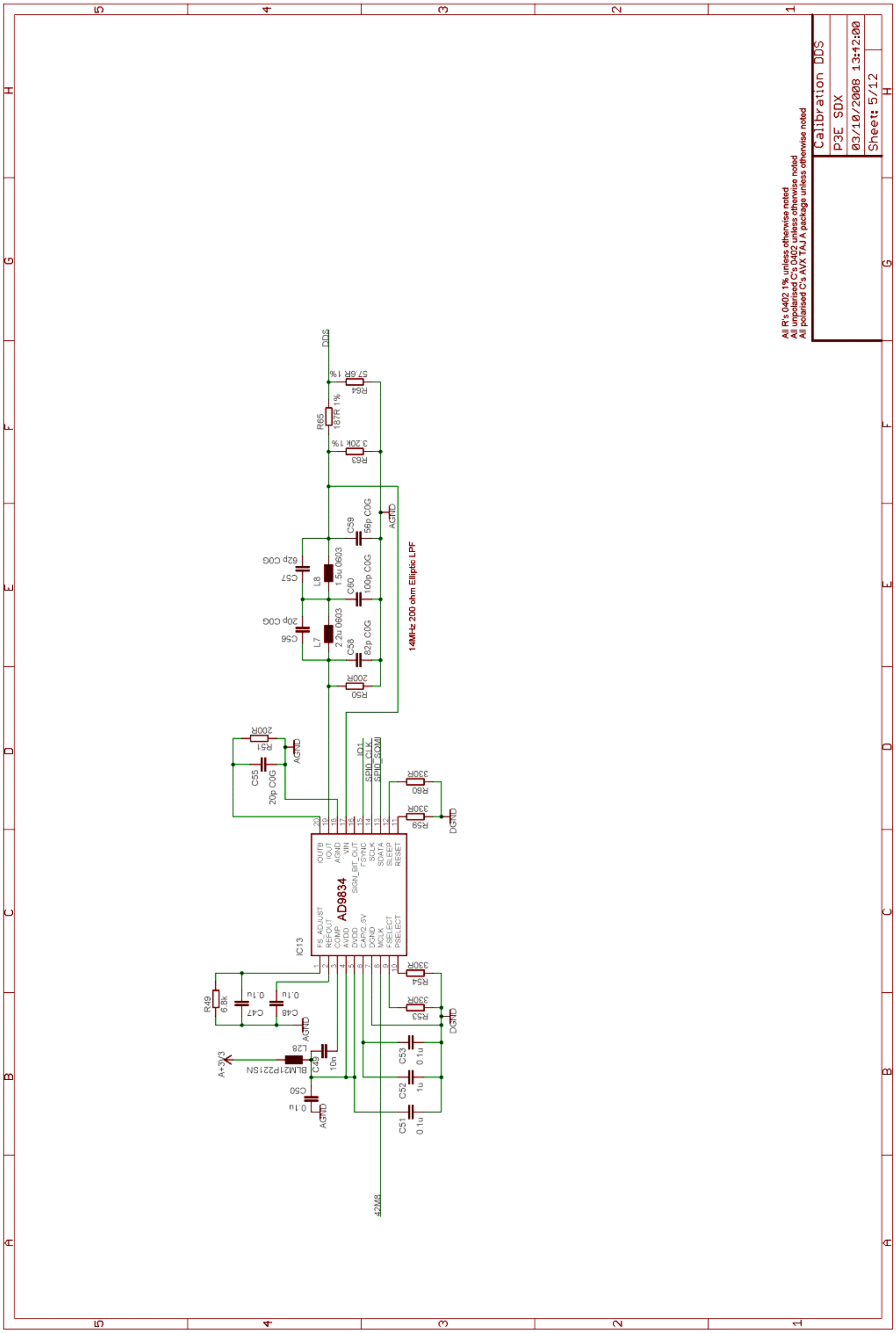

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Figure 11: P3E SDX Schematic - Calibration DDS

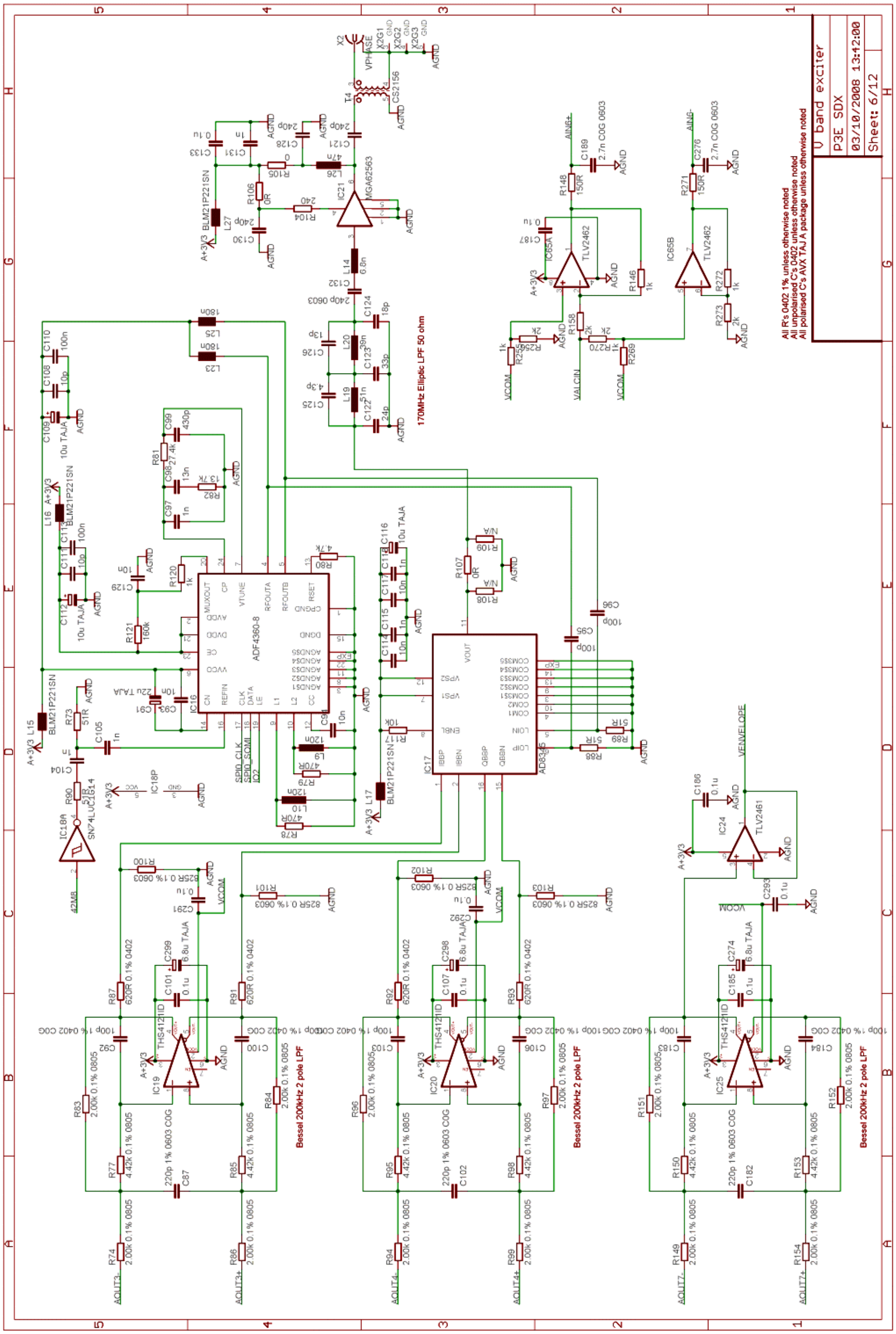

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Figure 12: P3E SDX Schematic - V band exciter

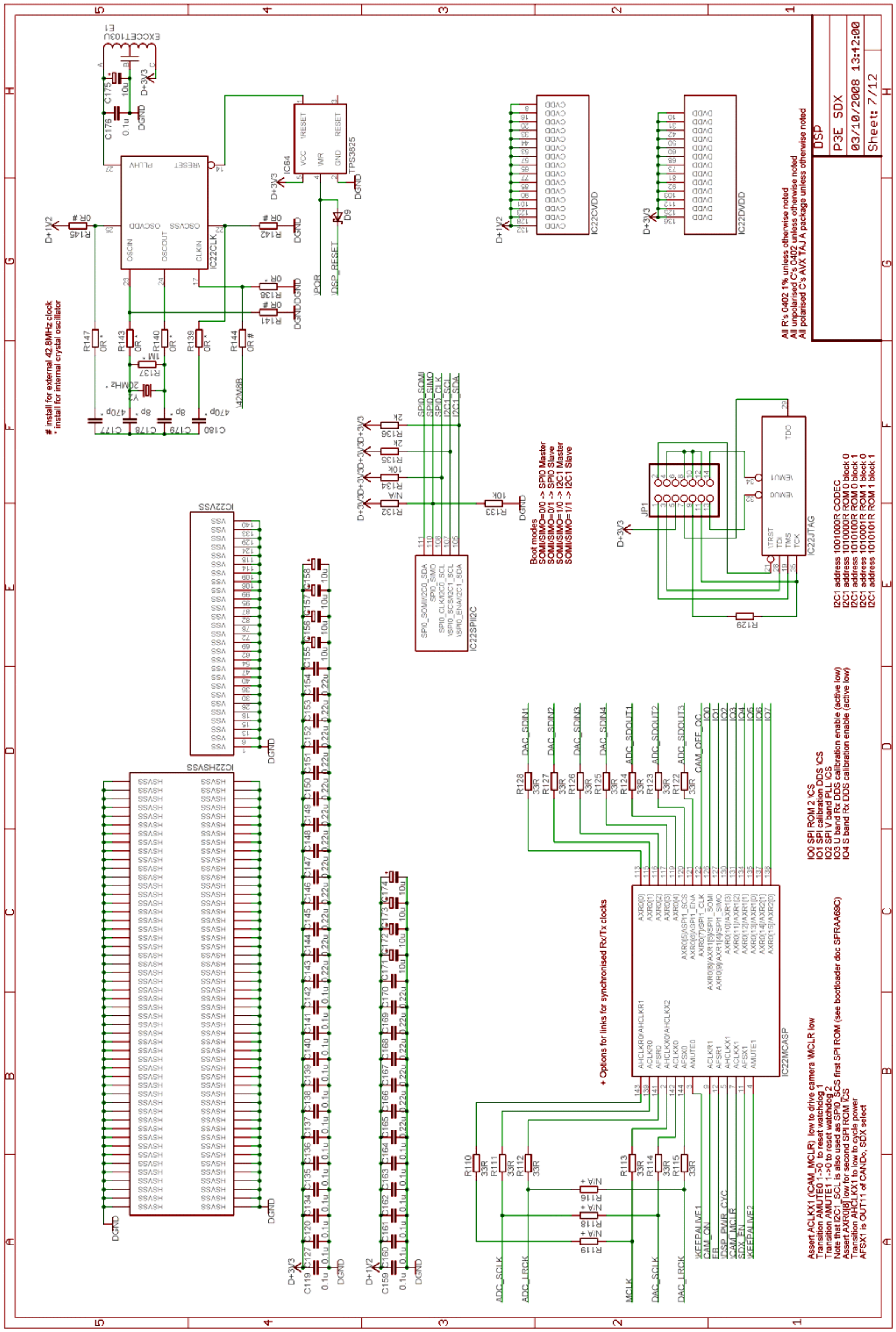

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Figure 13: P3E SDX Schematic - DSP

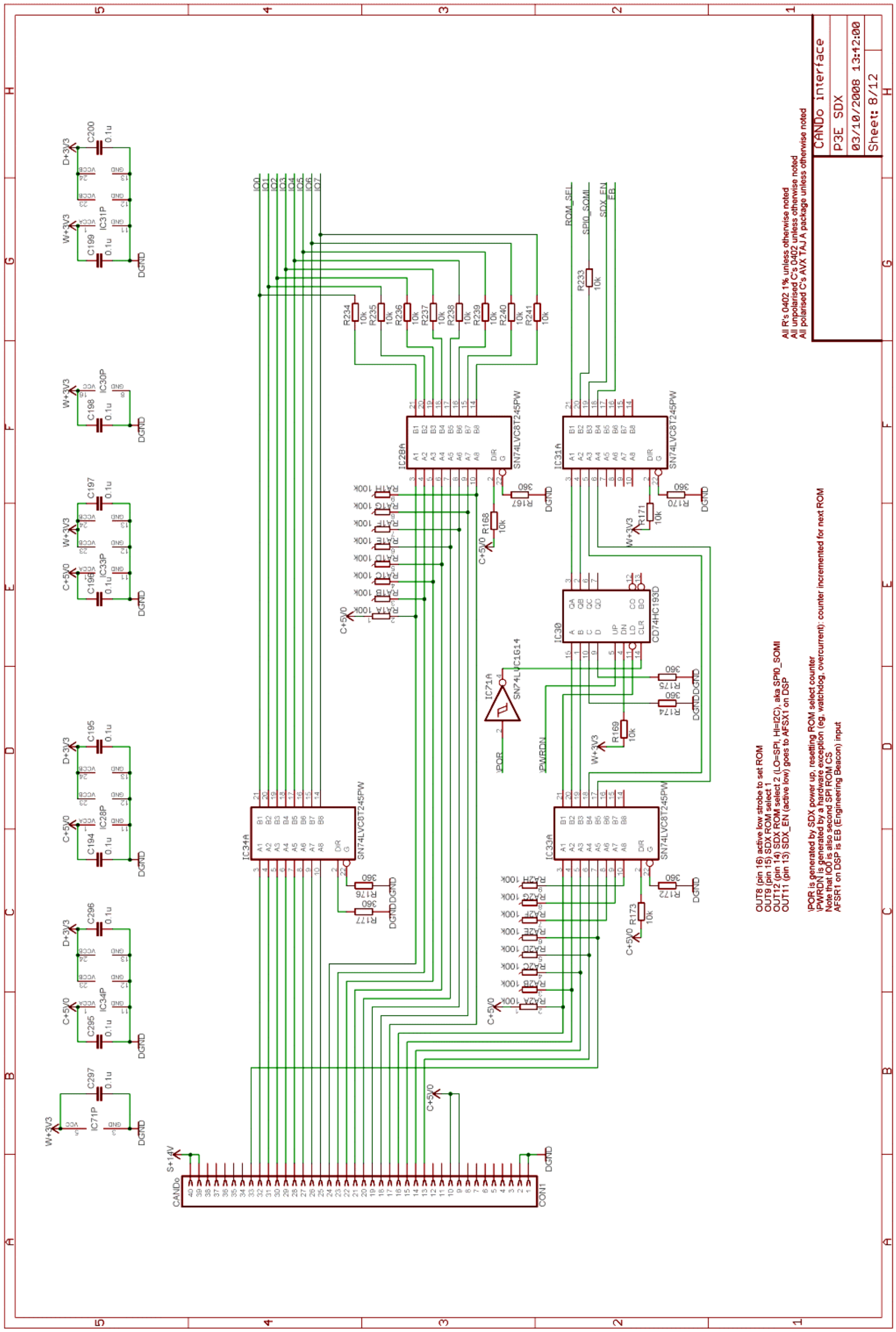

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Figure 14: P3E SDX Schematic - CANDo interface

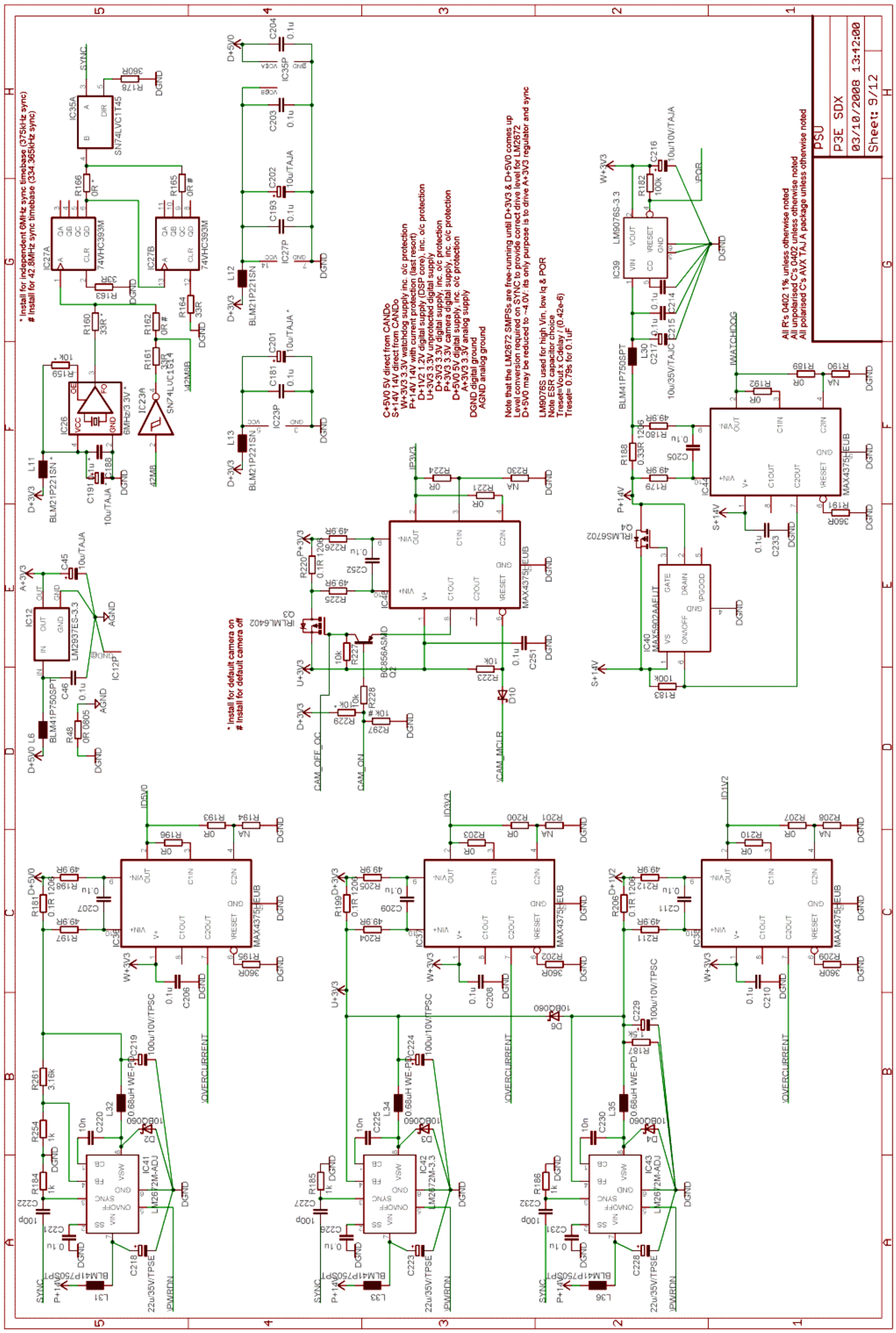

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Figure 15: P3E SDX Schematic - PSU

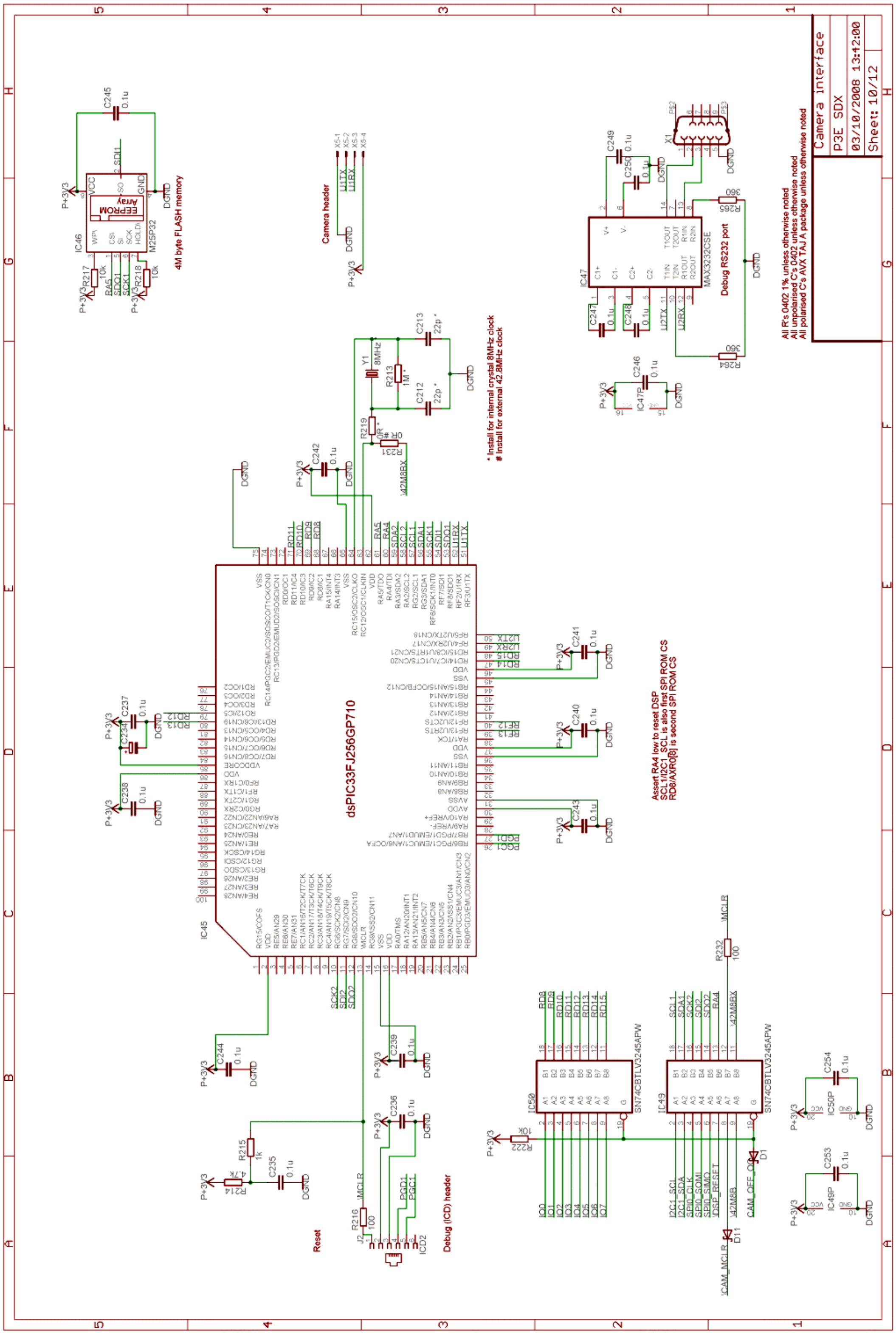

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Figure 16: P3E SDX Schematic - Camera interface

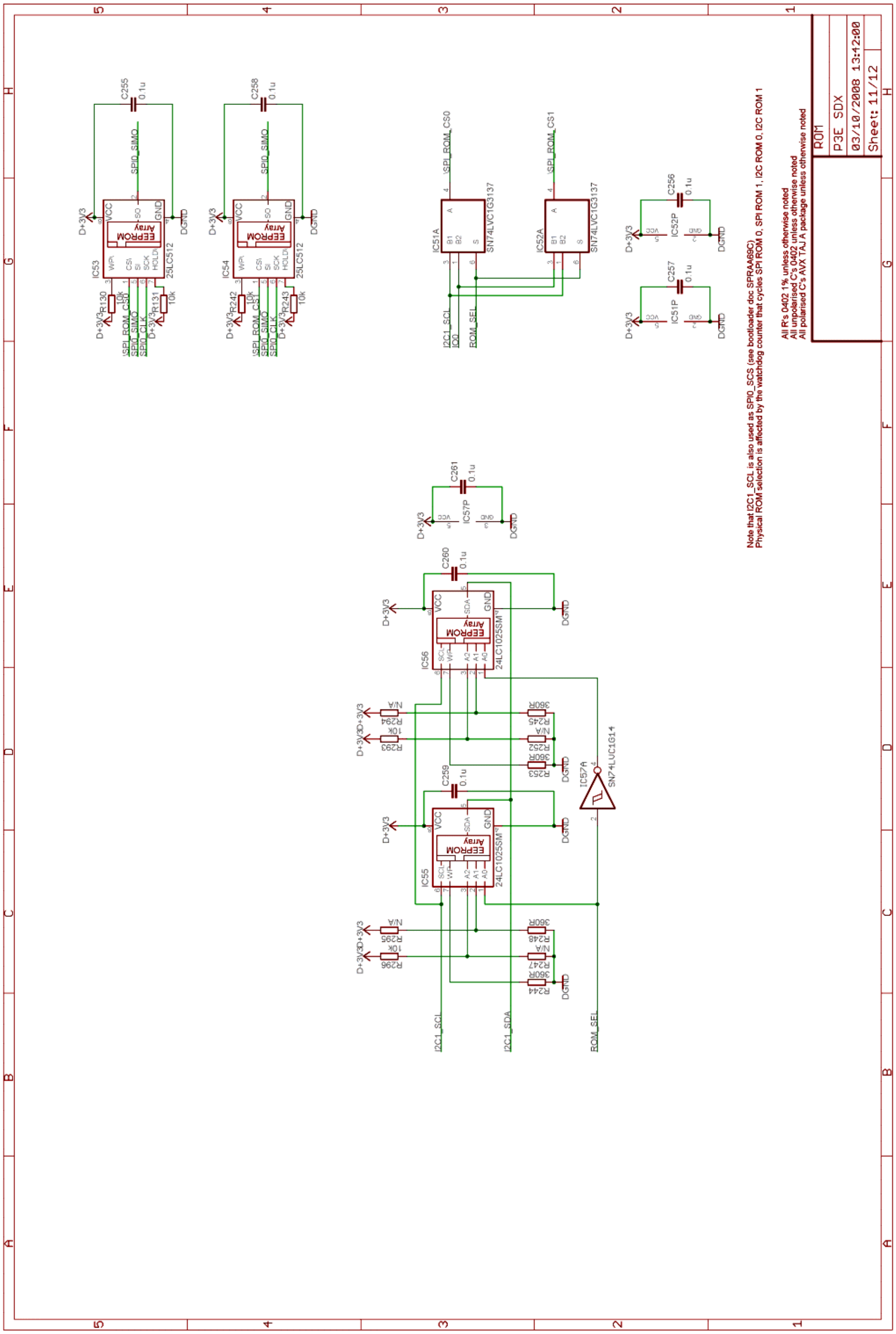

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Figure 17: P3E SDX Schematic - ROM

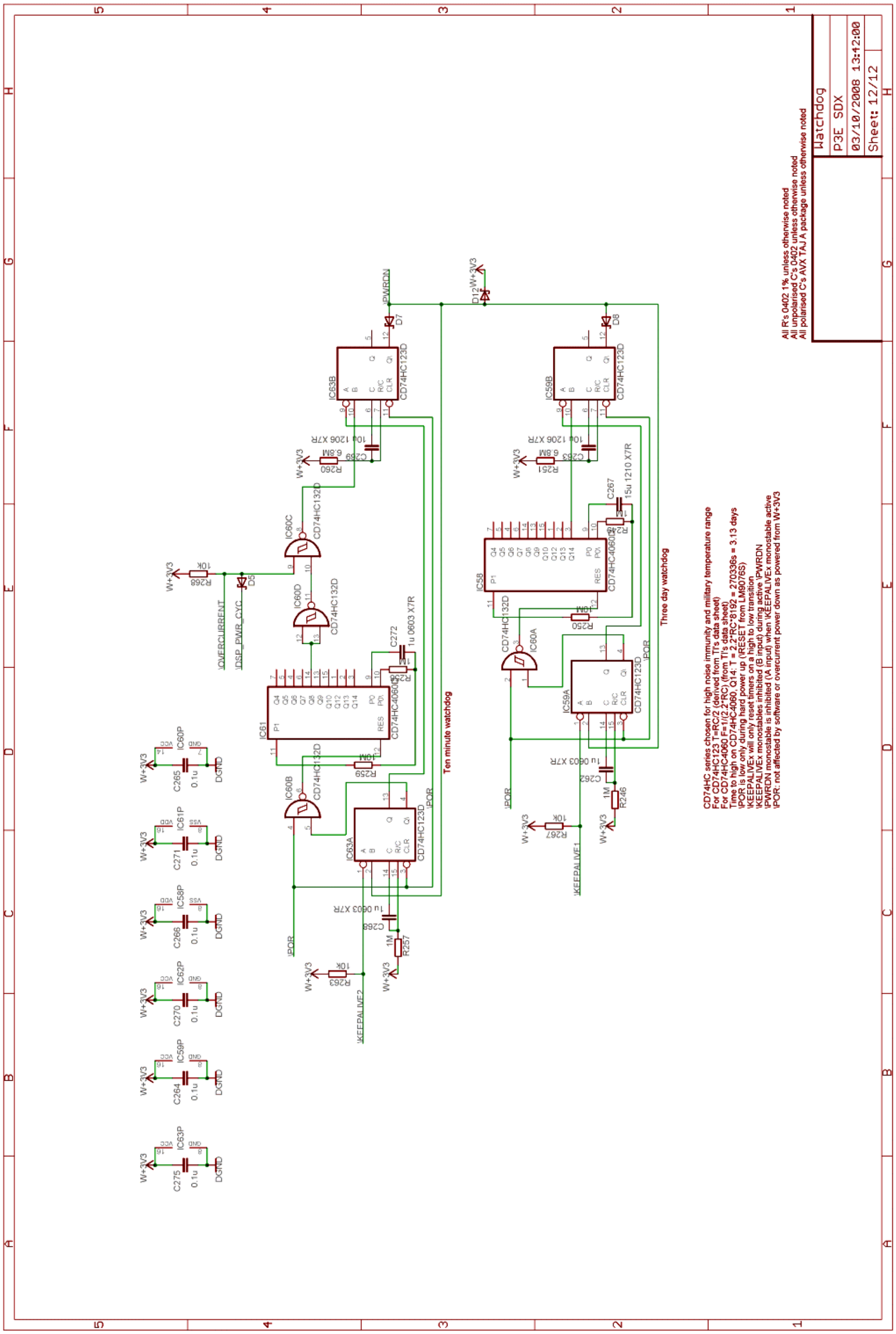

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Figure 18: P3E SDX Schematic - Watchdog

Proposed Network-Centric Architecture for the Advanced Communications Package (ACP)

Timothy J. Salo
Salo IT Solutions, Inc.

Abstract –This paper suggests a system-level architecture for the Advanced Communications Package (ACP). The architecture presented here employs the lessons of the Internet architecture and leverages the Internet protocols to create a network-centric, system-level architecture for the ACP. This high-level architecture is developed by partitioning the required functionality into subsystems, defining interfaces between those subsystems, and assigning the subsystems to hardware platforms. Following that, several fundamental design issues are highlighted, and potential solutions to these challenges are outlined. The resulting system-level architecture should stimulate thought and discussion about the design of the ACP, and may provide a foundation for future ACP design and implementation efforts.

1. Introduction

The Advanced Communications Package is a novel, satellite-based, digital communications system that is enabled by software-defined radio (SDR) technology. The ongoing ACP design work has, up to this point, focused on the lowest communications layers and on the application layer. This paper examines everything that is architecturally in between the lowest communication layers and the ACP applications. The result is a proposed network-centric, system-level architecture. Important benefits of this proposed system-level architecture are that it:

1. Simplifies the design and implementation of the ACP system by placing clear boundaries on the ACP system,

2. Provides a general communications service that supports a broad range of applications, both those that are already planned, as well as not-yet-conceived applications,

3. Opens application development to *any* interested party, by cleanly separating applications from the ACP communications services and by providing a standard interface between the two,

4. Leverages existing Internet protocols and the Internet architecture to enhance interoperability and reduce technical risk, and

5. Helps to identify architectural and design issues that warrant additional study.

2. The Advanced Communications Package (ACP)

The Advanced Communications Package (ACP) uses software-defined radio technology to

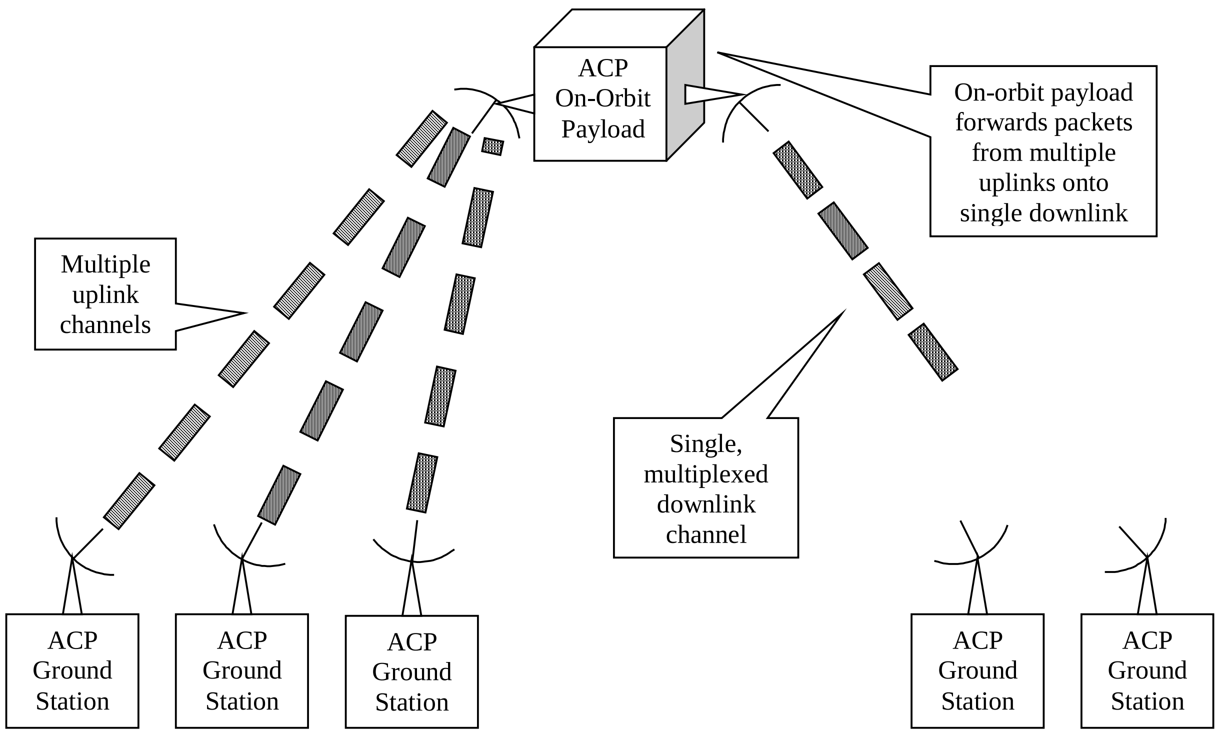

Figure 1. Advanced Communications Package (ACP) Configuration

provide a satellite-based, multi-user, digital communication system [Ettus 2006], [Ettus 2007], [Ettus 2008]. ACP ground stations transmit data to the on-orbit ACP payload on different channels. The ACP payload employs SDR technology to demodulate all of the uplink channels simultaneously. Packets received by the ACP payload on the uplink channels are statistically multiplexed onto a single downlink channel. Each ACP ground station extracts from the single, multiplexed downlink the packets in which it is interested. Figure 1 below illustrates how the ACP payload multiplexes packets received on different uplink channels onto a single, statistically multiplexed downlink channel.

An important design objective of the ACP project is to minimize the complexity of the ACP on-orbit payload. As a rule, intelligence should be placed in the ground stations, rather than in the ACP payload. Consistent with this objective, the ACP payload should do little more than forward packets from the uplink channels onto the downlink channel.

The ACP will support numerous simultaneous channels [Thompson 2008b]. Each ground station will use its own uplink channel (although the ACP payload won't be able to prevent ground stations from sharing an uplink channel, either inadvertently or intentionally).

Multiple classes of ground stations will be supported. Less-capable ground stations will transmit at lower bit rates, while the ACP payload will encode packets destined for less-capable ground stations in a fashion that makes them easier to decode reliably. The ACP payload will forward fixed-length 225-byte packets.

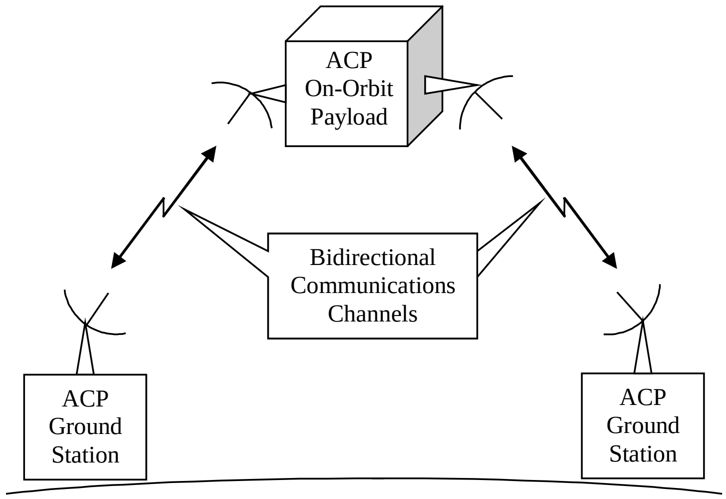

Figure 2. ACP Configuration - Abstracted View

The ACP system is being developed by the Radio Amateur Satellite Corporation – North America (AMSAT-NA). AMSAT anticipates that the ACP payload will be carried on either a high earth orbit (HEO) satellite or a geosynchronous earth orbit (GEO) satellite. Information about the project can be found on the AMSAT Web pages (http://www.amsat.org/).

Most of the design work on the ACP to date has focused on the lowest communications layers (e.g., modulation techniques and forward error correction (FEC) technology) and on the applications that will use the communications services provided by the ACP payload. This paper outlines a proposed system-level architecture that uses the lower-level services provided by the ACP payload in order to support ACP applications, both the applications that have been proposed, as well as those that have not yet been invented.

For the purpose of exploring a system-level architecture for the ACP, it is useful to abstract away the details of the lower communication layers, such as how the uplinks and the down link are multiplexed and the details of the on-the-air encoding of bits and packets. In this abstracted view, illustrated in Figure 2, the ACP payload simply provides a bidirectional, packet-based, digital communications channel between two ground stations. With a little forethought, this simple model can easily be extended to include simplex communications (e.g., systems that transmit sensor data, but don't receive), point-to-multipoint communications (e.g., publish/subscribe disseminations models, such as RSS feeds) and multipoint-to-multipoint communications (e.g., full-duplex multiparty audio or video conferences).

3. Proposed ACP System Architecture: An Initial Refinement

The initial architectural design decisions segment the ground station two major subsystems, identify the boundary of the ACP system, and specify a standard interface between the ACP system and its users.

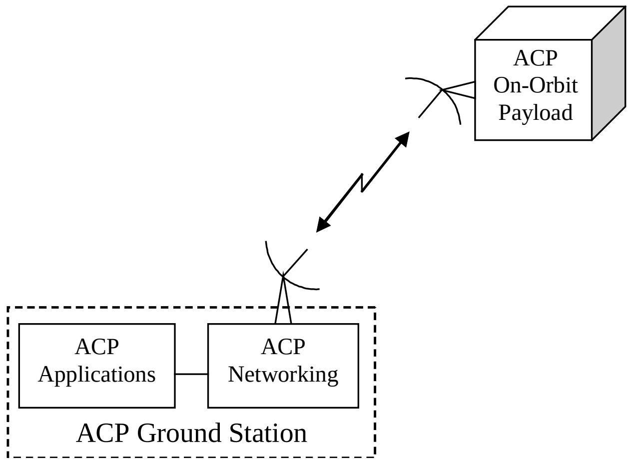

Figure 3. ACP Ground Station – High-Level View

3.1 ACP Ground Station Architecture

An important lesson of the Internet architecture is that it is often highly beneficial to separate the design and implementation of the network-related functionality from that of the systems that use the network [Clark 1988]. Applying this widely employed architectural principle to the ACP ground station yields the structure shown in Figure 3. From this perspective, the ACP ground station is composed of two major subsystems: "ACP Applications" and "ACP Networking". The ACP applications include those that are under consideration, such as text-based messaging, voice communications, and video conferencing [Thompson 2008a]. The ACP architecture and implementation should also permit additional applications to be easily developed in the future.

3.2 ACP System Boundary

Properly specifying the boundary of a system, deciding what functionality is provided by the system and what is not, is often critical to the success of a project. The system boundary shown in Figure 4 places the ACP applications *external* to the ACP system. In this view, ACP applications use the ACP system, but are not part of the ACP system. This architecture emphasizes the ACP system as a networking solution that interconnects applications. (Note that the scope of the ACP Ground Station is smaller than is shown in the previous figure.)

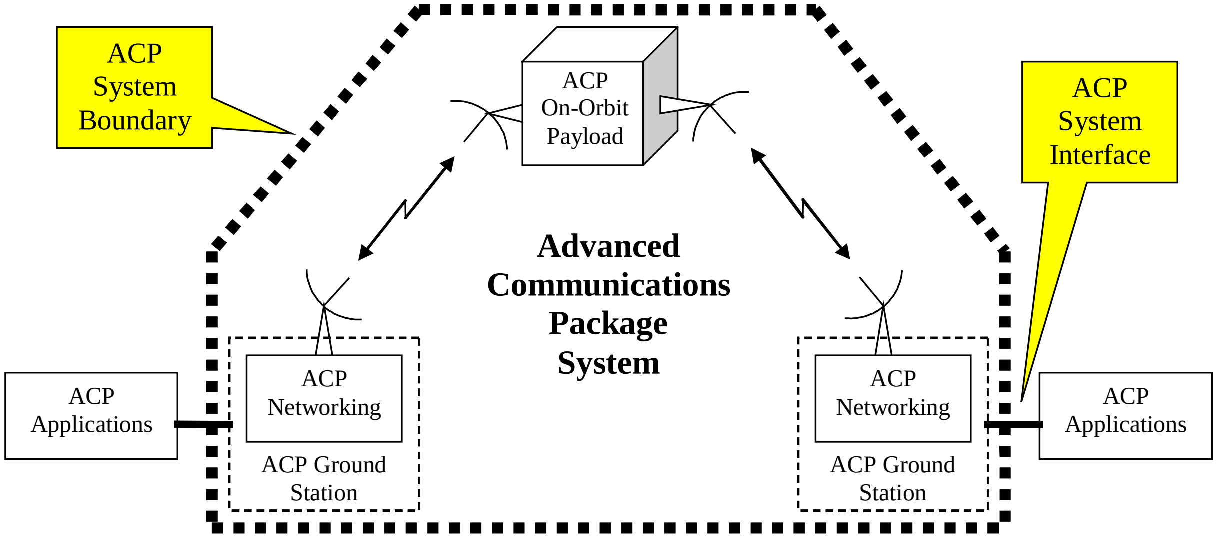

Figure 4. ACP System Boundary and Interface

3.3 ACP System Interface

A significant benefit of this particular specification of the ACP system boundary is that the ACP applications simply view the ACP system as a network that interconnects them with each other, a perspective summarized in Figure 5. The next fundamental design question is: What is the interface between the ACP applications and the ACP system? Describing the ACP system as a network makes one answer obvious: Use the Internet protocol (IP). Specifically, the ACP system forwards IP packets between end systems that host ACP applications. More directly, the ACP system appears to the ACP applications (and to the machines hosting these applications) to be simply an IP network.

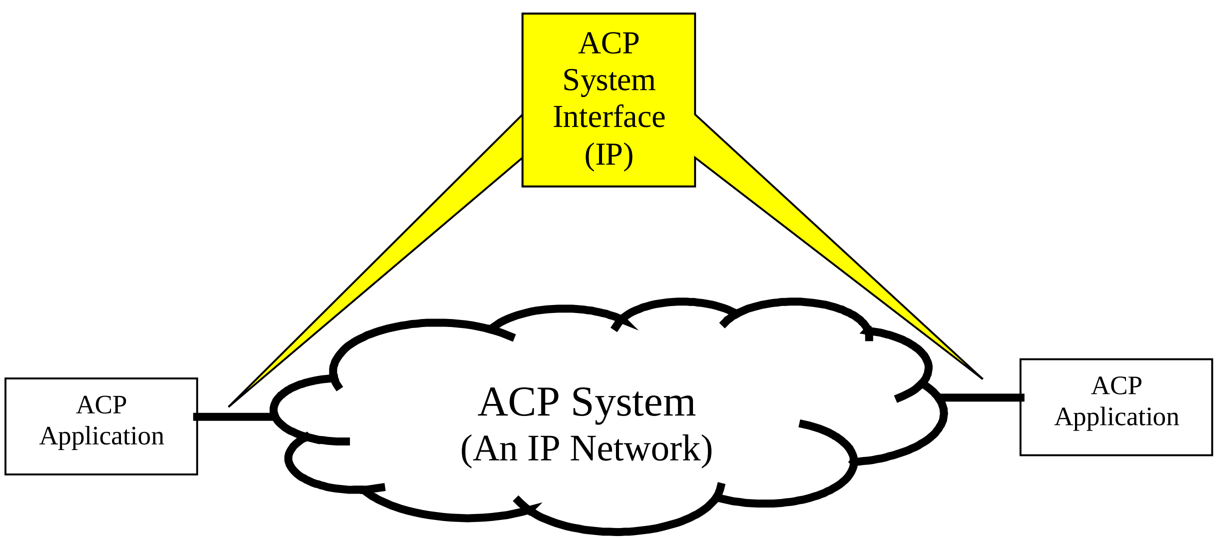

Figure 5. ACP Application Perspective of the ACP System

3.4 Assigning Ground Station Subsystems to Hardware

The architectural decisions described above facilitate the implementation of the ACP applications and of the ACP ground station on different hardware platforms. The ACP ground station can be hosted on a machine that is tailored to its needs, without regard to the needs of the application software, and conversely.

If the ACP applications and the ACP ground station are implemented on different machines, then the interface between them must include a physical link. Inasmuch as the applications and the ground station will exchange IP packets, the most general, applicable physical link is Ethernet. But, this shouldn't be a serious constraint: pretty much every readily available machine supports, or can easily be enhanced to support, an Ethernet interface and the IP protocol suite.

The machine selected for the ground station probably won't have a graphical user interface (GUI) or graphics hardware. And, the machine won't need a lot of memory (because it won't host the applications) and it might not even require a hard drive (perhaps using flash memory instead).

The machine that hosts the ACP applications can be, well, pretty much anything that is able to run the application software and that has IP software and an Ethernet interface. Presumably, most ACP applications will run under Windows or Linux, or under both. But, the application developers are free to choose. In fact, the developers of each application are free to make their own choices about which machine, operating system, and development environment to use, provided that their choices support IP over Ethernet.

4. ACP System-Level Architecture

The system-level architecture proposed here can be summarized succinctly as: The ACP system appears to external devices to be an IP network. More emphatically, external systems are, for the most part, unaware that they are communicating over a satellite-based communications system, rather than over, for example, the Internet.

This architecture naturally divides the ACP development effort into three projects:

- **ACP Applications** This project will develop applications that use the IP networking services provided by the ACP system. It ought to be staffed by software developers who think about human computer interaction (HCI) and graphical user interfaces (GUI). This team will develop application software that runs under Windows, Linux and maybe even MacOS.

- **ACP Ground Station** The objective of this work is to implement the functionality that makes the ACP system appear to external devices to be an IP network. This team will include developers who view the world in terms of packet formats and network protocols. The software they develop may operate in a more specialized environment, perhaps an embedded variant of Linux.

- **ACP On-Orbit Payload** The ACP payload must operate in a very demanding, inaccessible environment. These developers will be concerned with creating highly reliable software that can operate onboard a spacecraft. Fortunately, the functionality that this team must implement is limited to forwarding packets between the uplinks and the downlink, and perhaps a few other tasks that can't easily be performed elsewhere.

This proposed architecture makes the objective of the ACP development clear: the ACP system must look like an IP network; to its users, the ACP system must be *indistinguishable* from any other IP network. The test of whether the ACP development is complete and whether the development team has been successful is very simple: Does the ACP system exhibit the behaviors expected of an IP network?

This IP-based system architecture dramatically simplifies the development of ACP applications. To the extent that application developers are assured that the ACP system behaves like an IP network, they can develop and test their applications using any convenient IP network – like the Internet. If these applications work well over the Internet, but poorly with the ACP system, the first question should be whether the ACP system properly mimics the operation of an IP network. Of course, the ACP system *will* exhibit a few peculiarities that can't be controlled, such as high latency and perhaps high packet-loss rates. But, these unique characteristics can easily be identified. Furthermore, numerous techniques have been developed to mitigate the effects of high-latency paths and high packet-loss rates.

Another benefit of this architecture is that it makes it easy for applications to execute on existing machines. For users, deploying an ACP application should be no more difficult than installing a new software package on an existing machine (assuming, of course, that the machine is running a recent, common operating system and has adequate memory, storage and processing power). (Note that the ACP ground station networking functionality is likely to be deployed on a dedicated machine, but that is really an implementation decision that is up to the ACP development team.)

This architecture opens the development of new ACP applications to almost any motivated person or group. Little specialized knowledge is required, beyond that necessary to develop Internet-enabled software. And, no permission or special dispensation is necessary. The ACP system will transport any IP packets generated by an application, no questions asked. This open application development environment should stimulate the creation of numerous ACP applications, and may even attract new (and much needed) members to the amateur radio and amateur satellite communities.

By this point, it should be clear that even existing networked applications will be able to use the ACP system, and probably without modification. Some applications will require configuration, and some may require that servers be deployed. But, servers, whether they are Web servers or servers that support voice-over-IP (VoIP) networks, can use the ACP system as well – it's just another IP network. In fact, the ACP development team doesn't even need to implement any voice functionality – users could simply connect inexpensive VoIP phones or VoIP software (similar to the Skype software) to the IP services provided by the ACP system.

But, simply asserting that the ACP system will behave like an IP network doesn't mean that this is feasible, or even that it is possible. The remainder of this paper demonstrates the feasibility of this architecture by suggesting how the most significant functionality expected of IP networks might be provided.

5. Potential ACP Design Solutions

In this section, potential solutions are proposed for the most fundamental ACP system design issues. What follows is *not* a proposed design for the ACP system. Rather, this material is merely intended to demonstrate the feasibility of implementing the network-centric, system level ACP architecture proposed above. The actual ACP system design may, in some cases, employ alternative technologies.

5.1 End-to-End Routing

The principle function of the ACP system is to forward IP packets between end systems, namely hosts running ACP applications. Figure 6 illustrates the end-to-end path between *Host A* and *Host B*, including the addresses assigned to interfaces and partial, stylized route tables. Readers with an exposure to IP routing should be able to convince themselves that this information is adequate to forward packets from *Host A* to *Host B*. The next challenge is to dynamically maintain the appropriate information in the route tables.

5.2 Active Ground Station Announcements

One way to construct the necessary route tables is for every active ground station to periodically transmit Active Ground Station Announcements via the ACP payload. Perhaps, a special control channel could be dedicated to this function. If these announcements contain the following information, then every ground station will be able to create an up-to-date route table for the whole system:

- **Ground Station Address** The address of the ground station's ACP interface would be announced. Using the example above, *Ground Station A* would include its address ($Addr_3$).

- **Ground Station Name** Ground stations could be assigned names, as well as addresses. Perhaps, these names could be of the form *host.call*.amsat.

- **Host Address and Name** The other ground stations also need to know about the hosts to which this ground station can connect. In this example, the announcements created by *Ground Station A* might include an address/name pair something like ($Addr_1$, “HostA.ab0do.amsat”).

- **Text Description** While names are more informative than addresses, descriptive text might be even more useful. Perhaps, this example announcement will include the following text: “ACP design video conference”. Or, perhaps this sort of information could be disseminated in an Available Resource Announcement.

- **Transmitter Identification** While the precise requirements for transmitter identification warrant additional study, the call sign of the transmitting station might also be included in this announcement (e.g., “AB0DO).

Each ground station could use a traditional routing protocol (e.g., the Route Information Protocol, RIP) to distribute the route information learned from the Active Ground Station Announcements to the hosts to which it provides service. Note that this Active Ground Station Announcement also provides some other capabilities that will be discussed shortly.

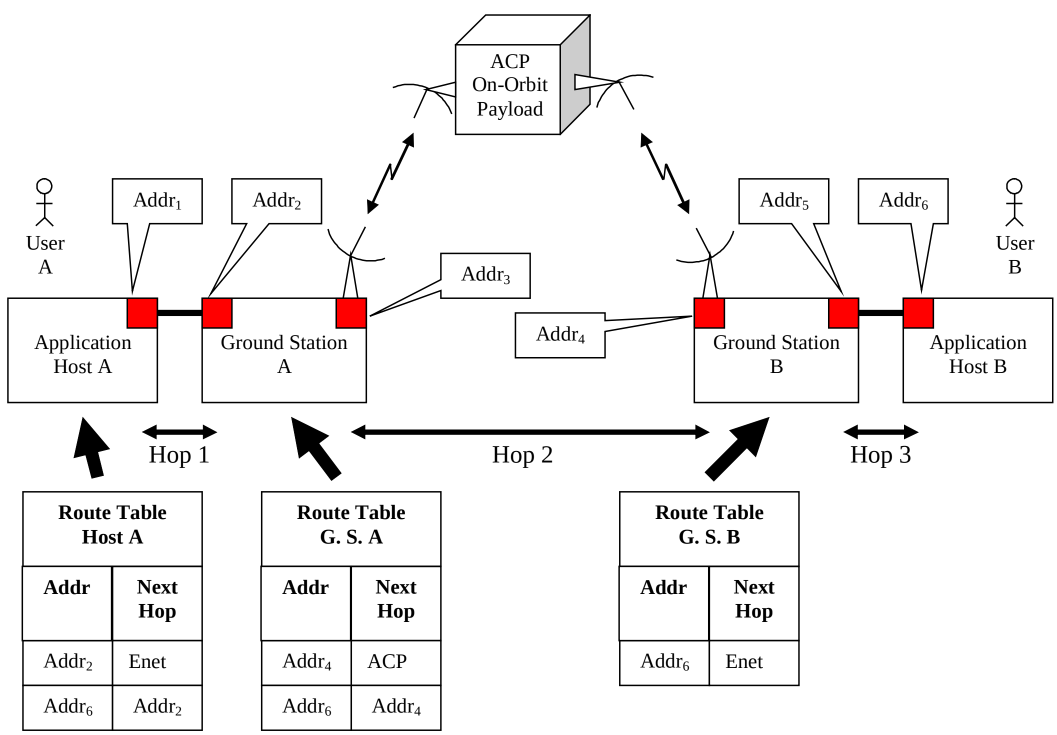

Figure 6. End-to-End Routing in the ACP System

5.3 Resolution of Names to Addresses

Humans generally prefer domain names (e.g., "www.amsat.org") to numeric IP addresses (e.g., 128.54.16.15). The Active Ground Station Announcement described above could be used to make the devices in the ACP system appear as if they were part of the Internet Domain Name System (DNS). Each ACP ground station could implement a DNS resolver, software that translates domain names into numeric IP addresses. Hosts that want to use the ACP system (e.g., machines that host ACP applications) would consult the ACP resolver anytime that they need to translate a DNS name to an address. The ACP resolver would translate ACP names (e.g., names of the form *host.call*.amsat) to IP addresses, based on information learned from the Active Ground Station Announcements. The ACP resolver would forward traditional DNS names to Internet DNS servers. As a result, applications could treat names assigned to ACP devices as if they were Internet domain names. In fact, the applications won't even know whether a name is associated with an ACP device or with a traditional Internet device.

5.4 Segmentation and Reassembly (SAR) Protocol

Because ACP packets are much smaller than IP packets, a simple protocol is required to segment IP packets into multiple ACP packets, and to reassemble those ACP packets back into an IP packet. The ATM Adaptation Layer 5 (AAL5) may provide a useful example.

5.5 Uplink Channel Status Announcements

ACP ground stations will need to determine which uplink channel they should use. One approach is to let each ground station pick a channel that doesn't appear to be currently in use, and then deal with any collisions that might occur. Uplink Channel Status Announcements, messages that describe the status of the uplink channels, could be transmitted on the downlink periodically. Perhaps, each packet on the downlink could include the number of the uplink channel on which it was received. A single control ground station could monitor the downlink channel and periodically transmit Uplink Channel Status Announcements on the uplink channel, enabling every ground station to easily learn the status of the uplink channels.

6. Conclusion

This paper proposes a network-centric, system-level architecture in which the ACP system provides general networking services to its users, ACP applications. By appearing to be an IP network, the ACP system can support existing Internet-enabled applications, as well as open the development of new ACP applications to any interested party. This model has applicability well beyond satellite communications. It is beneficial to terrestrial wireless digital communication systems that use technologies similar to the ACP. In fact, this model is useful for *any* digital communications system. The benefit is the same: nearly any existing

Internet-enabled software or device can, with minimal effort, use the services offered by these communications systems.

7. References

1. [Ettus 2006] Ettus, Matt. "Proposed Eagle Advanced Communications Downlink Design" in *Proceedings of the AMSAT – North America 2006 Space Symposium*. San Francisco, CA, October 5-8, 2006, pages 195-200.

2. [Ettus 2007] Ettus, Matt. "Advanced Communications Package", slides presented at AMSAT – North America 2007 Space Symposium. Pittsburgh, PA, October 26-28, 2007. <http://www.delmarnorth.com/namaste/meetings/ACP2007.pdf>

3. [Ettus 2008] Ettus, Matt. "Advanced Communications Package", slides prepared for ACP 2008 Planning Meeting [cancelled]. Summer 2008. <http://www.delmarnorth.com/namaste/meetings/ACP2008PlanningMeeting.pdf>

4. [Clark 1988] Clark, D., *The design philosophy of the DARPA internet protocols***,** ACM SIGCOMM Computer Communication Review, Volume 18 , Issue 4 (August 1988), Pages: 106 – 114

5. [Thompson 2008a] Thompson, Michelle. "Namaste: A Ground Station Project Supporting the Advanced Communications Package on Eagle and Intelsat", presented at Dayton Hamvention, Dayton, OH, May 16-18, 2008. Presentation and notes available at: <http://www.amsat.org/namaste/>.

6. [Thompson 2008b] Thompson, Michelle, Phil Karn, and Paul Williamson. *Namaste Link Analysis*, version 3.3. June 22, 2008. <http://www.delmarnorth.com/namaste/requirements/Namaste_Link_Analysis.pdf>

AMSAT Opportunities for Communications Interoperability

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Introduction

The digital 5 GHz uplink – 3 GHz downlink on the AMSAT Eagle/Phase IV Advanced Communication Payload (ACP) will enable amateur radio operators to provide unprecedented disaster communication support services between stations within range of the satellite's footprint.

One of the most common disaster communications interoperability problems arises when multiple agencies are required to respond to an incident. Each agency may utilize different radio frequencies, digital vs. analog modulation, and have limited ability to retune their equipment. At times, the geographic realities of the response environment impose additional constraints. Communication problems of this nature are so common that the US Department of Homeland Security has established its Office for Interoperability and Compatibility to address the problem.[1] This paper will discuss how AMSAT's high orbit amateur radio satellite can provide solutions to fill in these interoperability gaps.

A standard model for most local, state, and federal emergency response is the Unified Command/ Incident Command System (UC/ICS). Modern emergency management includes pre-planning as many likely disaster scenarios as possible. Many times logistical support is enhanced when the emergency responder's equipment is pre-positioned based upon pre-planned scenarios.

When an incident activates the responding agencies, the key participants are those included in the UC/ICS pre-planned scenarios and have participated in training and drill situations. In most cases responding individuals or teams outside of the scope of the ICS pre-planned environment are treated as convergent volunteers. Convergent volunteers, who are viewed as well-intentioned but untrained, unprepared, and incompatible-with-ICS responders may be turned away in most scenarios or held in a holding area until a need is identified.

The ACP ground station offers a unique communications tool to enhance an Emergency Manager's capability to stay in touch with the diverse teams operating as segments of the Incident Command System. This paper will propose AMSAT works to become part of the UC/ICS model to define pre-planned roles for our ACP ground station as a communications interoperability solution. Our multi-channel, multi-mode (voice, digital, video) capability needs to be introduced to the UC/ICS community and become a part of their disaster planning scenarios (1) as a means of securing the interest and support of launch funding sources in the new launch environment; and (2) gain acceptance by the responder community as a viable communications solution.

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[1] http://www.safecomprogram.gov/NR/rdonlyres/FD22B528-18B7-4CB1-AF49-F9626C608290/0/SOSApproachforInteroperableCommunications_02.pdf

The assumption is that ACS and other satellite based operation will remain within the amateur radio service with a licensed amateur control operator. This means that amateur radio operators will need to prepare for operation within ICS scenarios in addition to preparing communications equipment. Until the receipt of actual requirements from a government or funding group, we should not presume that the ACS will directly carry commercial or government radio traffic. This analysis is based on opportunities to inject an amateur radio operator into the national UC/ICS system. AMSAT should be able to speak the language of ICS management to demonstrate how our capacity fits into emergency communications scenarios.

AMSAT Faces a New Operating Environment

AMSAT will need to generate a mission that excites potential funding sources. We have to justify our use of the resources beyond launching a platform that supports casual conversations by a group of hobbyists. A geosynchronous orbital slot will allow AMSAT an opportunity to offer a leap forward in amateur radio emergency communications capability. The Advanced Communications Payload will be designed to be within reach of average amateur radio operators and based on adequate communication coverage with small dish antennas, allowing for a portable satellite radio system to be easily and quickly deployed to disaster areas.

The newest generation of launch vehicles with improved lift capacity, along with changes in government policy allowing ridesharing by secondary payloads which are compatible with the primary mission, have brought about new opportunities to get AMSAT payloads into orbit. However, even in this launch environment these launch opportunities will not simply be given away. AMSAT has received ballpark quotes of $2M to $7M as our cost for rides to high-earth orbit or geosynchronous orbit.

In the case of the Intelsat rideshare opportunity for AMSAT's Phase IV Lite and Eagle missions we will need to find ways to fit in with the business case models of the primary company. AMSAT will need to cover certain costs of adding our payload to the launch and we need to make our own business case to secure this funding through grants.

For $7M who will we provide emergency communications for? Most municipalities have already spent considerable funds to ensure their local responders have communication capability within their jurisdictional boundaries. Amateur radio based systems still require licensed control operators for anyone using our systems. Clearly we cannot make a good business case by proposing the addition of a satellite link, staffed and controlled by amateur radio "outsiders", in many local communication scenarios.

While almost all emergency response is initiated at a local level, if the emergency is large enough additional resources need to be added. Local response will initiate the Incident Command System (ICS) to bring additional resources to the emergency scene. The ICS is a well-known and standardized tool for most modern emergency response today. It is at the expanded response level where AMSAT's satellite communication capability becomes more valuable.

It is usually at the point of introducing additional resources to an emergency response where local communication systems are discovered to be incompatible with the communication systems of the assisting agencies. AMSAT's ACP should be introduced as an opportunity to allow communications coordination between the ICS functional blocks (Incident Commander, operations section, planning section, logistics section, finance & administration section) defined in the National Incident Management System (NIMS), regional response teams, and the unified command concept of major disaster response.

National Response Overview

Of the multitude of disaster scenarios likely to affect the civilian population, most may be managed by the agencies participating in the National Response Team. This is an organization of sixteen federal agencies with emergency resources which are empowered via legislative authority to plan, coordinate, and participate in emergency response. These agencies are named in Table 1 of the Appendix.

The National Response Team

Natural disasters such as hurricanes, tornados, earthquakes, wildfires will require the resources of several local, state, and federal agencies. The Department of Homeland Security (DHS) and the Federal Emergency Management Agency (FEMA) have taken the lead in responding to these.

Expanding the scope beyond natural disasters, the U.S. National Response Team provides technical assistance, resources and coordination on preparedness, planning, response and recovery activities for emergencies involving hazardous substances, pollutants and contaminants, hazmat, oil, and weapons of mass destruction in natural and technological disasters and other environmental incidents of national significance.

Federal Disaster Type Planning			
Chemical Emergencies	Hazardous Materials	Nuclear Power Plant	Tsunami
Dam Failure	Heat	Terrorism	Volcano
Earthquake	Hurricane	Severe Thunderstorm	Winter Storm
Flood	Landslide	Tornado	Wildfire

The UC/ICS response system provides a flexible management tool, allowing agencies best equipped to handle specific events to assume lead roles. For example, a hurricane response may likely require more involvement of FEMA personnel than from the Department of State. At times geographic demarcation of the disaster area may require specific response of certain agencies or assets.

The major building blocks of the UC/ICS response system are pre-planned and rehearsed by the responsible agencies within their own jurisdictions and with the entire Response Team. These building blocks are defined by the Incident Command System. For AMSAT to provide an effective solution as a communications asset the associated disaster pre-planning should include the capability of amateur radio operators equipped with the ACP link in the Incident Commander’s toolbox.

The sections below will first provide an overview of the Incident Command System and then introduce AMSAT-capable solutions that excite our potential funding sources.

Incident Command System

The Incident Command System allows for systematic, standardized, on-scene management that adopts an integrated organizational structure growing to match the complexity and demands of any single incident or multiple incidents and is not hindered by jurisdictional boundaries.

The basic structure of an Incident Command System is shown in Figure 1. Each of the functional sections of the UC/ICS provides an opportunity to introduce an interoperability radio link. Additional radio links may be required within individual sections when they are composed of several functionally divided teams or are geographically separated. The ICS is designed to telescope outward as responding resources are brought to bear and to telescope inward as the incident is resolved.

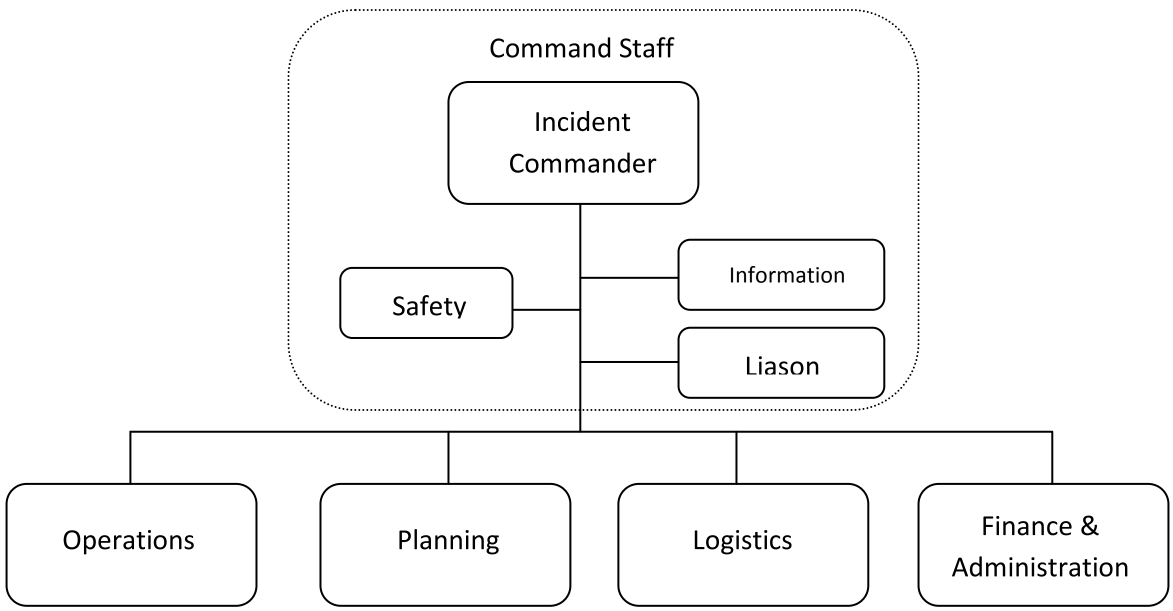


Figure 1: Basic Incident Command System Structure

The Incident Command System was originally developed to manage rapidly moving wildfires. It was designed to address problems such as:

- Too many people and job roles reporting to one supervisor
- Different organizational structure for every responding agency
- **Incompatible and inadequate communications**
- Uncoordinated planning capability for multiple agencies

As the ICS evolved, many local and federal agencies have mandated it use. Almost all emergency response is initiated at the local level when a problem is discovered. The ICS allows the scope of the response to telescope outward as additional resources are added. The emergency response maintains a manageable span of control by dividing the key tasks into subunits commonly called “Sections”:

- **Command Operations Staff** – The Incident Commander is responsible for developing the incident objectives and managing all incident operations.
    - Information Section – the Information Officer's role is to develop and release information about the incident to the media.
    - Liaison Section – the Liaison Officer serves as the point of contact to coordinate activity between the Incident Command and groups such as law enforcement, Congress, etc.
    - Safety Section – the Safety Officer assures the health and safety of the responders and affected public population.
- **Operations Section** – responsible for all work directly applicable to the primary mission of emergency response. This section usually includes the firefighters, search and rescue teams, emergency medical system, law enforcement, flood rescue, etc.
- **Planning Section** – responsible for collecting, evaluating, and reporting the tactical information related to the incident, and for preparing and updating the Incident Action Plan.
- **Logistics Section** – responsible for providing facilities, services, and materials for the incident response. This section provides vehicles, staff, shelter, food and water, and manages the staging areas.
- **Finance and Administration Section** – responsible for all financial, administrative, and cost analysis of the incident.

Each of the operating sections may be co-located in a command post with the Incident Commander or may be located elsewhere in the field. Staffing of the sections may be provided by a single agency or by several agencies. Inter-section communications may be relatively simple in the co-located, single agency response, growing increasingly complex as the scope of the disaster response requires.

Communications become more challenging when the Incident Commander needs to add more agencies to the incident team and to move operational components out to the field. The added agencies may not have compatible radios; remote sites will require establishment of a solid communications link back to the Incident Commander.

Figure 2 illustrates an interoperability opportunity between the Incident Commander and a remote Operations Section. This example assumes that this response requires the Incident Commander to remain in a centralized location but the Operations Section's work and responding staff may be spread over several miles, cities, counties, or states.

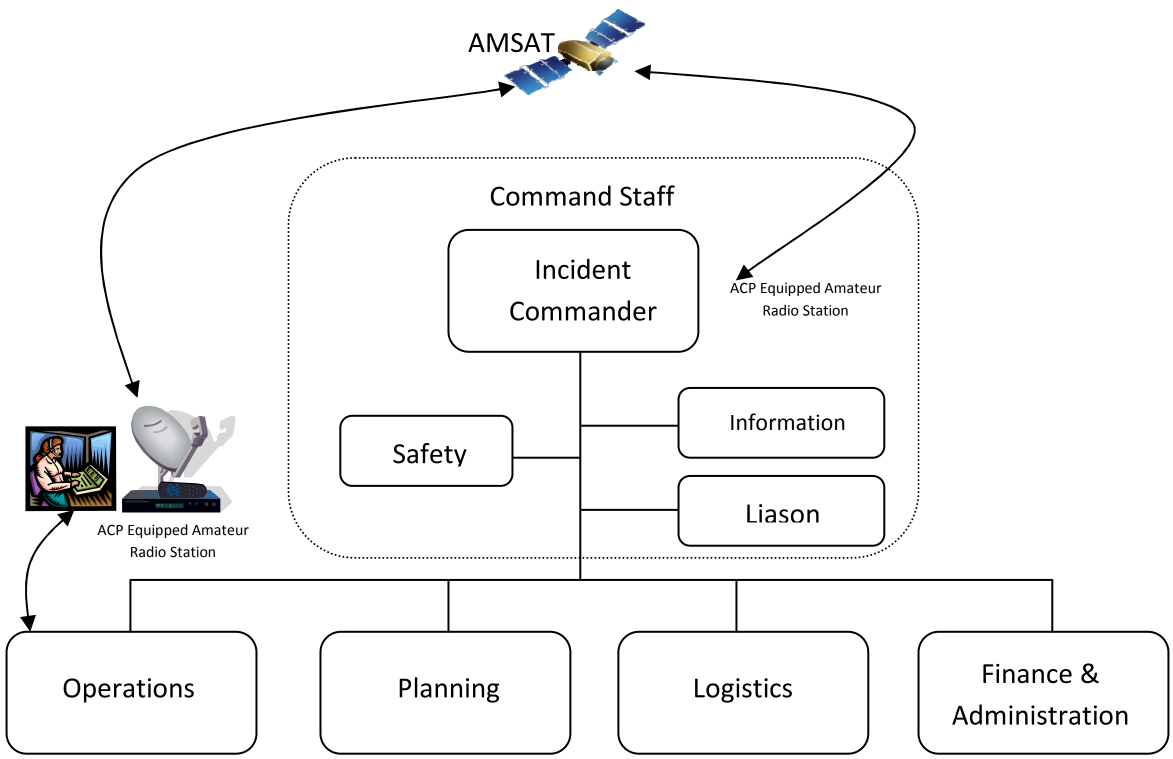
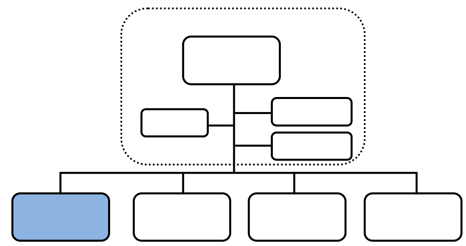


Figure 2: Communications support scenario – Incident Commander with remote Operations Section

Discussion of Interoperability Scenarios

This section provides examples where AMSAT can add value within the UC/ICS model. The Operations Section will be expanded to include its likely teams; the Logistics Section will be expanded to its likely teams. In addition to enhanced communications within a section's span of operation, communication with the Incident Commander is maintained.

Operations Section



The types of agencies that could be included in the Operations Section include fire, law enforcement, public health, public works, emergency medical services, working together as a unit or in combinations depending on the situation. Many incidents may also involve private individuals, companies, or non-governmental organizations, some of which may be fully trained and qualified to participate as partners in the Operations Section.[2]

The Incident Commander and staff decide upon the best organization of the Operations Section depending on the type of incident and their operating plan. The organizational layout of the Section may depend upon geographic divisions; other times it may make sense to organize the Section according to functional responsibilities.

Geographical assignment (an ICS Division) is driven according to natural separations of terrain such as mountains or rivers and also according to the distance separating cities or regional areas involved in the incident.

In the diagram at the right, communications problems due to the terrain or distance separating the teams can be overcome with the availability of an amateur radio operator equipped with an ACS ground station.

The ACS equipped amateur radio station may also assist the Operations Section Chief to maintain communication with the Incident Commander via the satellite link in this organization.

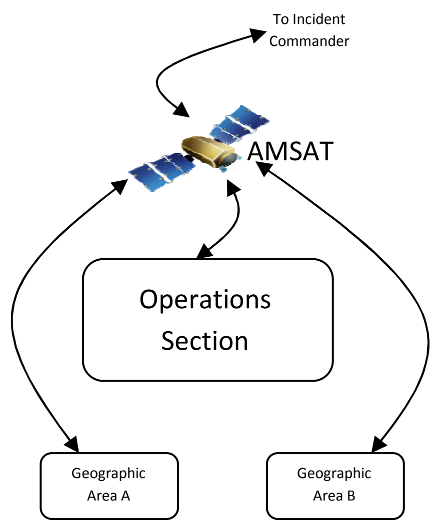


Figure 3: Geographically Distributed Operations Section

[2] NIMS-9.0, National Incident Management System, Department Homeland Security, March 1, 2004, pages 67-71.

Functional assignment (an ICS Group) can be used with areas of related activity such as:

- Fire Fighting
  - Fire suppression
  - Fire Water Supply
- Law Enforcement
- Emergency Medical Services
  - Search and rescue
  - Triage
  - Mass immunization
  - Associated Hospitals or treatment areas
- Shelter operations

In the diagram at the right, incompatible communications between the participating functional areas can be overcome with the availability of an amateur radio operator equipped with an ACS ground station.

The ACS equipped amateur radio station may also assist the Operations Section Chief to maintain communication with the Incident Commander via the satellite link in this organization.

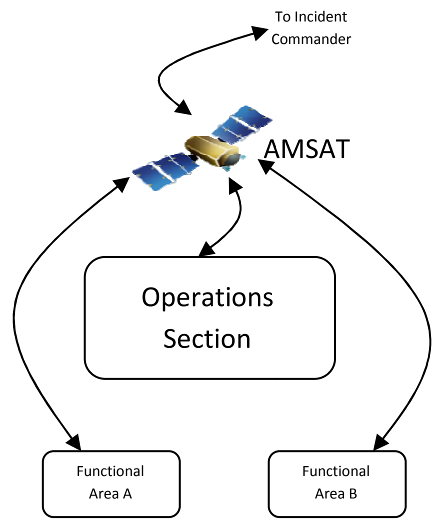
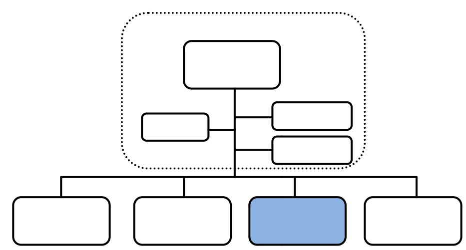


Figure 4: Functionally Distributed Operations Section

Logistics Section

The Logistics Section meets the support needs for the incident, including ordering resources. It provides services for:



- Food service
- Operating facilities
  - Staging areas
- Transportation
- Fuel
- Maintenance
- Communications
- Medical Services and Supplies

Effective communications depend upon a Communications Plan designed for multi-agency operation. This includes design of incident based communications centers, selection of equipment/frequency inventories/ frequency coordination, and pre-positioning inter-agency communication resources. Training for all sections is required in advance of the incident.[3]

[3] NIMS-9.0, National Incident Management System, Department Homeland Security, March 1, 2004, pages 81-85.

Incident communication plans generally establish radio networks organized as:

- **Command Net** – links together the incident commander with the command staff and section chiefs.
- **Tactical Net** – several networks may be organized to support the multiple functions or geographic areas of the Operation Section.
- **Support Net** – tracks the status of resources and logistical response to handle resource requirements.

The National Interagency Incident Communications Division (NIICD), a partnership between the USDA Forest Service and the Department of the Interior's agencies, is the federal agency supporting communications for wildfire operations. NIICD's mission is to provide portable emergency communications, technical training, and airborne remote sensing imagery.[4]

Their major focus is wildland fire suppression, but their equipment and personnel have been utilized on hurricanes, floods, earthquakes, volcanic eruptions, oil spills, and other man-made and natural disasters where federal assistance is required.

NIICD provides an initial system to support basic incident communications requirements which facilitate immediate communications for command, tactical, logistical and ground-to-air needs. The standard ICS Command/Logistics Radio System consists of the following terrestrial communications components:

- 1 Command Repeater/Link
- 3 CMD/TAC Radio Kits (total of 48 radios)
- 1 Ground Aircraft Radio/Link Kit (with 4 ICOM radios)
- 2 Remote Kits
- 1 Satellite Iridium Phone Kit (when available)
- 1 Logistics Repeater
- 1 Logistics Radio Kit (total of 16 radios)
- A logistics capability is sent with all Starter Systems, i.e., logistics repeater, logistics radio kit with NIICD frequency coordination and radio programming.

The ACP Ground Station with its small dish is being designed to be easily deployed to the field for satellite based emergency communications response. The standard packaged NIICD Incident Command communications system could be expanded to include one or more ACP stations which will enable satellite communications as the Command Posts and corresponding sections are established.

The multi-channel, multi-mode capability of the ACP could have several command, tactical, and support radio nets organized according to the ICS section’s requirements. Radio traffic could be kept separated for each network to have its own virtual channel. Additionally, radio traffic could be coordinated as required at the ACP interface points between the sections and the Incident Commander.

[4] http://www.fs.fed.us/fire/niicd/index.html

Operation in a Unified Command Environment

An Incident Command structure may be expanded into a Unified Command (UC). The UC is a structure that brings together the "Incident Commanders" of all major organizations involved in the incident in order to coordinate an effective response while at the same time carrying out their own jurisdictional responsibilities. The UC links the organizations responding to the incident and provides a forum for these entities to make consensus decisions. Under the UC, the various jurisdictions and/or agencies and non-government responders may blend together throughout the operation to create an integrated response team.

The UC may be used whenever multiple jurisdictions are involved in a response effort. These jurisdictions could be represented by:

- Geographic boundaries (e.g., two states, Indian Tribal Land)
- Governmental levels (e.g., local, state, federal)
- Functional responsibilities (e.g., fire fighting, oil spill, Emergency Medical Services);
- Statutory responsibilities

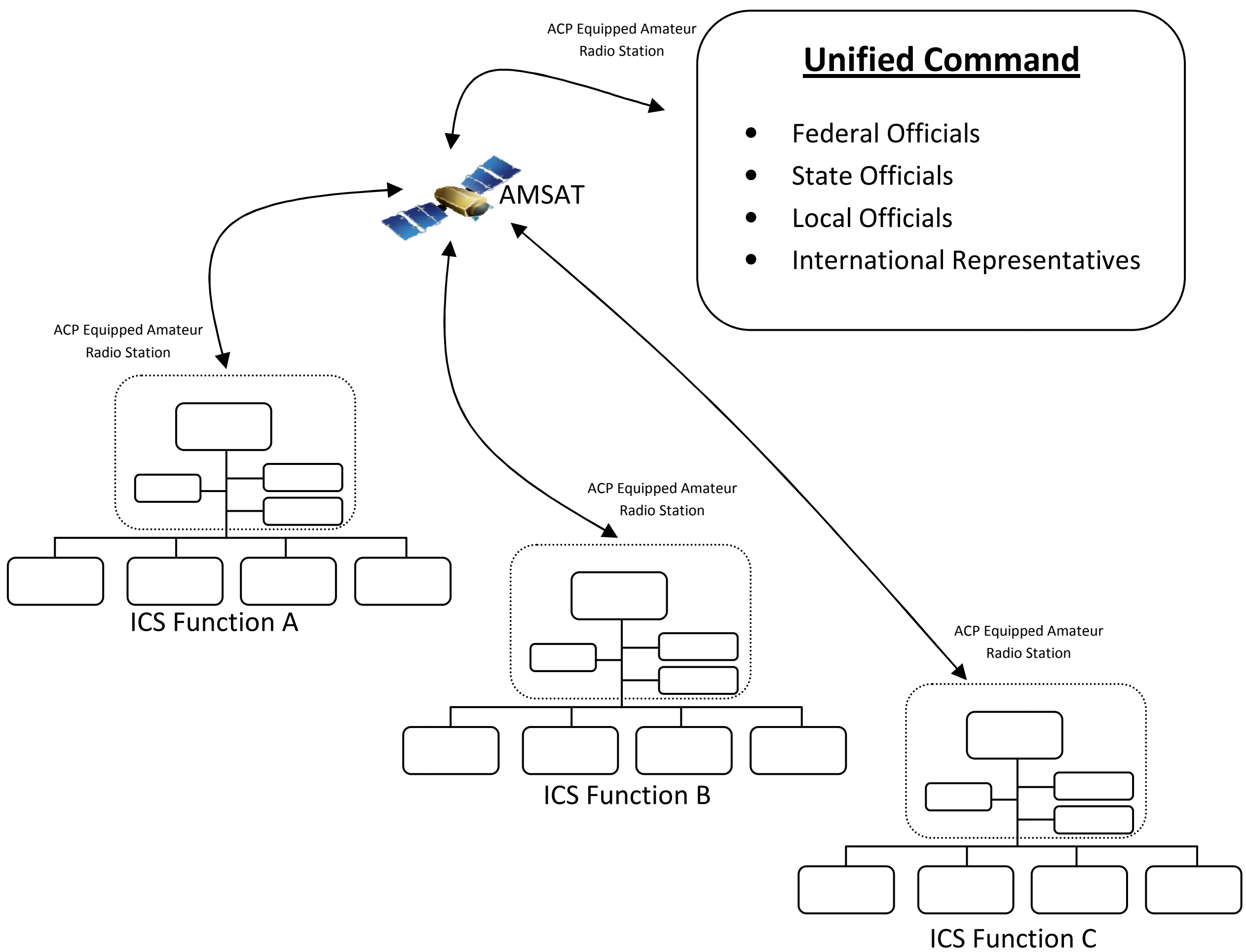


Figure 5: Multiple Incidents Operating Under Unified Command

Case Study: Communication Support for Wildfire Response

The wildfire siege in California in June/July 2008 included more than 2,000 fires at its peak and scorched more than 887,000 acres. California local and state government officials coordinated firefighting operations with the federal government, resources from 40 states, and a number of international partners. As of July 9, 2008 the combined California and Federal response provided:

- 301 fire trucks
- 12 fixed-wing aircraft
- 50 helicopters
- More than 3,500 personnel
- NASA drone
- 12 counties declared a state of emergency
- FEMA funding $31 million
- American Red Cross provided 300,000+ meals (46 fixed/63 mobile feeding centers)
- 30,000+ overnight shelter stays
- 10,000+ Red Cross Staff and Red Cross Volunteer workers

The Incident Command System was originally designed to address large scale wildfire operations. An incident of the scope of the 2008 California wildfires (Figure 6) would provide AMSAT with several opportunities to provide satellite communication links.

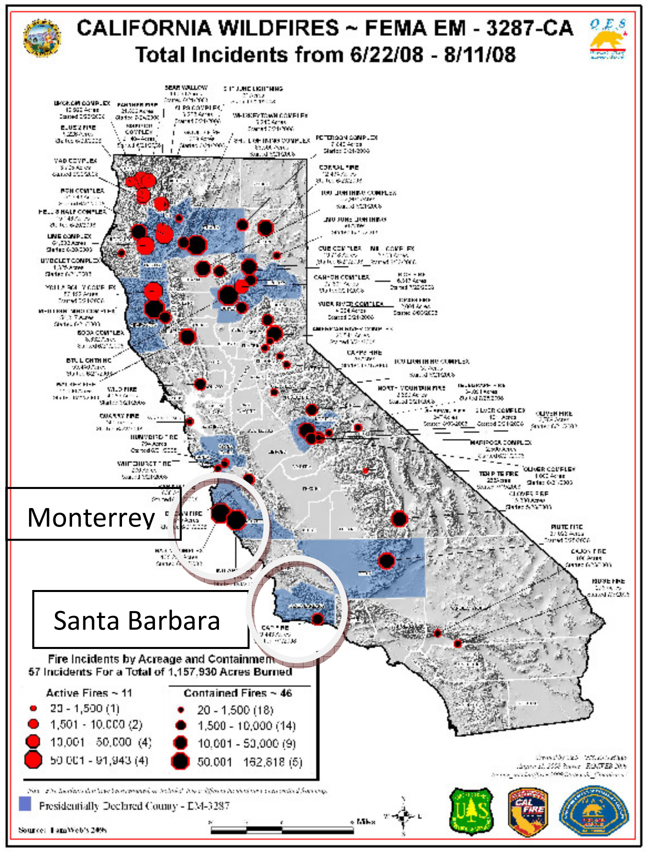


Figure 6: California Wildfires June/July 2008

A wide distribution of resources will drive the expansion of the Operations and Logistics sections to include divisions, groups, and units operating under the command of the Section Chief.

The operational subdivisions are established when the number of resources exceeds the Section Chief's manageable span of control. Deputy Chiefs can be assigned within the Operations Section to manage specific geographic areas called a *division* in ICS terminology (Monterrey and Santa Barbara for example), or functional assignments called a *group* in ICS terminology (firefighting, rescue/evacuation for example). A statewide firefighting response would provide several opportunities for AMSAT-provided communication links between the divisions/groups back to the Section Chief; and, from the Section Chief back to the Incident Commander (Figures 6 & 7).

The Logistics Section meets all of the support needs of the incident from ordering supplies, equipment staging, and delivery. This includes facilities for evacuees, disaster personnel and equipment, transportation including fuel, food services, communications, and medical services (also Figure 7).

For the sake of discussion, Figure 7 shows additional detail of the Operations Section of the Monterrey Fire and the Logistics Section of the Santa Barbara Fire. This example can be expanded to include all of the fire operations in the State of California.

The geographically separated Basin and Indian fires in Monterrey represent Incident Command divisions that may need to use satellite communication links back to their Incident Commander. The Monterrey Incident Commander may also use the satellite link for communications back to the Unified Command Center.

The example shown under the Santa Barbara Fire Command demonstrates widely distributed Logistics Section functionality which may use the satellite link to communicate with their Incident Commander. Likewise, the Santa Barbara Incident Commander also uses the satellite link for communications back to the Unified Command Center.

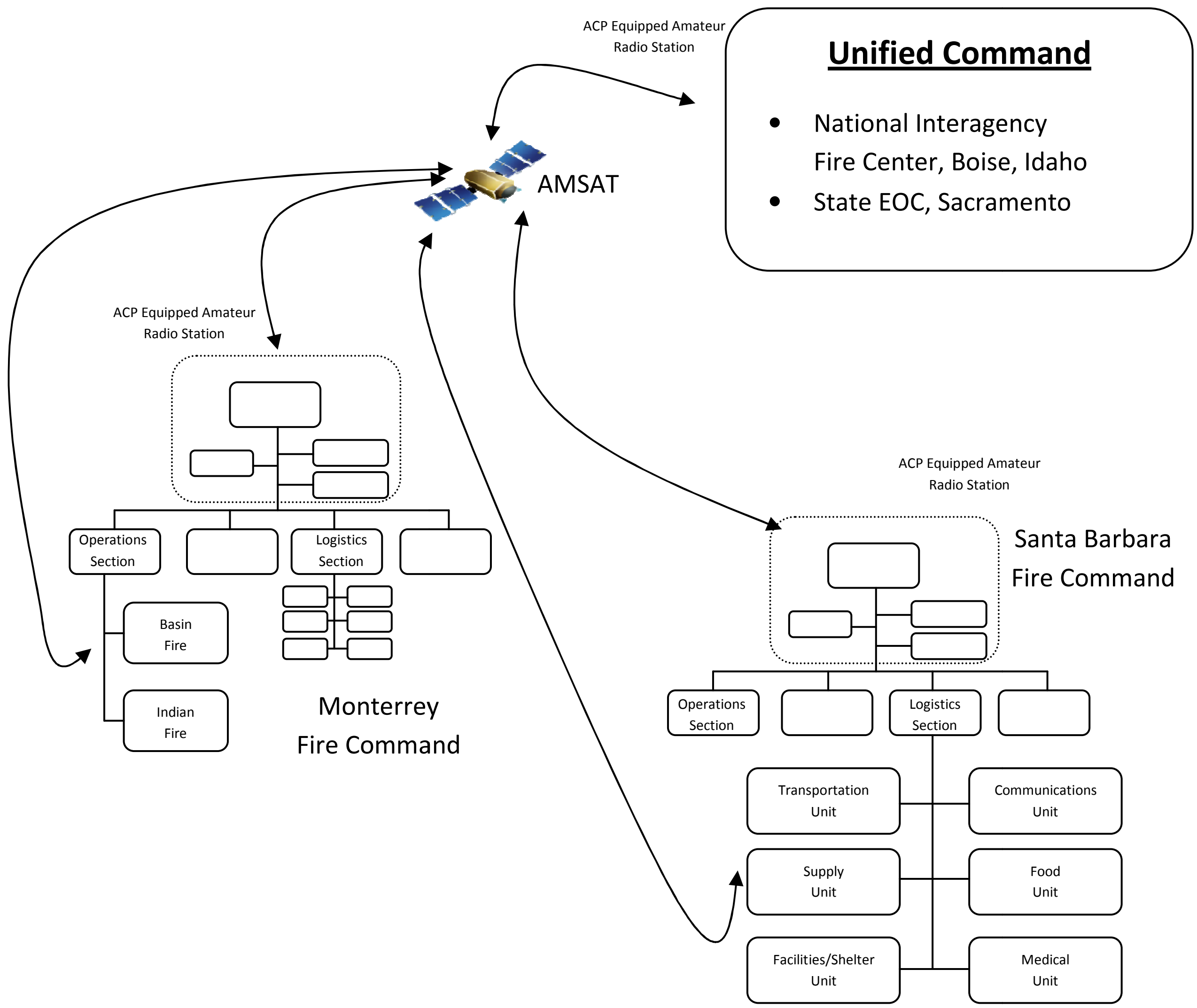


Figure 7: Example – Monterrey and Santa Barbara Fire Operations Satellite Links to Unified Command

International Response

The U.S. National Response Team has established planning for international coordination with Canada, Mexico, Canal Zone, and other international agencies:

- **Canada**
    - Canada-U.S. Joint Inland Pollution Contingency Plan, Annex III
    - Canadian Coast Guard
    - Environment Canada
    - Emergency Preparedness Information Exchange
    - Public Safety and Emergency Preparedness Canada
    - CANUTEC - Canadian Transport Emergency Centre of the DOT
    - Canadian/US Atlantic (CANUSLANT) Joint Response Team
- **Mexico**
    - U.S. Mexico Joint Contingency Plan (1999)
- **Canal Zone**
- **Additional International Agencies**
    - Organization for Economic Co-operation and Development (OECD)
    - Environmental Media Services (EMS)
    - United Nations Environment Programme
    - European Space Agency (ESA)
    - International Federation of Red Cross and Red Crescent Societies

International emergency response coordination presents additional opportunities for AMSAT to offer ACS ground station equipment and amateur radio assistance. Some of these agencies may also be potential funding sources when the AMSAT's emergency communications capability is discussed with them.

Conclusion

The National Incident Management System and the Incident Command System provide AMSAT with the opportunity to offer communications interoperability between several responding agencies. Our satellite link may prove most useful and more interesting to Emergency Managers when offered in the context of international, national, regional response, and in multiple agency scenarios.

Some question the viability of seeking government funding for amateur radio projects. With the ACP AMSAT will expand amateur radio's emergency communications capability into a viable national and international resource. We need to first build a mission that excites potential funding sources which is why this discussion has been focused on government response to disasters. Our beneficial side-effect will be the availability of high orbit transponders for amateur radio experimentation and communication in all the ways we enjoy them.

Short term plans

- Demonstrate ACP operations on ground based platforms.

- Identify disaster-related agencies likely to benefit from AMSAT amateur radio satellite communications (potential funding sources) and define the details of their interface with the Unified Command/Incident Command System.
- Identify additional case studies of disaster scenarios (widespread chemical incident, hurricane, earthquake, etc.) to be able to fully propose the scope of AMSAT's capability across several agencies.
- Get the AMSAT word out (magazine articles, presentations) revealing ACP-based communication capability for civilian operations including Red Cross, Salvation Army, ARES/RACES.

Long term plans

- Work with the AMSAT team to complete the ACP design:
    - Channel capability (bandwidth, TCP/IP, user class, support for APCO P25)
    - ACP Ground Station operational details
    - ACP Ground Station packaging
- Identify launch opportunity
- Deploy the ACP in space and groundstation.
- Integrate ACP multi-channel voice, data, and video capability with communication groups such as Salvation Army SATERN, National Traffic System, Hurricane Watch Net, Red Cross, DHS/FEMA, National Interagency Fire Center, regional teams (such as Orange County Sheriff's Department's Professional Services Civilian Responder Volunteer Corps), ARES/RACES.

References

1. The System of Systems Approach for Interoperable Communications, published by US Department of Homeland Security, Office for Interoperability and Compatibility, http://www.safecomprogram.gov.
2. Incident Command System/Unified Command System (ICS/UC) Technical Assistance Document, The U.S. National Response Team, http://www.nrt.org.
3. NIMS-9.0, National Incident Management System, Department Homeland Security, March 1, 2004
4. http://www.calfires.com/
5. http://www.fire.ca.gov/
6. http://www.fs.fed.us/fire/niicd/index.html

Appendix

U.S. Environmental Protection Agency, Chair	U.S. Department of Justice
U.S. Coast Guard, Vice-Chair	U.S. Department of State
U.S. Department of Agriculture	U.S. Department of Labor
U.S. Department of Commerce	U.S. Department of the Treasury
U.S. Department of Defense	U.S. Federal Emergency Management Agency
U.S. Department of Energy	U.S. General Services Administration
U.S. Department of Health and Human Services	U.S. Nuclear Regulatory Commission
U.S. Department of the Interior	U.S. Department of Transportation

Table 1: U.S. National Response Team Member Agencies

Medium Earth Orbit. - An affordable alternative to HEO?

David Bowman G0MRF

Abstract

This paper examines the communications potential for an AMSAT spacecraft located in Medium Earth Orbit and poses the question Is MEO an affordable and acceptable alternative to the traditional High Earth Orbit P3 series. The paper considers the increased RF path loss on system design and the implications of operating in a higher radiation environment. It concludes by examining propulsion technologies, methods of achieving orbital transfer from LEO to MEO and outlines a possible compromise between fuel mass, launch cost and apogee height.

Background

At this time, AMSAT does not have a satellite in orbit capable of routine intercontinental communication. It has been 8 years since the last launch of an AMSAT high earth orbit spacecraft and 5 years since the loss of AO-40.

As an organisation, AMSAT is blessed with having industry professionals and many highly skilled and capable individuals. In addition, AMSAT has built up working relationships with many organisations in the space industry and is respected. But in the world of 2008 there are more satellites awaiting launch and less launches per year than at any time in the last 20 years. Also, the affordable launches traditionally used by AMSAT came during the early proving flights of the Ariane 4 and Ariane 5 series from Kourou. Now Ariane 5 and the Soyuz launchers are technically mature and reliable designs. If you want to fly to Geostationary Transfer Orbit now, you compete with commercial organisations and national governments paying the full commercial rate. The harsh reality is that the cost of launching a 150kg satellite to GTO is beyond the reach of AMSAT alone.

Communication range and altitude

The current 'fleet' of LEO spacecraft carrying amateur radio have a typical altitude of 700km and are frequently launched as secondary payloads with other satellites into 'Sun synchronous' orbits. Of these 'satellites carrying amateur radio', the International Space station satellite, ISS, at 350km has the lowest maintained orbit. In addition to the ARISS equipment onboard the ISS, there have been several satellites carrying amateur radio deployed from the space station. All of these, including Suitsat 1, which inspired the public imagination in 2006, quickly re entered the atmosphere having descended to 170km 3 – 12 months.

Increasing in altitude we have the very popular AO-51 at 800km, FO-29 at 1000km, but the two highest LEO satellites operating in the amateur space allocation are Amsat Oscar 7 launched in December 1974 and the recently launched RS30, which both have similar altitudes at 1500km. It is unfortunate that RS-30 appears to only contain a beacon serving a small number of individuals within the organisations responsible for its construction.

The ISS and AO-7 represent the lower and upper limits of satellites carrying amateur radio in Low Earth Orbit, but even these LEO satellites have a widely different communication range. The maximum range across a satellites footprint can be calculated using the formula:

$$\textbf{Max range} = 2R \arccos\{ R / (R + h) \}$$

Where R = radius of the Earth h = height of satellite. R = 6371km (spherical model)

Solving for various satellites and orbits we find:

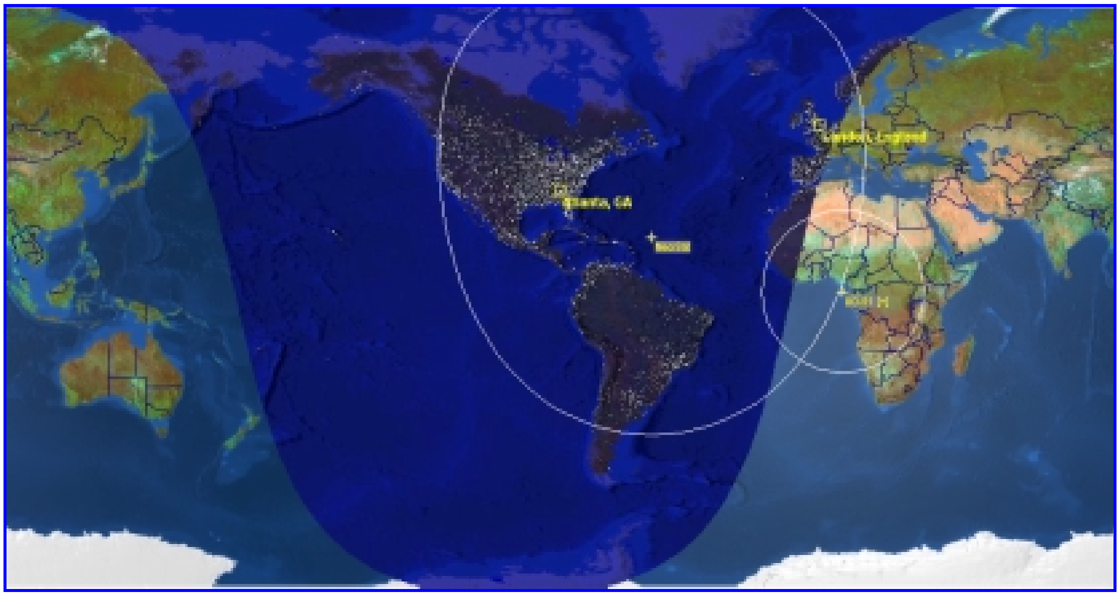
Satellite	Altitude km	Maximum communications range
ISS	350	4130
AO-51	780	6006
AO-7	1500	7997
MEO	7000	13687
MEO	13000	15745
P3e	36000	18091

Looking at the maximum ranges calculated, we can see that the ISS has a typical limit for communication across the footprint of 4130km, but for AO-7 the distance approaches 8000km. This is just enough for some enterprising radio amateurs to enjoy the thrills of intercontinental communication and clearly the higher the apogee the better. Note that at 13,000km you have 87% of the range offered by P3e. More on this later.

Medium Earth Orbits

The medium earth orbits shown in the table above have excellent DX potential compared to a LEO. But how far above the earth should the satellite be? The figures above of 7000 and 13000km altitude have not been chosen at random. Potentially, there are two areas that can be used for MEO. The first is at 20 – 23000km which is currently populated with satellites providing global positioning signals. As these satellites are essentially military, it is unlikely that the launch agency responsible for GPS launches would accept secondary payloads. But having said that, I wonder if anyone has asked? Below 20000km are two radiation belts. The Van Allen radiation belts are separated into two layers. The lower layer is comprised of high energy protons between 600 and 6000km. The second radiation belt comprises high energy electrons that occupy altitudes from 13 - 18000km. So any ‘MEOSAT’ could avoid damaging radiation by orbiting in the "safe zone" between. 6000 and 13000km. (6)

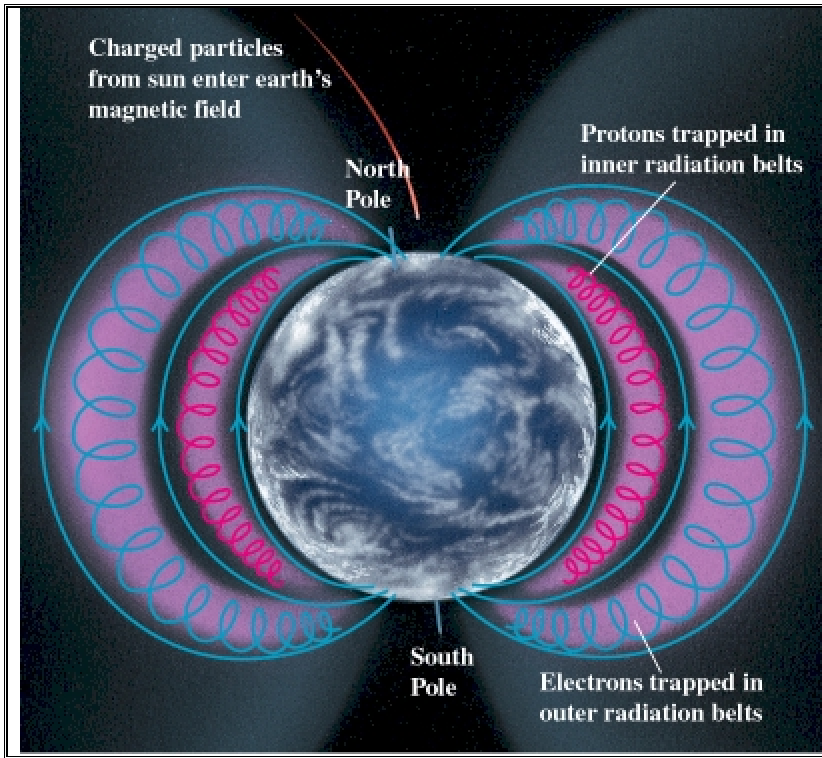
Footprint of a Medium Earth Orbiting satellite at an altitude of 7200km



The plot above shows AO-51 at 780km and 'MEOSAT' at 7200km
From Atlanta a typical overhead pass from MEO lasts not for the 12 or 15 minutes of a LEO satellite, but a full 90 minutes. The communications potential across the footprint is equally impressive:
California can work into Western Europe.
Italy can work into Western Australia (just)
Northern Finland can work Capetown South Africa.
A satellite in at an altitude of 7200km orbits 5.5 times in a 24 hour period. – Mean motion.

Van Allen Radiation belts

In 1958, experimental results from Explorer 1 and Explorer 3 led to the discovery by James Van Allen of the radiation belts which now bear his name. Unfortunately, their high energy charged particles cause the rapid failure of sensitive electronic components. The radiation intensity increases with altitude and although there is a well documented ‘hot spot’ known as the South Atlantic anomaly which extends down to 200km, it is generally accepted that Low Earth orbit is relatively benign below 1000km. However, above apx. 1500km lies a hostile radiation environment in which the long term reliability of a spacecraft electronics is very doubtful, indeed the control electronics onboard AMSAT Oscar 10 failed from radiation damage following an orbital manoeuvre that left it in the radiation belts for a higher percentage of its orbit than planned.



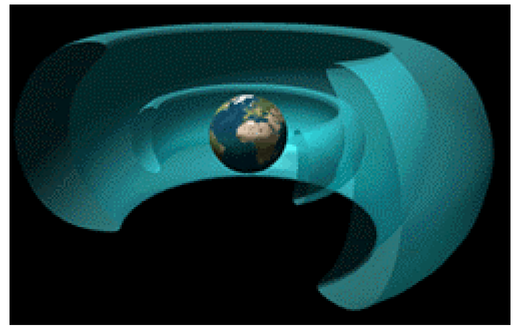


Image above – NASA jgc
Image left – Addison Wesley Longman Inc.

The diagrams illustrate the geometry of the Van Allen radiation belts. Both belts are centered over the equatorial region and are 'doughnut' shaped. Spacecraft therefore experience a higher intensity of ionising radiation over the equator than they experience over the higher latitudes of the planet.
The polar regions have the lowest radiation levels from the Van Allen belts but suffer from high energy cosmic rays which travel along the Earth's magnetic field lines.
The lower belt of protons is relatively well defined with an upper altitude of 6000km. However, the upper radiation belt is subject to fluctuations in the Earths magnetic field. Its position can vary with solar storms and with the eleven year 'sunspot' cycle.
Given the position of the radiation belts, a high inclination orbit offers significant advantages over a more equatorial low inclination orbit.

The geometry of the Van Allen belts present several possibilities for satellites carrying communication systems operating in the amateur radio space allocation.

- To fly as close to the lower belt as the electronics will allow. 1500km to 2000km. This could be a circular orbit or could be an elliptical orbit. – see propulsion section.
- A circular orbit within the safe zone at 7000km just above the lower belt.
- An elliptical orbit that has an apogee at 13000km just below the upper belt

It is possible to reach all of these orbits with a satellite equipped with propulsion that has been launched into a high inclination low earth orbit.
Although a circular orbit at 7000km would represent a conventional choice, the elliptical orbit option is worth further examination. It is an orbit than can be reached with a singe burn from LEO and although the orbit will pass through the lower radiation belt 9 times every day, but the amount of time it is within this harsh environment is surprisingly small..

The following Keplerian element set shows the characteristics.

Epoch time	8247.41722406	Argument of perigee	173.087000
Inclination	98.068600	Mean anomaly	267.182300
RAAN	267.68780	Mean motion	5.68000000
Eccentricity	0.4600000		

The orbit is elliptical with a period of 4 hours and 13 minutes. The apogee is just under 13,000km and is in the upper part of the ‘safe zone’ between the two Van Allen radiation belts. Perigee is at 780km which is a typical height for a LEO launch. Analysis of the orbit with respect to Van Allen belts shows that the satellite spends just 19 percent of its time between 2000 and 6000km and that some of this time is in the areas of high latitude.

Total orbital period	253 minutes	
Time below 2000km	28 minutes	11%
Time between 2000km and 6000km (radiation belt)	48 minutes	19%
Time from 6000km – apogee – 6000km	177 minutes	70%

Reliability and lifespan

Radiation hardened components are expensive and in the past history of AMSAT are rarely used. A notable exception were the COSMAC 1802 processors used in the early Phase 3 series. If a flight to MEO is undertaken, then mitigating the radiation hazard is essential. Aluminium and Tantalum shielding can provide a physical barrier, but processors and control electronics probably need to be replaced by radiation tolerant FPGA. It is also worth remembering that the AO-7 transponder continues to function after absorbing a large total dose following 34 years at 1500km. Similarly, AO-10 provided many years service after all ability to control its attitude was lost due to radiation damage.

Medium Earth Orbit communications link budget

What equipment would be needed to operate a satellite in MEO? Let's compare AO-51 AO-40 at 50,000km and a satellite in medium earth orbit.

Satellite	Height km	Elevation deg.	Range km	2m Path loss	70cm Path loss
AO-51	750	15	2000	142dB	151.4dB
AO-40	35000	xxx	50000	169.7	179
MEOSAT	7200	25	15000	155.4	165

Mode UV - Downlink.

A typical LEO with a 100kHz linear transponder runs 1 Watt on 145MHz to a simple antenna (1W ERP) and can be received at the groundstation on a small handheld beam of 2 or 3 elements having a forward gain of perhaps +4dBd.
We've seen that MEOSAT has 13dB more path loss on 2m compared to AO-51 and so would need to have an output power +13dB or 20 Watts to a similar antenna to be received on the same small beam.
However, 20W is too high for this idea! Other choices would be to reduce the transponder bandwidth, use a directional antenna with some gain on MEOSAT or increase the gain on the groundstation receive antenna.
To ensure the 'practicality' of the idea, let’s keep the omni antenna on MEOSAT but reduce the bandwidth by 50% and save 3dB. Then we can save another 6dB by increasing the output power from 1 to 4 Watts. Now, instead of our -13dB deficit we now have -13 + 3 +6 = -4dB.
This final 4dB deficit can compensated for by increasing the gain of the groundstation antenna.
By adding 4dB, the required antenna gain is now +8dBd, but that is still a modest antenna for a system that is capable of routine intercontinental communication.

Mode UV - Uplink Power

For a mode U/V transponder, with an uplink on 70cms and the downlink on 2m, we can see the path loss is 13.6dB greater than AO-51 but 14dB less than the path loss out to AO-40.
Without doing a full analysis including receiver / antenna / path loss / filter and other losses, we can estimate the power needed by comparison with a typical AO-40 groundstation.

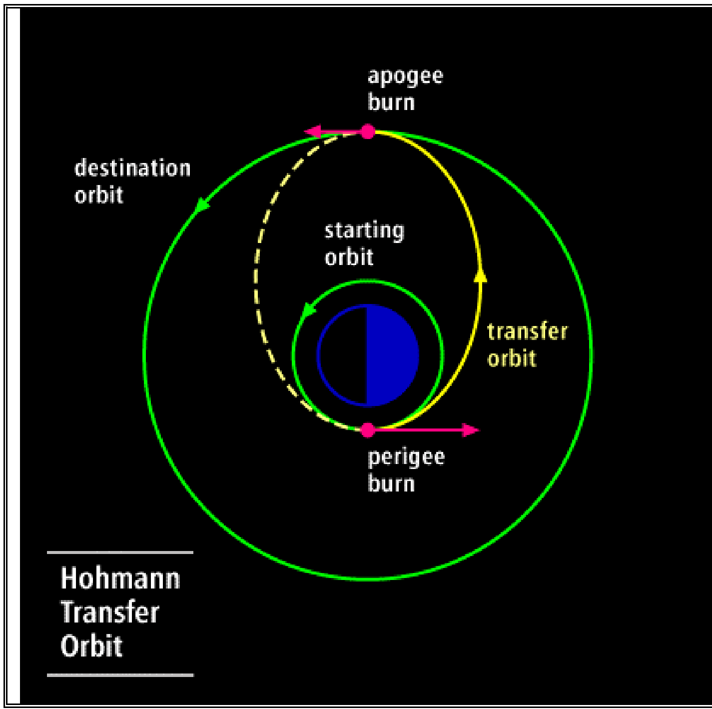
AO-40 groundstation UHF Uplink = 50W + 19 ele Yagi. = 2kW ERP.
MEOSAT = -14dB + 6 dB for simple antennas = 2kW - 8dB = 320 W ERP (for a very good signal)

So a typical station maybe a 30 Watt radio and a small 70cm yagi of around 9 elements for a good SSB signal, while 5 - 10W should work for CW / PSK.

A full link budget analysis could be made using Jan King’s Excel Link budget calculator. (2)
However, the approximation outlined above, even with some errors, shows that requirements for mode U/V from Medium Earth orbit are very modest.

Propulsion technologies and orbital transfer.

The following section looks at methods of raising the altitude of a satellite from a typical 800km LEO to higher altitudes. Achim Vollhard DH2VA has produced an Excel spreadsheet (4) which calculates delta V required to reach a specific destination orbit and the required propulsion capability of a satellite based on its mass, propulsion system and fuel load.



A Hohmann transfer is a fuel efficient method to transfer from one circular orbit to another circular orbit that is in the same plane (same inclination), but at a different altitude. It requires two engine burns. The first places the satellite into an elliptical orbit where the perigee is the same altitude as the original LEO orbit and apogee is at the destination altitude. The second burn raises the perigee and circularises the orbit.

Propulsion technology

Propulsion systems have been used on previous AMSAT satellites. AO-10, AO13 and AO-40 all used a 400 Newton engine fuelled by Hydrazine and Nitrogen Tetroxide. A similar 200N bi-propellant thruster will also be used on P3E. The fuels used on the phase 3 satellites are very hazardous and the use of such dangerous materials also means the control systems to operate a bipropellant engine are complex. So what other methods are there for generating thrust for a small satellite? The answer appears to include:

1) Cold gas thrusters. - As used on AO-40 (Ammonia) or SSTL's SNAP1 mission (32.6 grams of butane)

2) Hot gas thrusters - e.g. The ArcJet using Ammonia and an electrical ignition circuit. As fitted to, but not used on AO-40. Or Resistojet techniques, where a liquid or gas is passed through a heating element to increase the volume and generate a higher exhaust velocity.

3) A Monopropellant decomposed with a catalyst.
4) Hybrid thrusters. Single burn but using safe materials e.g. Plexiglas and Nitrous Oxide.
5) Chemical single burn engines. - e.g The solid rocket boosters used on the shuttle / Ariane 5. Or a much smaller version.
5) Electric or Ion propulsion - As used on the moon orbiter SMART1

Any engine will have a bewildering list of characteristics. A good site linking these is shown at (5)

To calculate the potential increase in altitude from a particular propulsion system we will need to know the mass of the satellite with fuel. The mass without fuel and finally we need to know the efficiency of the propulsion system which is known as the Specific Impulse - Isp

Thrust: Any engine will be designed to produce a certain amount of thrust. This is a measure of the force exerted in Newtons when the engine is operating. The thrust can vary from very small. 0.050 Newtons for SNAP1 to 19600 Newtons for the large bipropellant Russian Fregat engine. The engine will also be designed to provide this amount of thrust for a particular period of time. 297 seconds for SNAP1. 877 seconds for Fregat.

Total Impulse: This is the product of thrust and time. e.g. 0.050 x 297 = 14.85 Newton Seconds for SNAP1. Over 17 million NS for Fregat

Mass flow rate: This is the rate that the fuel flows through the engine. 32.6g / 297 seconds = 0.0001097643 grams per second for SNAP1.
For the Ariane, the fuel consumption is rather more at 6.1kg per second

Specific Impulse: (Isp) This is a very important parameter and it is a measure of the efficiency of a propulsion system..
Specific Impulse = Thrust / mass flow rate / gravitational acceleration
Where Thrust is in Newtons. Mass flow rate in kg/second Gravitational acceleration is a constant at 9.81 metres per second^2

Example 1. For SNAP1 Isp = 0.05 / (0.0326 / 297) / 9.81 = 46 s
- The unit of Isp is the second - Low efficiency (cold gas)

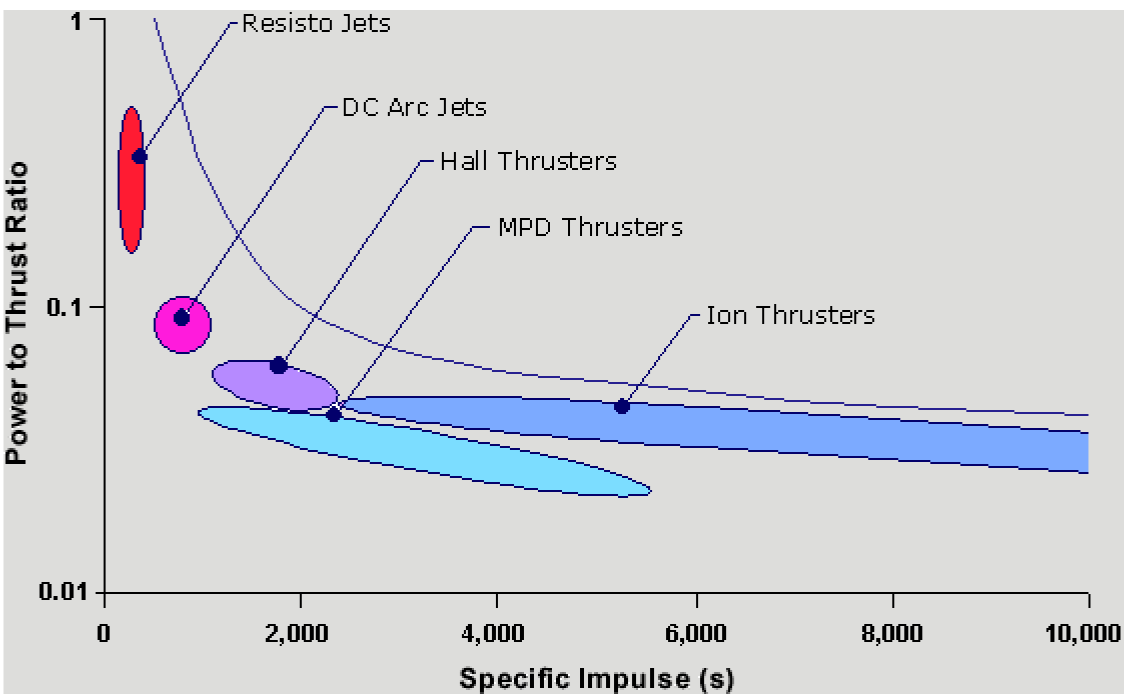
Example 2 For Russian Fregat . Isp = 19600 N / 6.1kg/s / 9.81m/s = 327 s
- This is typical for a bipropellant rocket. - high efficiency

The following comparison of propellant technologies gives comparative figures for chemical and electric propulsion systems. Note that the Ion engine can only produce very small level of thrust but the Isp is very high indicating that it is much more efficient than a bipropellant engine. Overall the Ion drive uses fuel more efficiently and would appear to be a good choice for deep space flight, but only if flight time wasn't an issue. For MEOSAT an ION engine would need a very small quantity of fuel but could leave the satellite travelling very slowly through the lower Van Allen belt.

Comparison of Chemical and Electro/chemical propulsion thrusters

Thruster Systems	Typical Thrust Level (N)	Specific Impulse	Comments
Cold gas e.g. Butane	.01 - 2	60	Low efficiency
Hydrazine (N_2H_4)	0.4-20	220	Simple self pressurising system
Bipropellant (MMH/N_2H_4)	20-40	302	Requires complex Helium pressure feed for propellants
Resistojet (N_2H_4)	0.2-0.4	300	High DC power for higher thrusts
Arcjet (N_2H_4)	0.15-0.3	520	High DC power for arc generation
Hall effect Ion drive Type PPS1350	0.06	1640	Xenon gas fuel and high DC power Required.

Comparison of Electro Chemical propulsion systems



With the aid of the spreadsheet (4) we can test ideas for a Hohmann transfer from 800 to 7000km

Initial mass of satellite 25kg.   Initial LEO orbit at 800km   Destination orbit 7000km.

Delta V required for elliptical transfer orbit. = v1 = 1050m/s
Delta V required for 2nd circularising burn   = v2 = 897m/s   total v1+v2 = 1947m/s

Mono propellant thruster Isp 220.   - Mass of fuel required for v1 = 9.7kg   v1+v2 = 15.1kg
Bipropellant thruster Isp 280   - Mass of fuel required for v 1 = 8.0kg   v1+v2 = 12.8kg
Hydrazine or NH3 Arcjet Isp 500   - Mass of fuel required for v1 = 4.9kg   v1+v2 = 8.8kg

It can be seen that using conventional mono or bipropellant thrusters requires around 50 percent of the satellite mass to be used for fuel. The exception is the Arcjet which requires 36%.   The final example is for an elliptical orbit with an apogee at 13,000km also using parameters for the arcjet.

Initial orbit 800km circular. Target orbit 13000km elliptical, perigee at 800km.

Delta V required. = 1551m/s   Mass of fuel required = 6.8kg   (27% of total mass)

With just 6.8kg of fuel there would be adequate mass remaining for structure and payloads. One additional advantage of the arcjet is, that should there be a technical failure, then the gas can be vented to space and the system operated as a cold gas thruster. While this is insufficient to reach MEO it could boost the orbit from 800km to a more interesting LEO. How much?

ISP for cold gas = 60.   Fuel mass = 6.8kg
Total delta V available in cold gas mode = 187m/s
Apogee height of LEO with 187m/s and 800km Perigee =   1175km

Details of some commercially available thrusters are given as an appendix to this paper. Further information is available (1) (3)

Launch opportunities ?

Low Earth Orbit is a popular destination for Earth observation, science and educational missions. There are however two new launchers due to come into service within the next year and these open the possibility of reduced cost launches during their initial proving flights. The Space-X Falcon 1 has had three flights from its base in Kwajalein in the Pacific. While it has yet to reach orbit, the 2nd and third flights only failed due to very minor problems. This launch vehicle is very nearly operational.

Meanwhile The European Space Agency is due to launch the maiden flight of Vega from Kourou in South America. Vega is the Europeans new low earth orbit launcher and is scheduled for its maiden flight in October 2009. The maiden flight payloads have already been selected and include 9 educational cubesats from European Universities. The cubesat launch is being generously sponsored by the ESA Education department. I am not aware of any other launch agency which has such a proactive and positive approach to supporting the study of space and technology education.

Following the maiden flight, Vega will have five VERTA flights. These are Verification flights and applications are invited for payloads that will fully test the launchers capabilities. Applicants are invited to contribute to the flight costs by offering a bid based on mass, required orbit and the degree of support required from ESA. The VERTA flights are scheduled to take place at intervals of six months from a successful maiden flight. An interesting aspect of the Vega programme is that the upper stage has the ability to perform orbital manoeuvres between each satellite deployment. Following the final satellite deployment, the upper stage uses the remaining fuel to deorbit, thereby reducing the amount of space debris in LEO.

Partnerships and Collaboration

One aspect that may not have been fully explored by AMSAT is the possibility of entering into partnerships or cooperating with other organisations who have mutually compatible needs. Examples of this are the cooperation between the students at the Delft technical University in The Netherlands and Dutch Space, which brought us Delfi C-3 (DO-64) in April 2008. Also, the work by AMSAT-UK on SSETI Express (XO-53) and the ongoing ESEO projects. Both of these add amateur radio functionality at the completion of a primary science or educational mission.

For a possible launch on the VERTA flights of Vega it is unlikely that a purely amateur radio mission, despite the educational outreach possibilities, will be sufficiently appealing to any selection panel. However, a mission that includes orbital transfer to an interesting but unoccupied region of space in the safe zone, which perhaps included a newly developed arcjet propulsion thruster or pulsed plasma attitude control, would add much scientific merit and could be seen as a positive addition to any mission proposal.

Summary

We have seen that propulsion systems are available for small spacecraft in the microsat or nanosat category. Simple systems like cold gas can raise an orbit to high LEO while it is possible for more advanced propulsion technology to reach Medium Earth Orbit. We have also calculated coverage and found that MEO orbits can provide coverage similar to the High Earth Orbit phase 3 series.

1.*http://cs.astrium.eads.net/sp/SpacecraftPropulsion/Monopropellant_Thrusters/1N_Monopellant_Thruster_CHT-1.html*

2 *http://www.amsat.org.uk/iaru/spreadsheet1.asp*

3 http://cs.astrium.eads.net/sp/

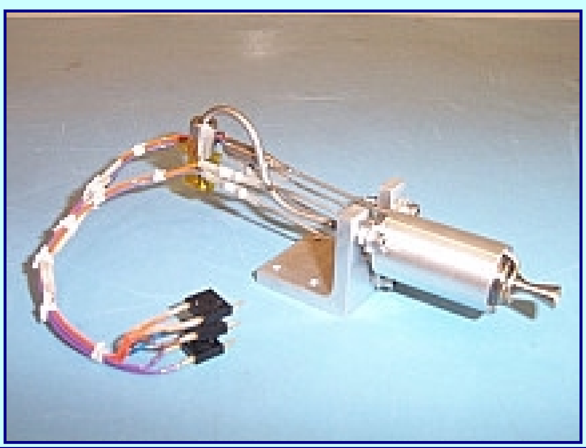
4 http://gulp.physik.unizh.ch/meosat_propulsion.xls

5 http://www.grc.nasa.gov/WWW/K-12/airplane/specimp.html

6 http://www.nasa.gov/vision/universe/solarsystem/safe_zone.html

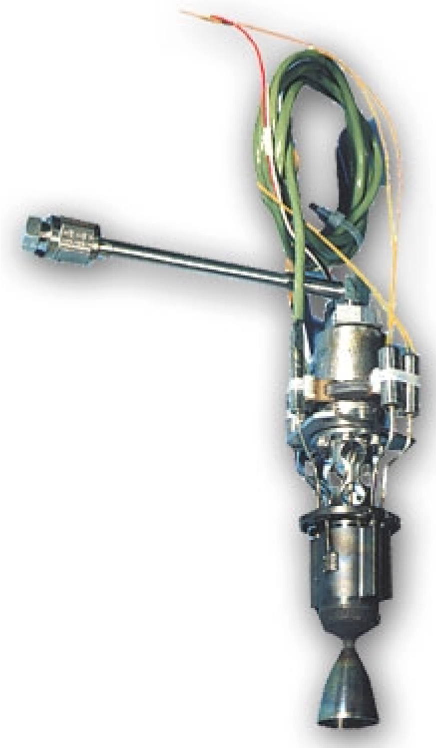
Appendix. Commercial propulsion thrusters

SSTL Nitrous Oxide resistojet. ISP = 127



RITA –10 Ion thruster ISP = 3300 Thrust 15mN

10 N HYDRAZINE THRUSTER Model CHT 10

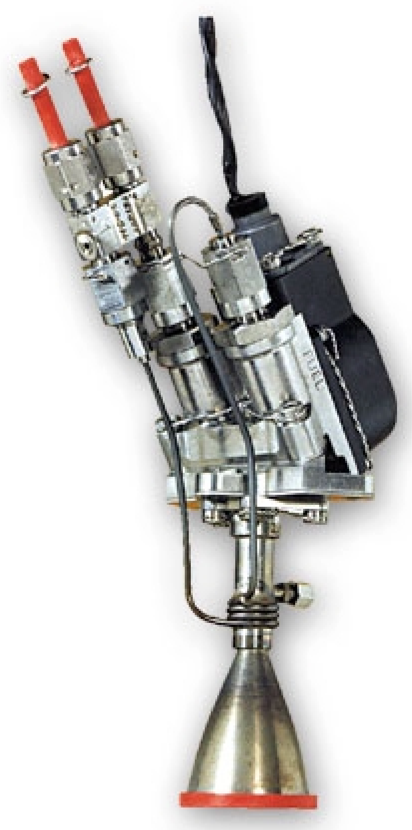


Characteristics	
Propellant	Hydrazine
Inlet Pressure Range	5.5 to 22 bar
Thrust Range vac	3.0 to 10.0 N
Isp vac	220 to 230 sec
Total Impulse	517,000 Ns
Cycle Life	108,000 cycles
Accumulated Burn Life	3.4 hours
Overall length	142 mm
Nozzle diameter	19 mm
Mass:	0.24 kg

Heritage

Spacecraft	Units
Meteosat	25
SAX	14

10 N BIPROPELLANT THRUSTER Model S10 - 01



Characteristics	
Propellants	MON / MMH
Thrust vac	10 N
Power	14 kW 19 hp
Isp vac	286 sec
Chamber pressure	7 bar
Overall length	138 mm
Nozzle diameter	37 mm
Mass	350g

AO-51 Operation Before, During and After the No Eclipse Period

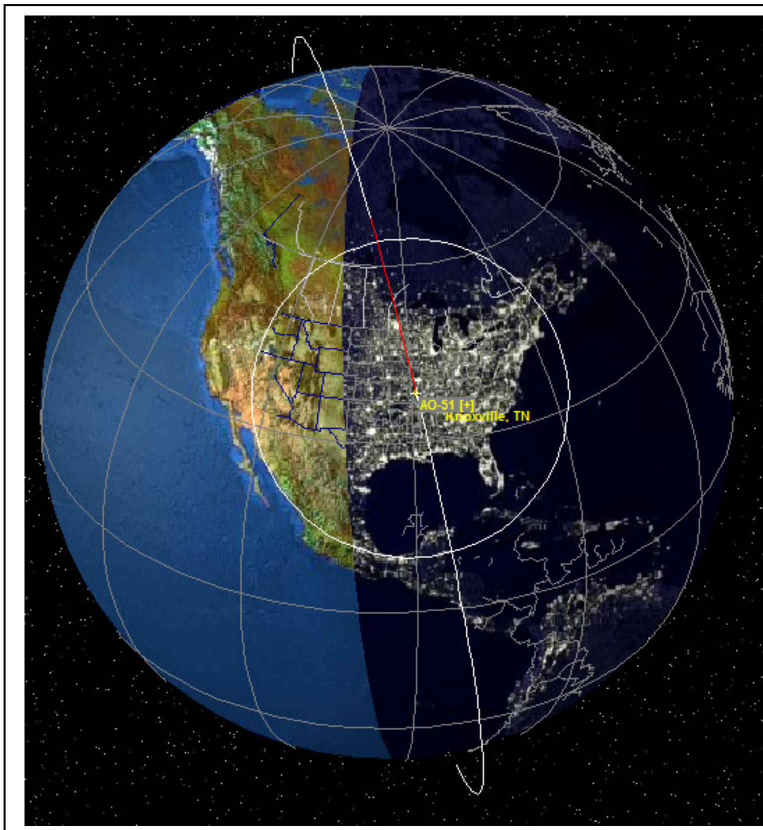
Gould Smith, WA4SXM
AO-51 Command Station

Abstract
After 3.5 years of operation with an eclipse every orbit, AO-51 went into a three month period of no eclipse in 2008. This paper will review the changes that have taken place in the satellite over its lifetime as well as the changes during the no eclipse period and its aftermath. These include Battery Voltage, Temperature, Solar Array Current and Spin.

AO-51 Background
Launched on 29 June 2004, AO-51 (ECHO) has been serving the amateur satellite community well for over four years. The multiple operational modes and reliable operation has made AO-51 a highly popular satellite.
In 2008 AO-51 has demonstrated its versatility by showcasing multiple simultaneous transmissions on many different combinations of uplink/downlink frequencies and modes. With the no eclipse periods that began in 2008, we are able to use increased power on both downlink frequencies. This makes it easier for the ground stations to receive the AO-51 signal in marginal locations.

AO-51 Orbit

Figure 1. AO-51 Orbit and Sun relationship Oct 2008



The orbit of AO-51 is in a nearly sun-synchronous orbit inclined 98.72 ° to the equator. The altitude of AO-51 ranges between 696 km and 817 km above the earth. A little known fact is that the range from the satellite to a ground station changes drastically from AOS (Acquisition of Signal) to mid pass called TCA (Time of Closest Approach). The elevation of the satellite during a pass is a major factor in the received signal strength; this greatly affects the ground station operation. Path loss contributes up to a 12 dB difference in downlink signal strength from AOS to TCA during high elevation passes. Low elevation passes have a much longer signal path and thus a lower signal strength during the entire pass and are subject to additional losses from trees and other structures. The best signal levels are found at TCA during high elevation passes when the satellite is closest and path loss is the least. Notice in Table 1 that on a 22° elevation pass that the satellite is about twice as close at TCA than at AOS. During a 60° elevation pass the satellite is almost 4 times as close at TCA as at AOS and LOS (Loss of Signal).

Table 1. Distances from the AO-51 satellite to ground stations for different max elevations

3 º pass	12 º pass	22 º pass	60 º pass
AOS 3100 km	AOS 3000 km	AOS 2950 km	AOS 3000 km
TCA 2900 km	TCA 2200 km	TCA 1517 km	TCA 800 km

AO-51 Eclipse Periods

The eclipse periods of AO-51 changed constantly during the first 3.5 years of operation. As seen in Figures 2 & 3, the eclipse period started about 34 minutes and decreased until Feb 2007, increased for six months and then fell for the next six months. In Jan of 2008 AO-51 entered into its first no eclipse period. During 2007 the engineering and command team spent a good deal to time discussing what to expect and the best way to handle the no eclipse period and the resulting heat. The discussions centered on turning the transmitters off or using as much power as possible. We decided to use as much power as possible to reduce the heat.

Figure 2. AO-51 launch – 11/2007 eclipse period graph from Colin Hurst, VK5HI

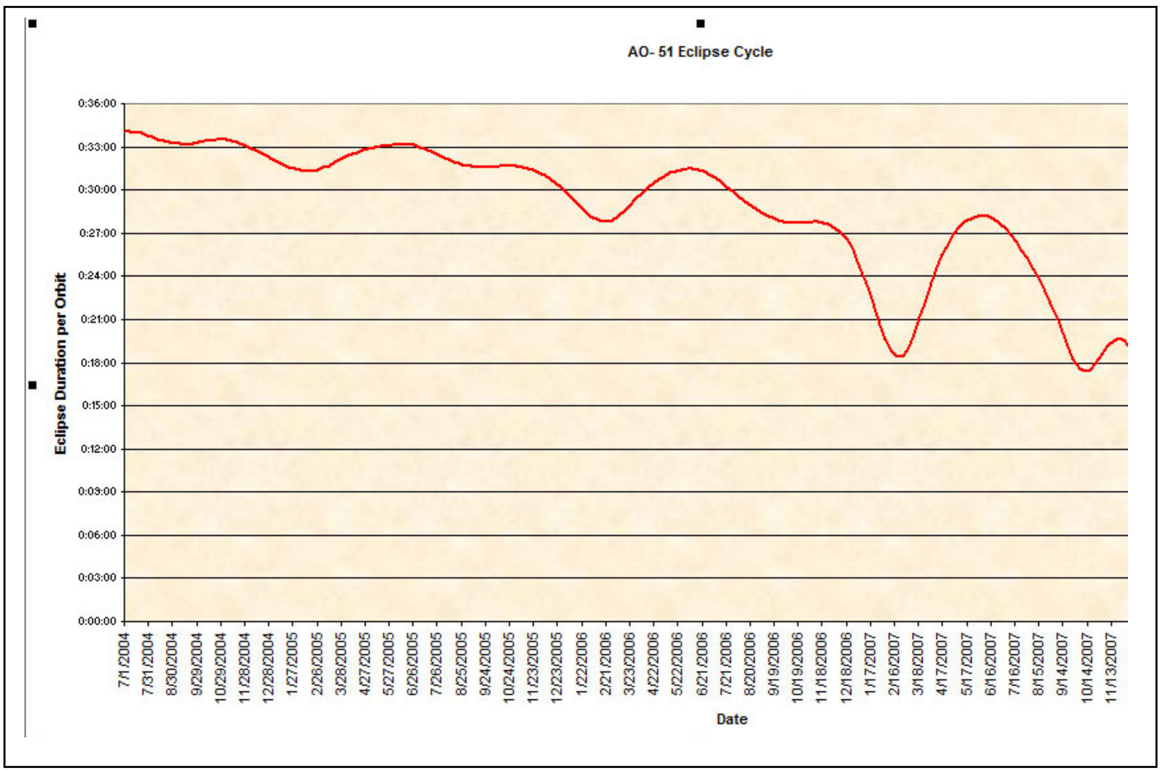
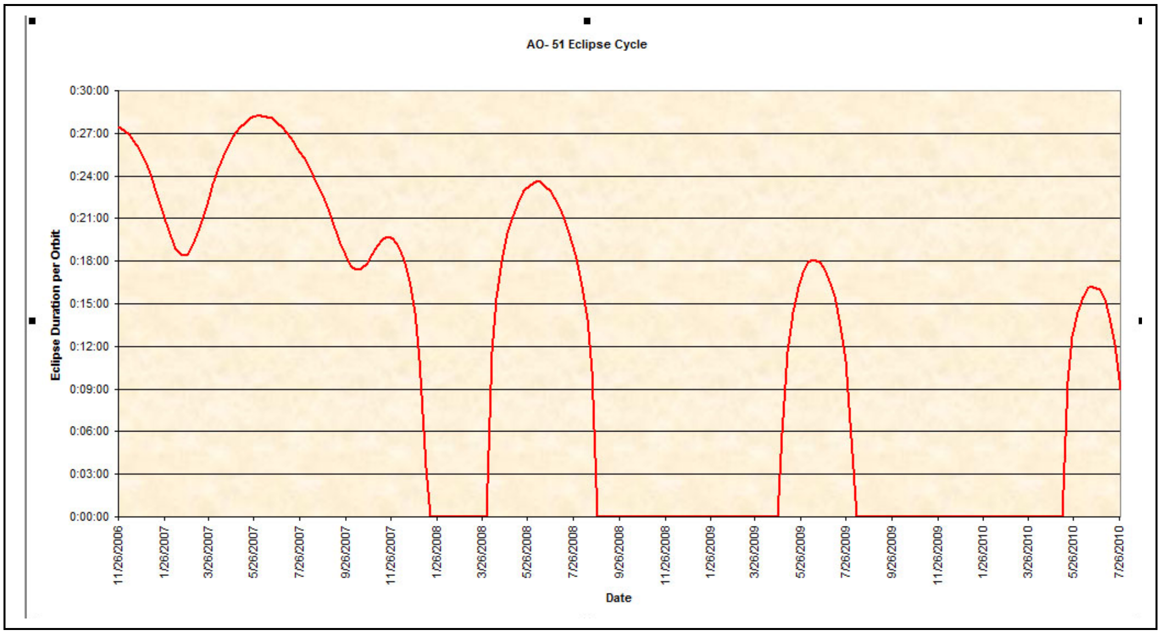


Figure 3. AO-51 11/2006 – 7/2010 eclipse period graph from Colin Hurst, VK5HI



Satellite Orbit in Relation to the Sun

In preparing for a talk at Dayton 2008 I noticed an interesting thing about the orbit of AO-51 and the no eclipse period. During the first years of AO-51 in space the orbit and the resulting eclipse period saw the satellite footprint completely inside and outside of the sun's grey line (see Figure 4). During the no eclipse in February 2008 notice that the orbit of AO-51 puts the satellite right around the grey line the entire orbit (Figure 5). It appears that the orbit is 90º out of phase with the grey line, then moves to in phase.

Figure 4. AO-51 orbit during eclipse period 15 June 2007

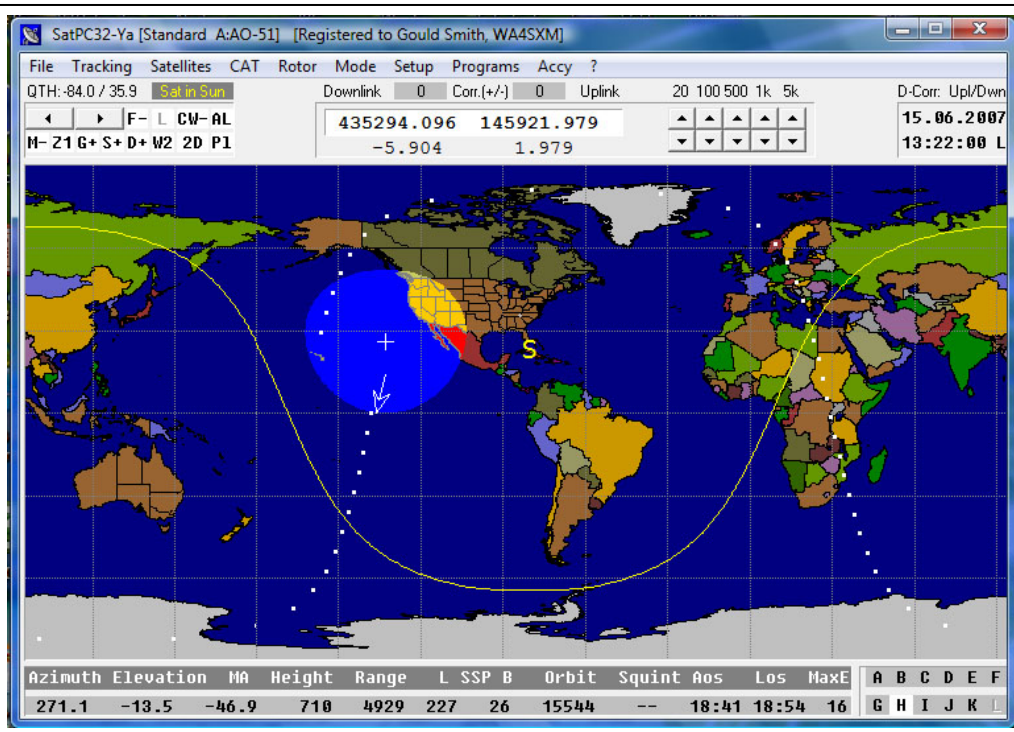
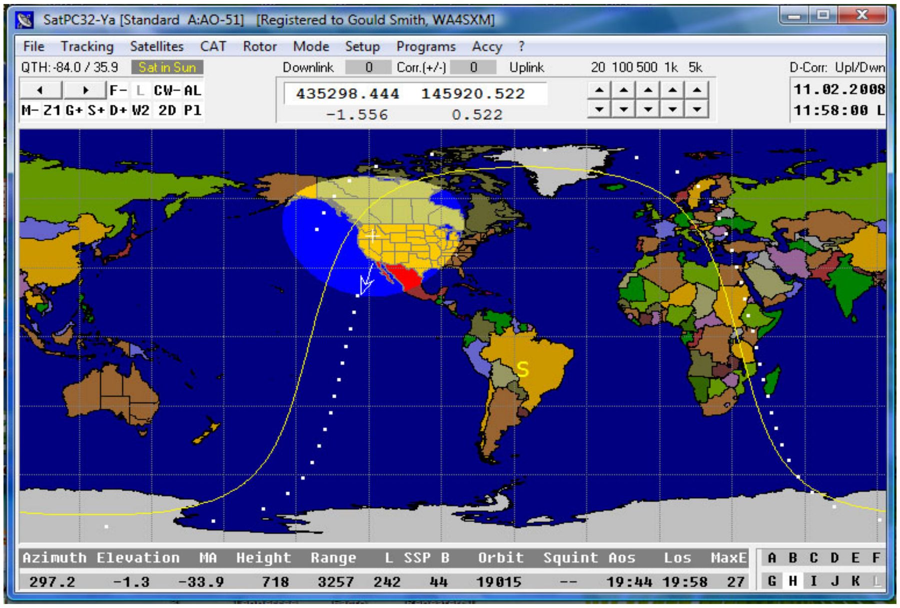
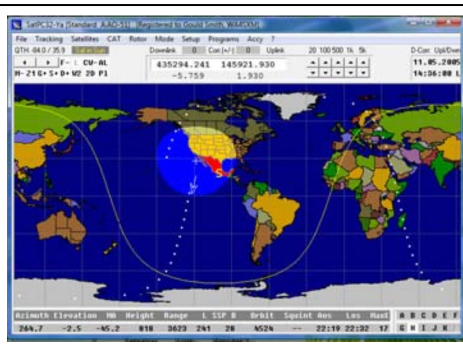


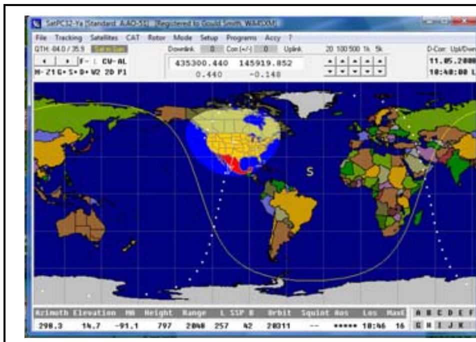
Figure 5. AO-51 orbit during no eclipse on the grey line 11 Feb 2008



So this brought up the question of what has happened to the orbit over time. Figures 6 & 7 show the orbit of AO-51 during the Nov 2005 and May 2008 eclipse periods with the satellite out of phase. Figure 8 shows the orbit of AO-51 almost exactly in phase with the grey line and at an interesting time of the year to get an unusual sun illumination display.

Figures 6 & 7. AO-51 during eclipse periods in 2005 and 2008





The eclipse/no eclipse periods for AO-51 the next couple of years shows:

August 2008	–	April 2009	no eclipse
April 2009	–	August 2009	in eclipse
August 2009	–	May 2010	no eclipse
May 2010	–	August 2010	in eclipse

Figure 8. Interesting picture of AO-51 orbit during no eclipse almost in phase with the grey line and close to the autumnal equinox (22 Sep 08, 1544Z), 25 September 2008

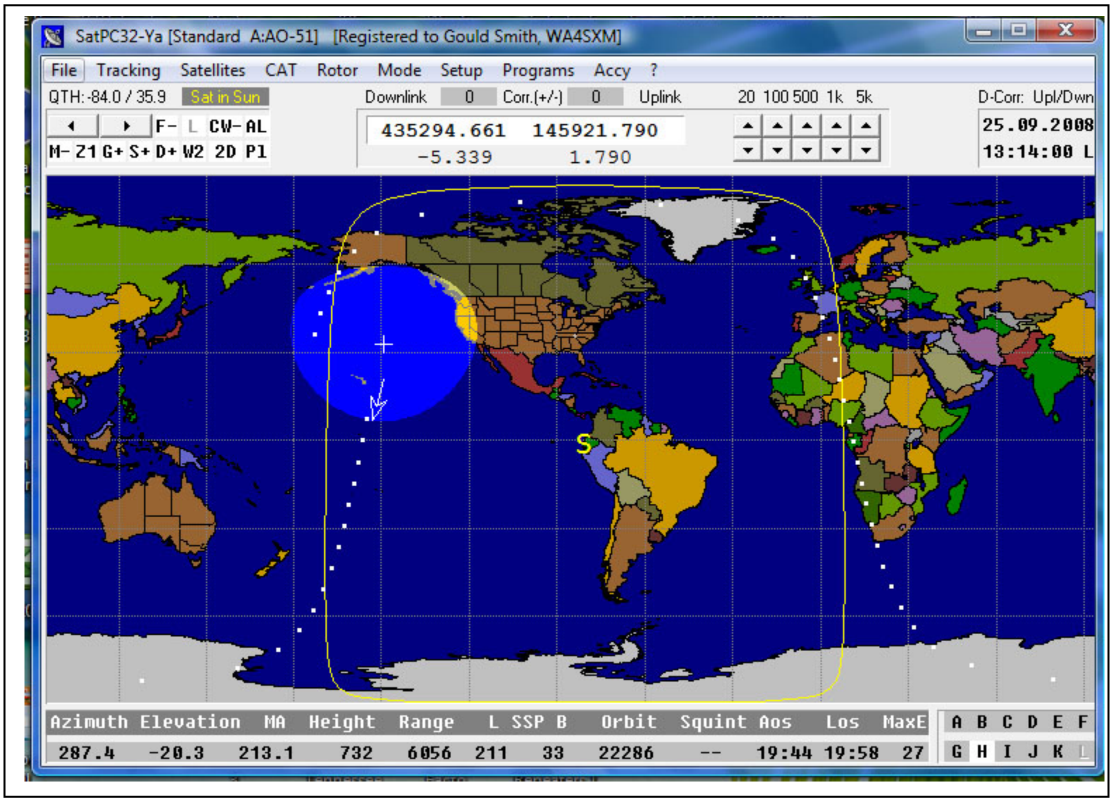
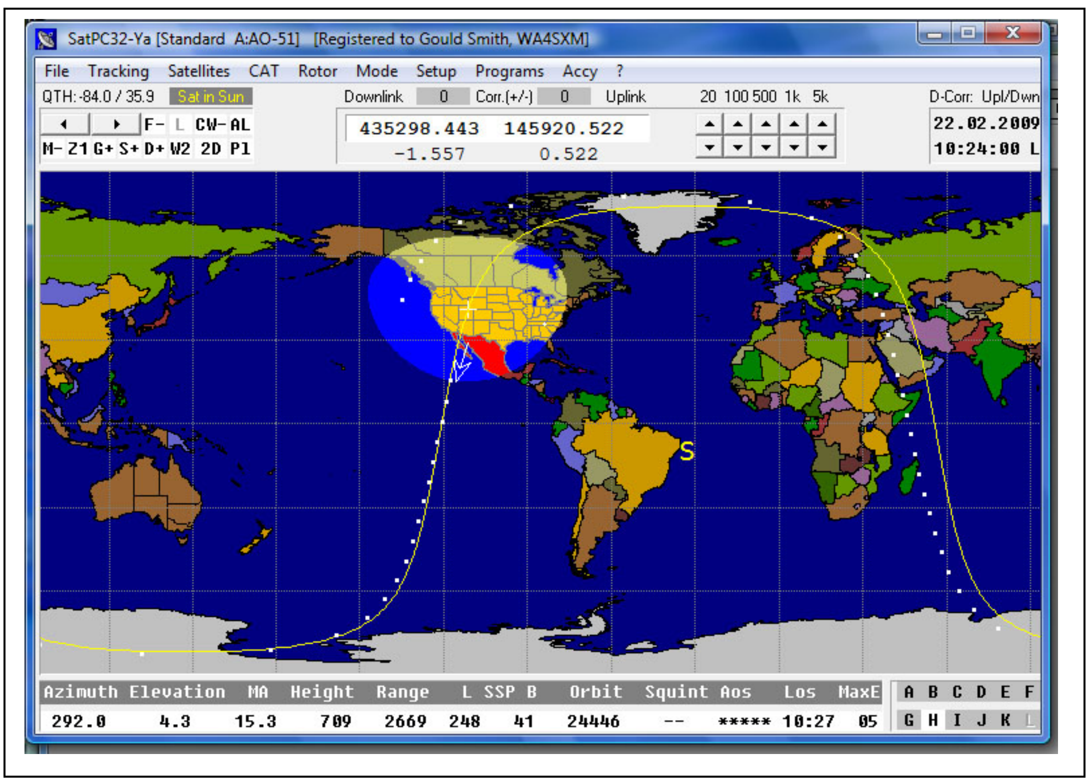


Figure 9. AO-51 orbit at the end of February 2009 still in phase with the grey line



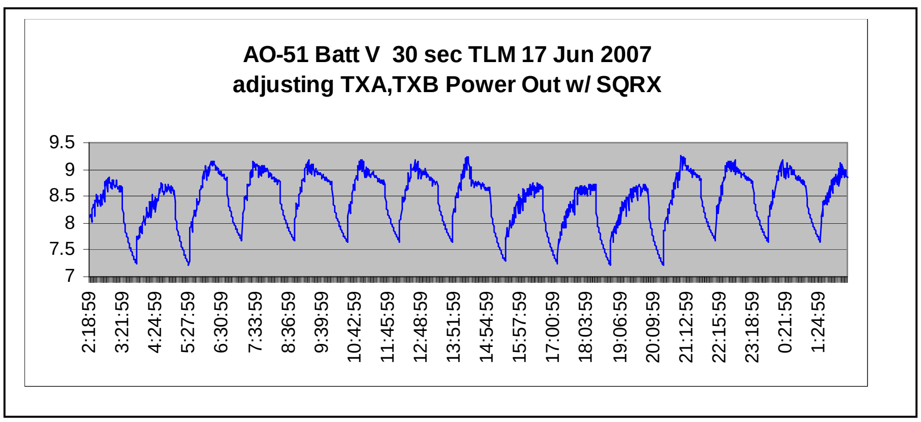
AO-51 Transmit Power and Eclipse Time

The main limiting factor for AO-51 transmit power before 2008 had been the necessity to have enough battery reserve to get through the eclipse periods using battery power only. The power level of the two transmitters was constantly adjusted to 1) make sure that the satellite had sufficient power to transmit through the eclipse period and 2) cycle the batteries to increase their lifetime. This proved to be a constant challenge, but all part of commanding a satellite and why we volunteer to do this.

The graph in Figure 4 shows the effect on the battery voltage during sun and eclipse. The higher battery voltage is during the period when the satellite is in the sun and the batteries are charging. The rapid decline is when the batteries are powering the satellite and being discharged. The two levels shown are from running different TX power levels. The graph starts with both TXA and TXB on, then TXB was turned off at 05:27, TXB back on at 14:54 and off again at 20:09. TXA was running 350 mW and TXB 480 mW. The transmit current changed from 880 mA with both transmitters on to 440 mA when TXB was turned off. The eclipse time determined the amount of total transmit power. The SQRX receiver uses about 110 mA, so this could be turned off and TX power increased or SQRX On and TX power decreased.

We generally used about 1W of total TX power during eclipse orbits.

Figure 10. Standard Battery Voltage graph during eclipse period



AO-51 Battery Voltages

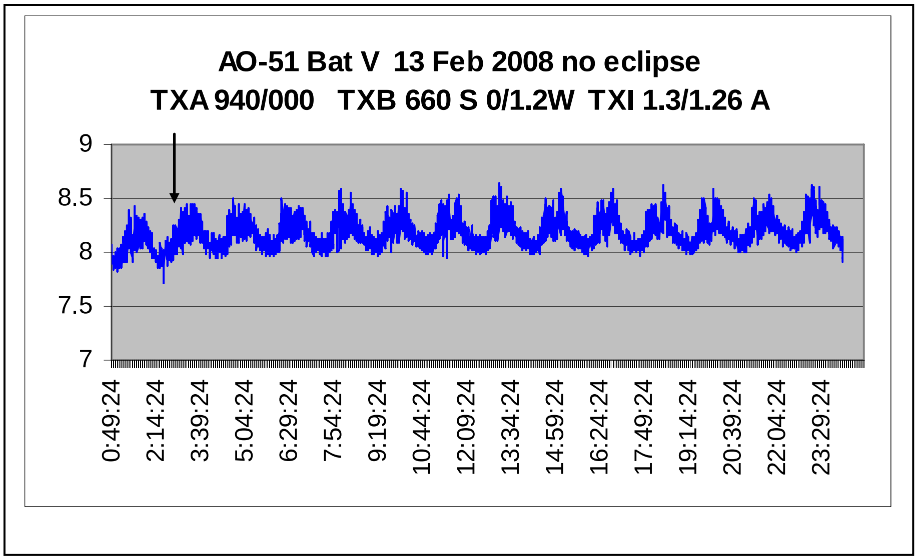
A description of the AO-51 battery voltages during eclipse were discussed in depth in my 2007 AMSAT Symposium paper, *AO-51 Power Generation, Storage and Transmitter Power*. The new information concerns how AO-51 operated during the no eclipse period of Jan 2008 – Apr 2008, performance changes noted during the Apr 2008 – Aug 2008 eclipse and operation during the second no eclipse period, Aug 2008 – early Oct 2008 when this paper was prepared.

Battery voltages during the Jan 2008 No Eclipse Period

During the first 2008 no eclipse period the battery voltage remained pretty consistent. Since the solar panels were constantly in sunlight, the batteries were able to be constantly charged so the battery voltage varied slightly. Figure 11 shows the battery voltages during TXA & TXB operation, then a change at 02:15Z to S band and TXB with the transmitter using about the same amount of TX current.

We generally used about 1.8 - 2.2W of total TX power during the no eclipse period.

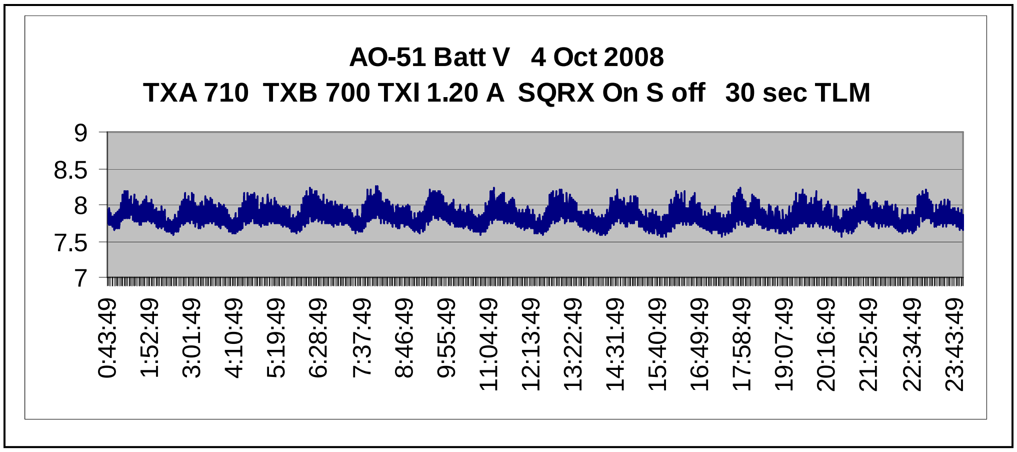
Figure 11. Sample AO-51 Battery Voltage during first no eclipse period



In Figure 11 the two U-band TXs produced about 1.6W of total TX power. When we switched to the S-band TX and the U-band TXB we generated about 1.86W at about the same current usage.

There has been concern that the batteries may not be holding power as well as before the no eclipse period. So, I am experimenting with TX power and the resulting battery voltages and temperature changes during the second no eclipse period. Starting with lower total transmit power levels and slowly increasing them. I am working on correlating the battery power, component and chassis temperatures at different power levels. In Figure 12 total transmit power is 1.41W plus the SQRX receiver

Figure 12. AO-51 Battery Voltages during the second no eclipse period



You will notice in Figure 12 that the battery voltage does not charge up as high as it did during the first no eclipse period with less TX power used.

During the eclipse period between the two 2008 no eclipse periods the battery voltages looked normal. Figure 13 shows the battery voltages during an S-band only session using 730 mW to produce a 1.2W S-band downlink. Figure 14 shows the battery voltages used to support TXA & TXB with a total output of 900 mW using 920 mA of TX current. Notice that the batteries don't charge as high as they do using less TX power in Figure 13, and they discharge to a lower level.

Figure 13. Battery Voltages between the two 2008 no eclipse periods

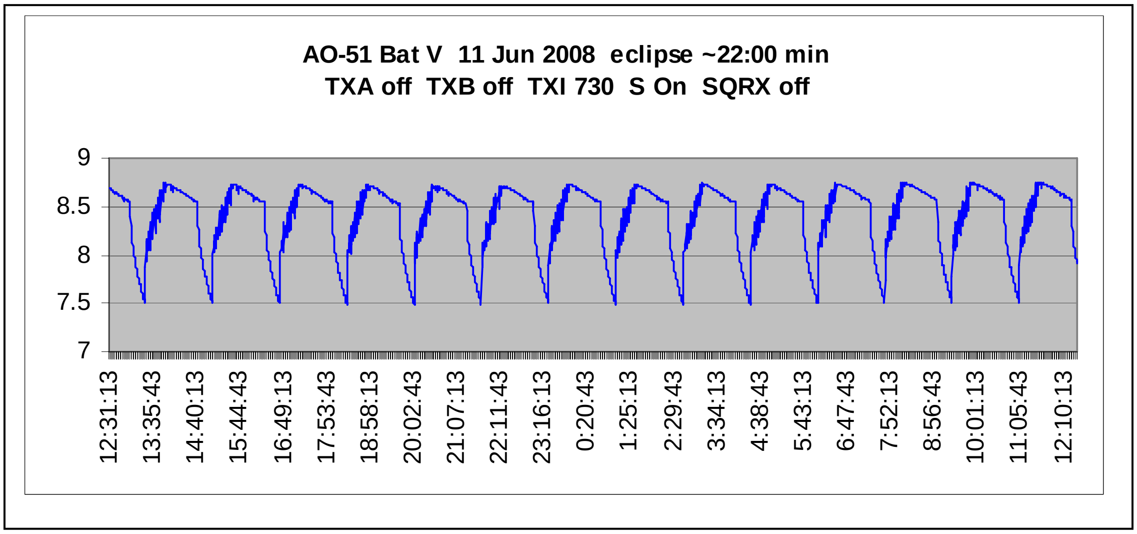
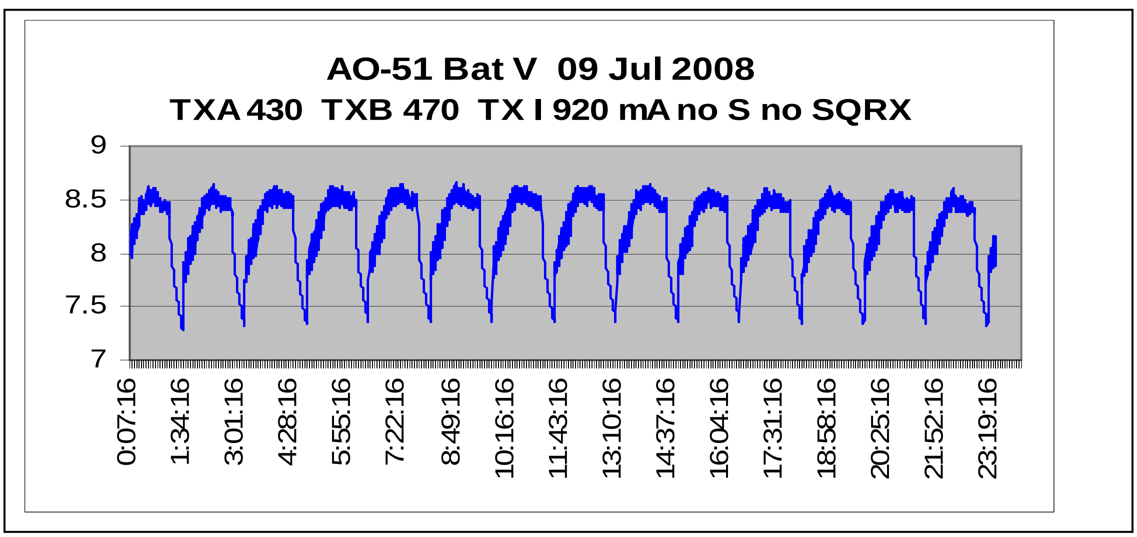


Figure 14. AO-51 Battery voltages using TXA & TXB July 2008 eclipse period



AO-51 Temperatures

AO-51 average temperatures increased during the first 3.5 years in space, but showed obvious seasonal variations. Each January the temperatures increased and each June/July they decreased during the eclipse time. One explanation is the distance of AO-51 and the earth to the sun.

Figure 15. AO-51 temperatures, graph by Colin, VK5HI

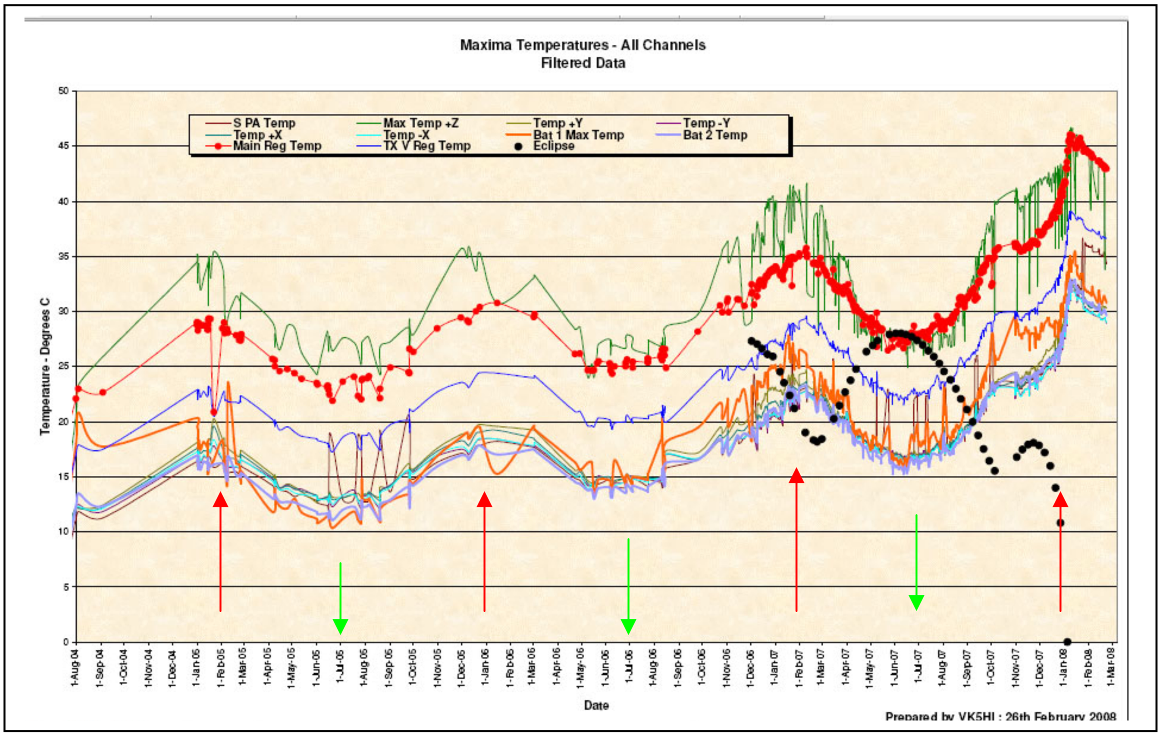
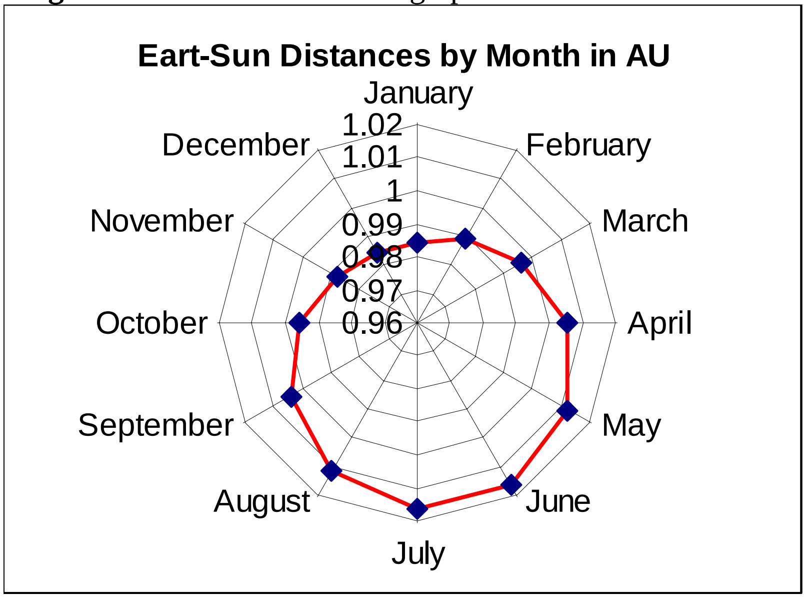


Table 2. Earth – Sun Distances in AU (1 AU = 149,597,900 km)

Earth - Sun Distances			
	AU	km	miles
January	0.984	147,204,333.60	91,468,532.27
February	0.9888	147,922,403.52	91,914,720.23
March	0.9962	149,029,427.98	92,602,593.34
April	1.005	150,345,889.50	93,420,604.61
May	1.0122	151,422,994.38	94,089,886.55
June	1.0163	152,036,345.77	94,471,005.43
July	1.0161	152,006,426.19	94,452,414.27
August	1.0116	151,333,235.64	94,034,113.05
Septembe	1.0039	150,181,331.81	93,318,353.20
October	0.9954	148,909,749.66	92,528,228.68
November	0.9878	147,772,805.62	91,821,764.41
December	0.9837	147,159,454.23	91,440,645.52

Figure 16. Earth – Sun Radar graph



The temperatures aboard AO-51 have remained proportional to one another for the last couple of years. There also was a fairly wide temperature swing from the illuminated to the eclipse period (see Figure 17). Once in the no eclipse period the temperatures were very stable with little temperature swing (see Figure 18).

The representative temperatures for AO-51 are Battery #1, Battery #2 which I have identified as actually the space frame in the battery compartment, Main Voltage Regulator, and the TX Voltage Regulator. There are also temperatures recorded for the S-band exciter, S-band Power Amplifier, and most of the solar panels.

AO-51 telemetry data is available for download from the AMSAT AO-51 Telemetry FTP site:

http://www.amsat.org/amsat/ftp/telemetry/ao51/

Table 3. Average AO-51 Temperatures at various areas of the satellite

		Batt 1	Batt 2 (chassis)	Main Reg	TX V Reg
Fall 2008	No eclipse	31	28	41	35
Summer 2008	eclipse	20	16	24	20
Spring 2008	eclipse	20	12	26	23
Winter 2008	No eclipse	32	31	44	37
Fall 2007	eclipse	20	19	27	25
Summer 2007	eclipse	14	12	18	15
Winter 2007	eclipse	20	15	23	20
Summer 2006	eclipse	11	9	15	13
Winter 2006	eclipse	15	12	20	17

Figure 17. Sample temperature profile for AO-51 during eclipse period

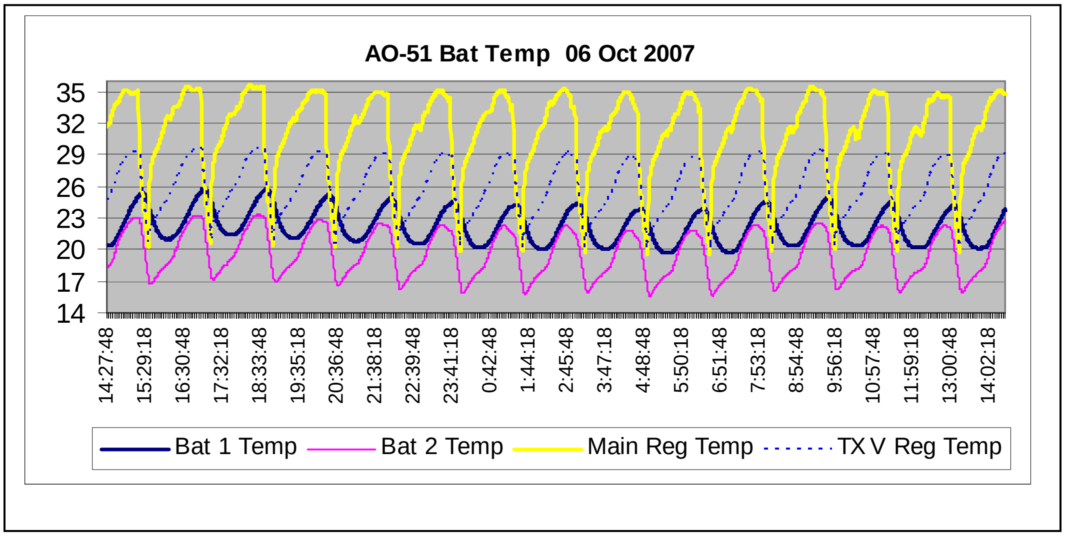
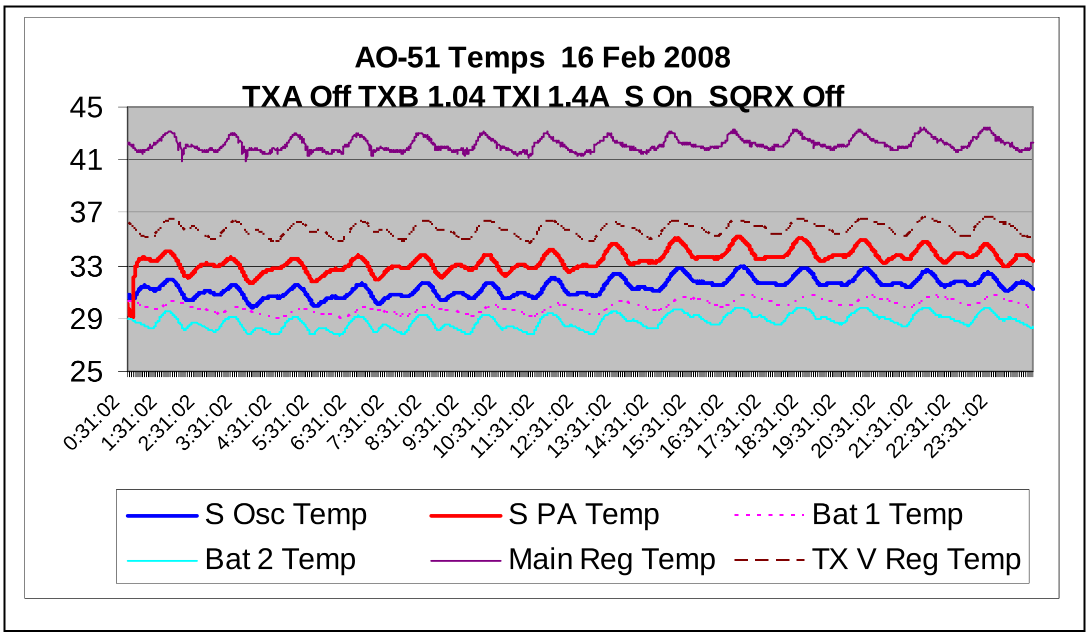


Figure 18. Sample AO-51 temperature profile during NO eclipse period 2008

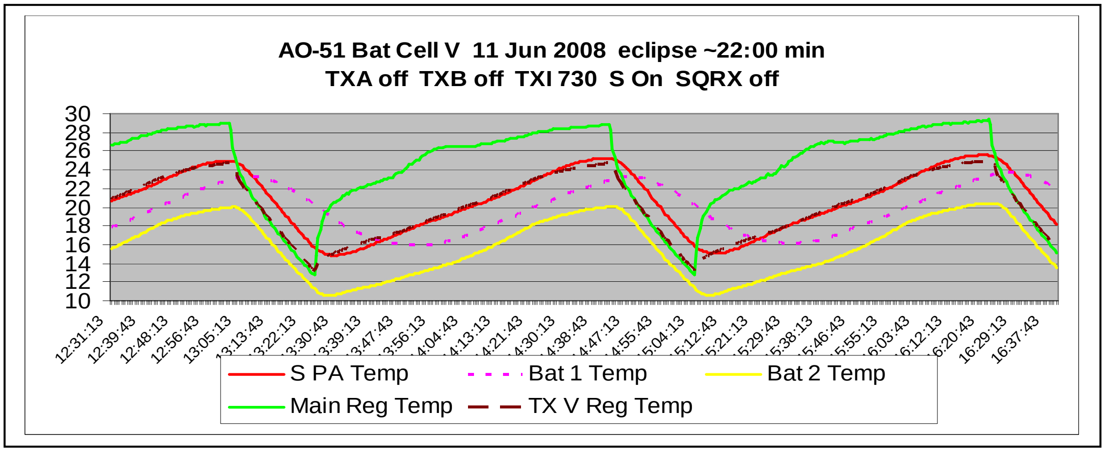


The Batt 2 (space frame) temperature is always the coolest part of the satellite, but you can see that it has a wider temperature swing than Batt 1. Batt1 is actually the temperature of Batt #1. The TX V Regulator is between Batt 1 and the Main V Regulator, with the Main Regulator always the hottest item recorded inside the space craft.

In Figure 18 you can see the temperatures are fairly constant, except for the S PA Temp. The S-band amplifier was turned on close to the left margin of the graph, you can see the rapid temperature increase as it heats up from 29 to 34 ºC. The S-band exciter and amp are the same temperatures as Battery 2 (space frame) when the S-band transmitter is off.

After coming out of the winter no eclipse period the satellite resumed the temperature cycling expected. In Figure 19 I am showing only three orbits for clarity. The bright, lower sine wave is the Batt 2(space frame) temp, the S PA and TX V Reg temperatures are sitting on top of each other in the center of the graph. The Batt 1 temp is also in the center of the graph, offset to the right of the S PA and TX V curves.

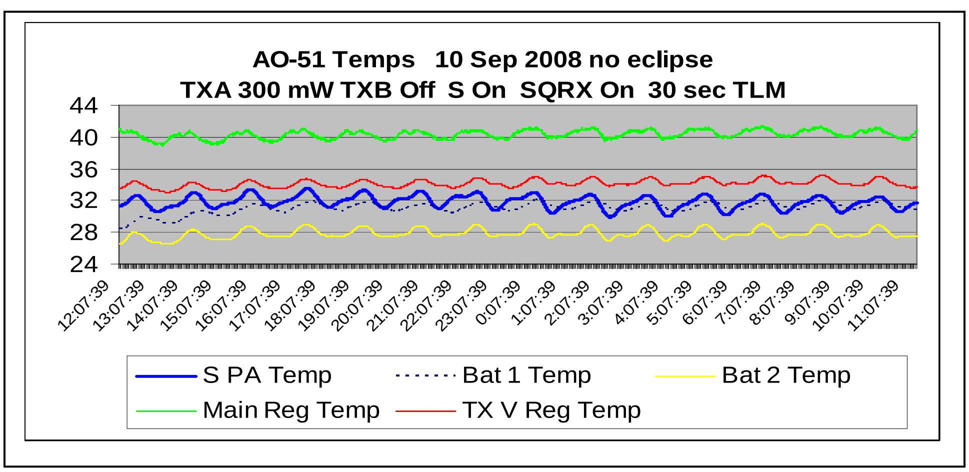
Figure 19. AO-51 temps during the summer of 2008 between the no eclipse periods



The temperature range of Batt 1 cycled between 18 – 24 ºC during the June 2008 eclipse time, in the winter 2008 no eclipse period a constant 30 ºC was noted. In Sep 2007 the Batt 1 temps ranged between 16-21 ºC. Oct 2007 saw the Battery 1 temps range between 20-25 ºC. Then in Nov 2007 they were back to 16-22 ºC. In Dec 2007 they were back up to 21-26 ºC. In the Fall 2008 no eclipse period Batt 1 was back to 30 ºC.

During the Winter 2008 no eclipse time the S-band amplifier was a pretty constant 33-34 ºC, in Figure 19 during the summer eclipse period it ranges between 15 – 25 ºC. In the Fall 2008 no eclipse period it returned to 32 ºC.

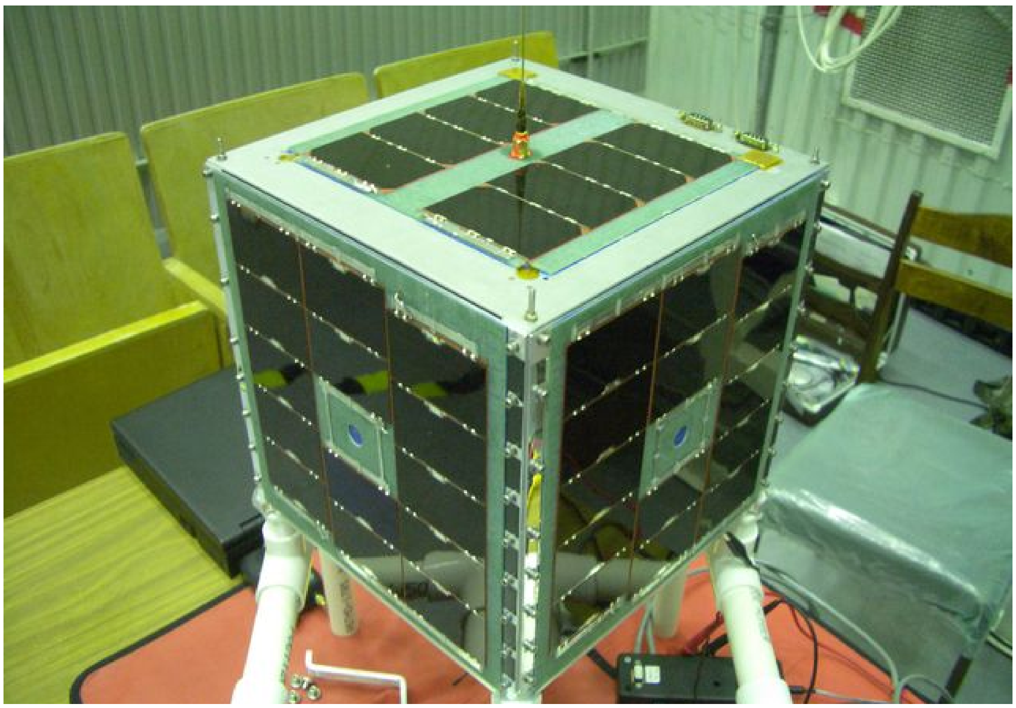
Figure 20. Fall 2008 no eclipse period AO-51 temperatures.



Solar Panel Array Currents

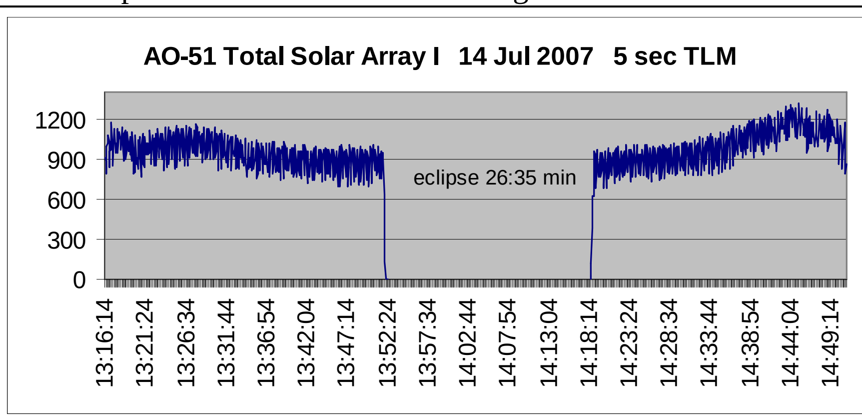
AO-51 has solar cells on all six sides. The larger solar panels are on the 'sides' of the space craft and are labeled +X, +Y, -X, -Y in that order. The 'top' and 'bottom' of the space craft are referred to the +Z and –Z sides. The satellite rotates around the Z axis and essentially lies on its side as it passes over the mid northern hemisphere.

Figure 21. AO-51 Solar panel layout



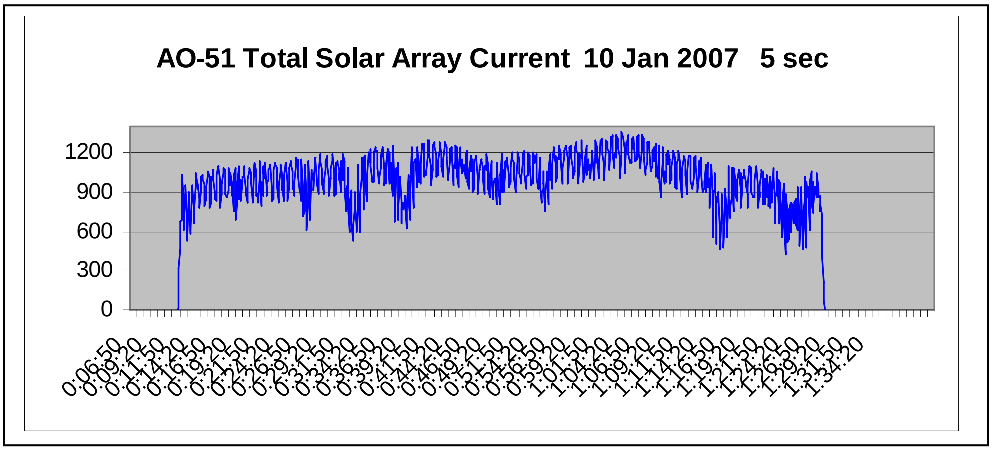
The solar cells are high efficiency [~27% efficient] triple junction, GaAs cells. They cost about $20,000. There are 14 cells on the X & Y sides and 8 cells on the Z sides. When new they are capable of producing about 20W when illuminated.

Figure 22. Solar panel currents when AO-51 is greatest distance from the sun



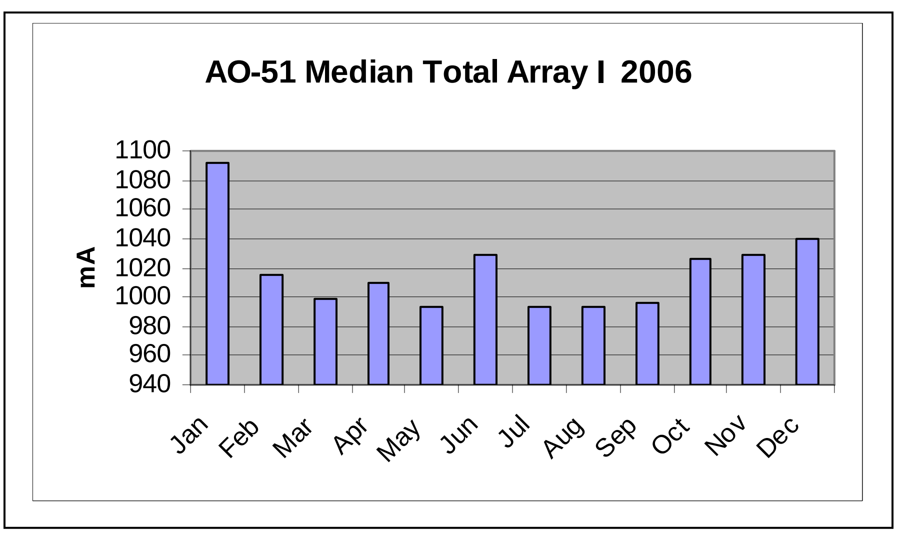
In Dec/Jan AO-51 and the earth are closest to the sun. So we would expect to see a higher total current produced, unless the solar cells are already at capacity. Comparing Figures 22 & 23, it seems that about the same total current is generated summer and winter. Looking closer at the data shows that the median array current during illumination for Figure 22 is 957 mA, and the median array current for Figure 23 is 1022 mA.

Figure 23. AO-51 solar panel currents in winter 2007 during eclipse period



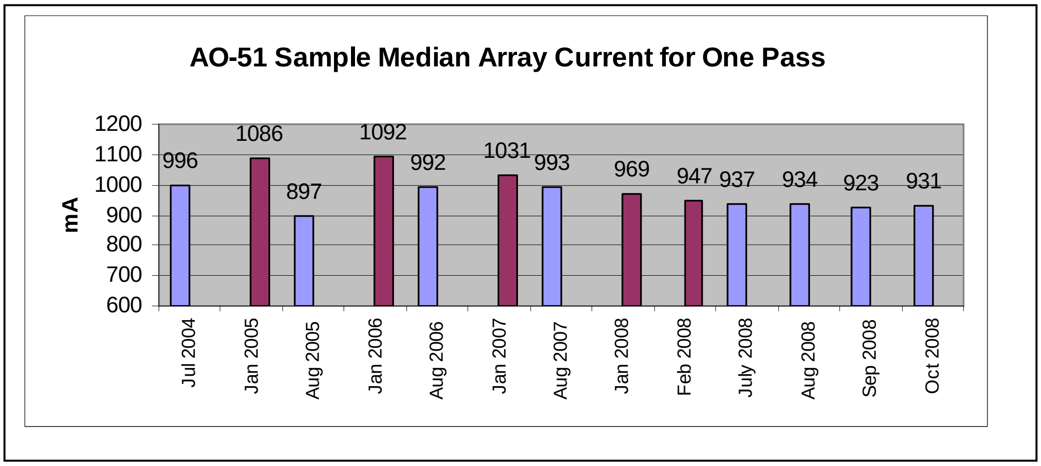
The telemetry data about the earth – sun distance effecting the solar production is conflicting. We need a more in depth study of the data. Looking at select samples of telemetry for each month during 2006 seems to show higher array current production during the winter and less during the summer. The graph in Figure 24 does show a spike in array current during July, when it should be lower. So there are obviously other factors at play.

Figure 24. Graph of the median total array currents for select data during 2006



Taking the data observation to the next level involves looking at the total array currents for larger samples of winter and summer passes and comparing them. We expected a deterioration of the solar cells and their capacity to produce energy. It is unclear to me whether the data in Figure 25. shows this deterioration or just less light available because the satellite is on the edge of the sun line.

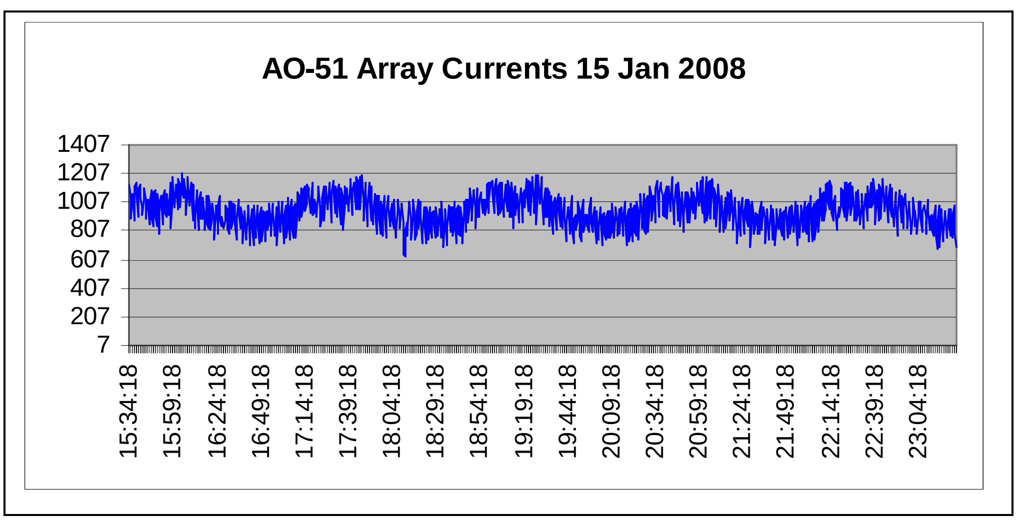
Figure 25. Sample AO-51 solar array currents over the last four years



Array Currents During No Eclipse

The fact that AO-51 first entered the no eclipse period at the same time that it was closest to the sun, made for some interesting conversations and speculations. The data shows that the median array current generated during an eight hour window in mid January 2008 were 952 mA, less than I expected for a January pass.

Figure 26. AO-51 Solar Panel Total Array Currents for 8 hours during no eclipse



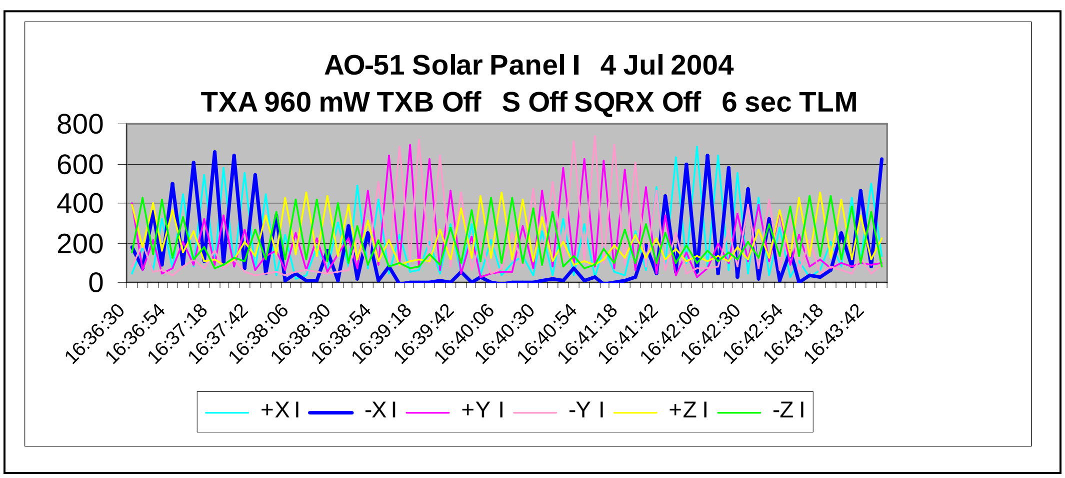
AO-51 Spin Rate and Wobble

If you look closely at the AO-51 satellite in Figure 21 out at the edges of the X and Y sides you will notice strips with a series of nuts in them. Looking closer, or at the color picture on the cover of the AO-51 book, you will notice they are black and white strips. These serve the same function as the black and white painted 70cm antennas on the original microsats, to cause the satellite to spin. Spinning helps thermally stabilize the satellite. Determining the spin rate of a satellite can sometimes be difficult. The rate that the telemetry is sampled in relationship to the spin can cause problems in accurately determining the spin rate. The Nyquist theorem says that to accurately reconstruct information, the object being measured must be sampled at more than twice the rate the object is producing information. In this case, if the satellite is spinning more than 3 RPM, this means that each of the four X/ Y sides will pass a spot each 5 seconds. So the minimum sample rate to accurately determine a 3 RPM rate would need to be every 2.5 seconds. For a 2.5 RPM rate the samples would need to be taken faster than every 3 seconds. Well it turns out that the AO-51 system can only complete its telemetry sampling every 3.x seconds. The telemetry sample rate can only be selected in integer second values. This makes the sampling rate and the normal spin rate at odds.

Knowing the structure of the satellite is important in evaluating the sample data. I generally do a 5 sec telemetry sample for one orbit about every two weeks. So, I expect the solar array currents to display a sequence of +X, +Y, -X, -Y, +X, … when graphed. If this is not what is shown, then the data can't be trusted. Of course, the spin rate could be some multiple of the graphed spin rate and still lead to invalid conclusions.

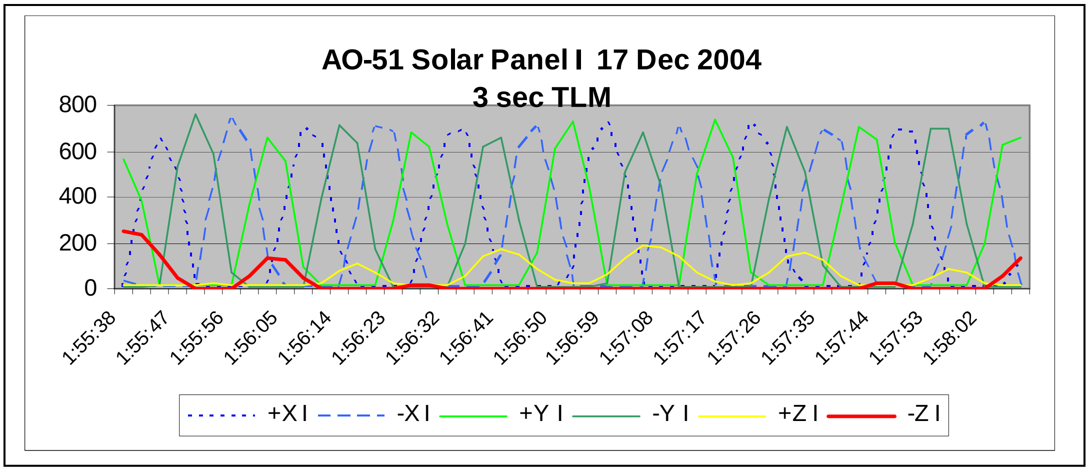
Early in the life of AO-51 we captured data that made a very colorful graph, but it was obvious that the spin rate was too fast for the sample rate because array peaks from panels on opposite sides of the spacecraft were graphing next to each other.

Figure 27. Invalid sample rate of the AO-51 solar panel current data



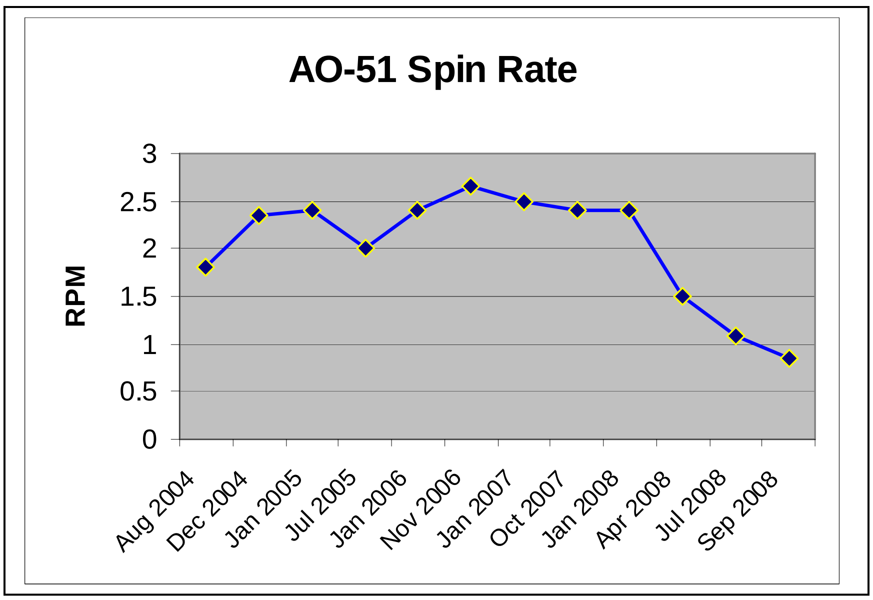
A good sample rate ratio to spinning panel currents will give the correct sequence of peaks, with the peaks about the same amplitude. Figure 27 shows how well a faster sample rate and a slower satellite spin produce good data for analysis. This 3 sec sample rate caused a large area of invalid data during the sample, because of the race condition between doing multiple samples and the length of time it takes to do a complete sample. The data show in Figure 28 was taken from the supposedly 'good' part of the data.

Figure 28. Good representative Solar Panel Current data to determine satellite spin rate



Capturing data at a 5 sec sample rate only gives you a resolution of ±5 sec best case, not including the Nyquist rate. So, often I will get times between peaks of 25 and 30 secs, quite a bit of inaccuracy induced. Nevertheless, I have assembled a small sample of data during the lifetime of AO-51 to show the changes in spin rate.

Figure 29. Long term AO-51 spin rate changes

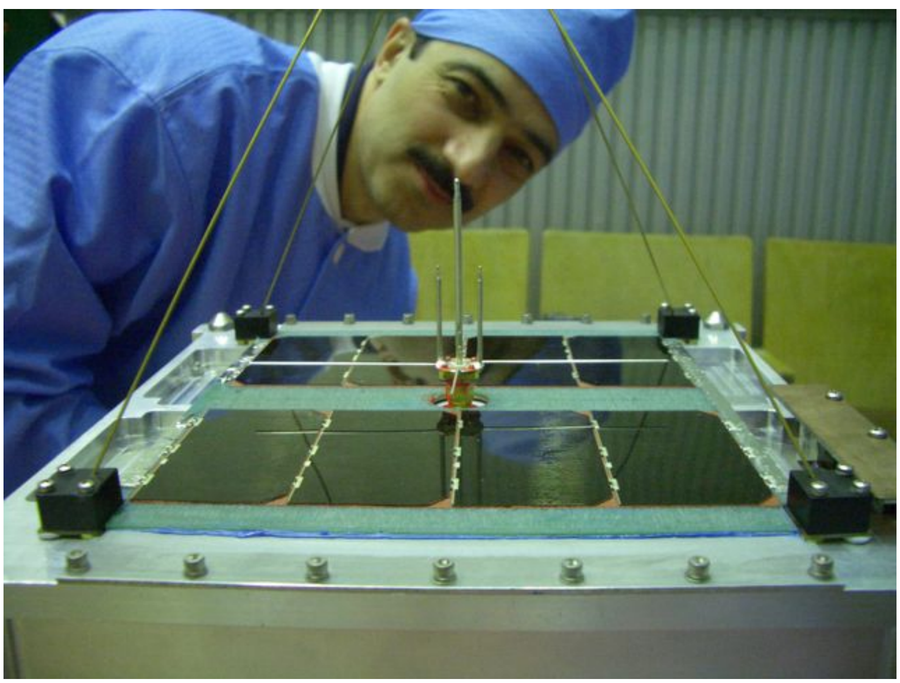


In Figure 29 you can see a noticeable slowing of the spin rate of AO-51 since the January 2008 no eclipse period. I will continue to follow this phenomenon. I believe that one or some of the microsats actually slowed and reversed spin direction. It will be interesting to see if the Fall 2008 no eclipse period changes or accelerates the spin rate. Stay tuned! With the slowing of the spin rate it makes it easier for the telemetry to capture a good representation of the actual spin rate.

Wobble

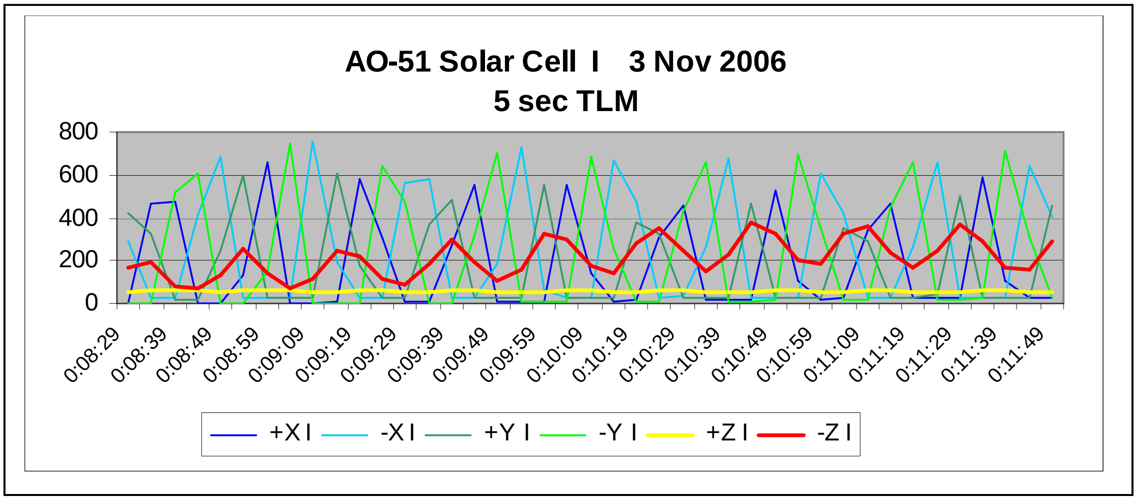
Related to the spin about the Z axis is an additional perturbation that the satellite doesn't spin perfectly about the Z axis. Think about a spinning top as it slows down and begins to wobble about the Z (vertical) axis. AO-51 exhibits this same phenomenon. You especially notice this if you are using the L-band uplin or S-Band downlink. The L/S band antenna is on the –Z side of the satellite with the 70cm antennas. As the satellite wobbles the small antenna is shaded from your location by the edge of the satellite.

Figure 30. AO-51 L/S antenna and the 70cm antennas on the –Z side of the satellite with Mark Kanawati, N4TPY of SpaceQuest, LLC in the background



It continues to amaze me that this diminutive antenna made by Lou McFadin, W5DID and Stan Wood, WA4NFY produces such a strong 2.4 GHz signal. Of course getting a 1.2 GHz uplink signal to AO-51 offers quite a challenge for many.

Figure 31. Sample telemetry data showing the wobble on the –Z side of the satellite, the +Z side apparently didn't see any sunlight during this 3 minute sample.



Summary

- AO-51 will spend most of the next few years in a no eclipse orbit
- No eclipse periods of sun synchronous satellites tend to follow the grey line
- No eclipse periods mean higher transmit power for AO-51
- No eclipse periods mean higher battery temperatures
- Investigate some of the AO-51 telemetry on the FTP site, teach me something
- Does the distance to the sun cause changes in the amount of solar current generation?
- AO-51 spin rate is decreasing.

References

AO-51 Development, Operation and Specifications, Gould Smith, WA4SXM, AMSAT 2005

AO-51 telemetry archives **http://www.amsat.org/amsat/ftp/telemetry/ao51/**

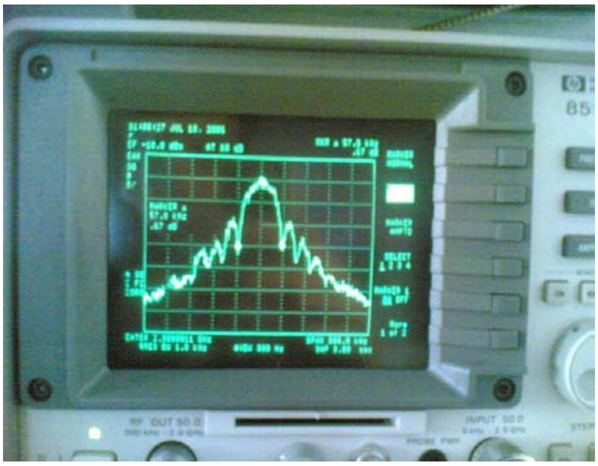
Colin Hurst, VK5HI AO-51 Graphs and descriptions

http://www.astronomycafe.net/qadir/q638.html

HSSDT Project

High Speed Satellite Data Transmitter

An FSK* Modulator *from 400 Mhz to 6.1 Ghz



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ITALY

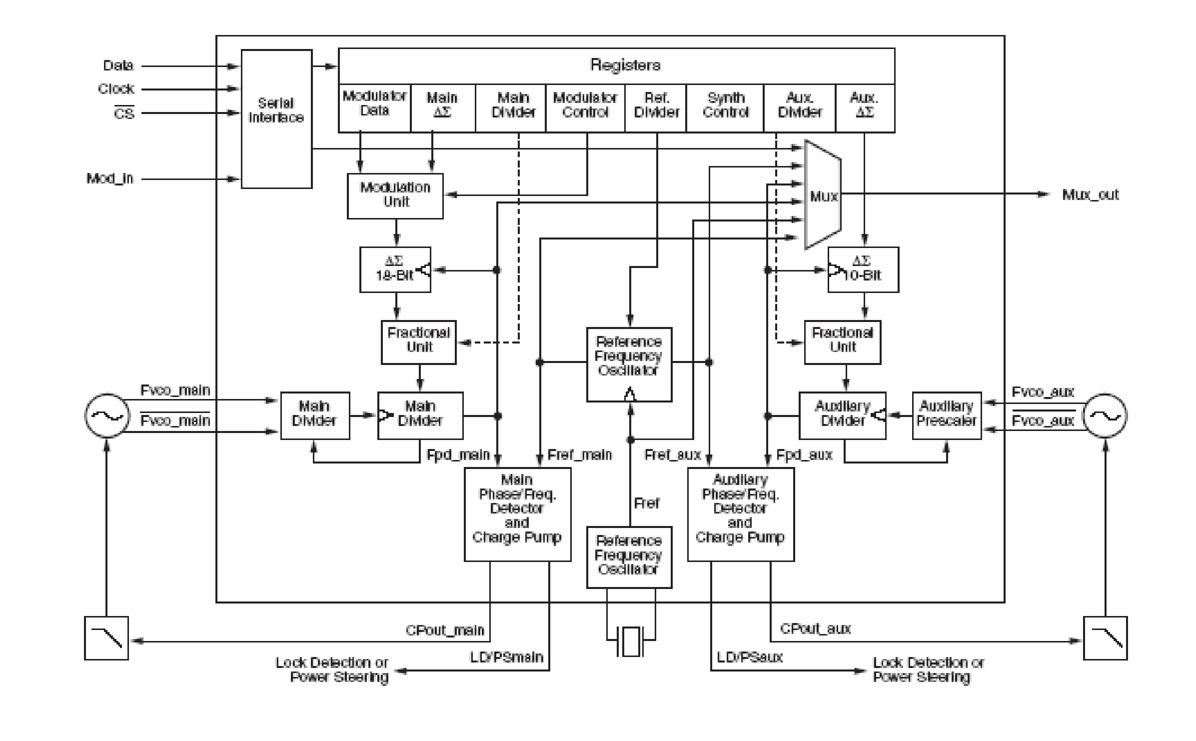
Introduction

This article describes the project: **HSSDT** – "*High Speed Satellite Data Transmitter"* a data-transmitter for *on-board Microsatellite use,* composed by an Atmel microcontroller [4] driving an N-fractional synthesizer:

SKY72302 *from Skyworks* [1]

This projects are capable to guarantee a high speed data link following, however, the low-cost requirements.
These configuration are capable to generate an FFSK Direct Digital Modulation (DDM) at a central frequency of 2400 Mhz. These system implemented in this way, work at the data rate of 38.4kbps and, without any hardware modification, can reach a speed over 115kbps.

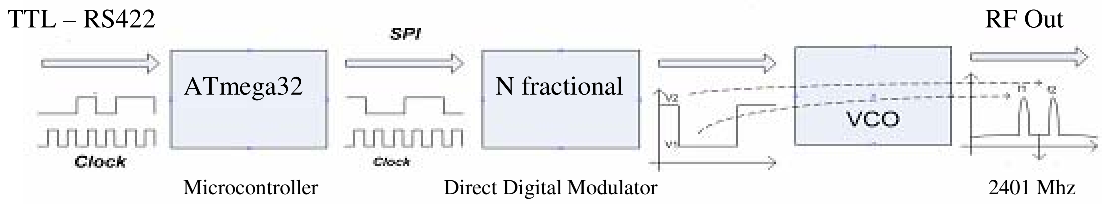
PLL Functional Block Diagrams



SKY72302 Functional Block Diagram

Microcontroller and N-Fractional PLL Interfacing

The first stage of the modulator is composed by the microcontroller, which works as an interface between the data bus and the synthesizer
The employed device is an Atmel ATMega32 [4] working at the speed of 16 MHz (fig.1), a parameter that represent the most important factor to the modulator final data rate. Input lines are the PTT, which is used to communicate when the telemetry board wants to send a message, Clock and Data, which are used to transfer the serial signal to be transmitted. All these lines are available both as TTL and RS-422 signals: through jumpers it is possible to select which of these two sources has to be used for the incoming data
The output comprises the signals needed for the correct functioning of N-Fractional modulator, that is a CS, a Clock and a serial Data. These lasts two lines are implemented through the microcontroller hardware SPI to guarantee the highest possible speed of data transfer.



Finally, the PTT signal, through a circuit taken by the telemetry board, controls the power supply of the whole modulator: when the signal is activated (from low to high level), the 12 volts bus is connected to the power stabilizers integrated in the circuit board, obtaining the 5 V for the digital circuits, 5 V for the synthesizer VCO and 3 V for the synthesizer logic.
These power lines are kept separated to prevent noise on the VCO supply that may be inducted by the presence of digital loads on the same power line; due to the very low power consumption of the board, the use of linear stabilizer does not affect significantly the efficiency of the system.
The same PTT signal also drives the supply of the final power amplifier: in this way it is possible to reduce the power consumption to the only instants when it is really necessary to send data. Particular attention with this solution must be paid to the evaluation of the necessity of a wait time between the modulator and final amplifier switching on instants and the start of the data flow; this is needed to have a regular working conditions.

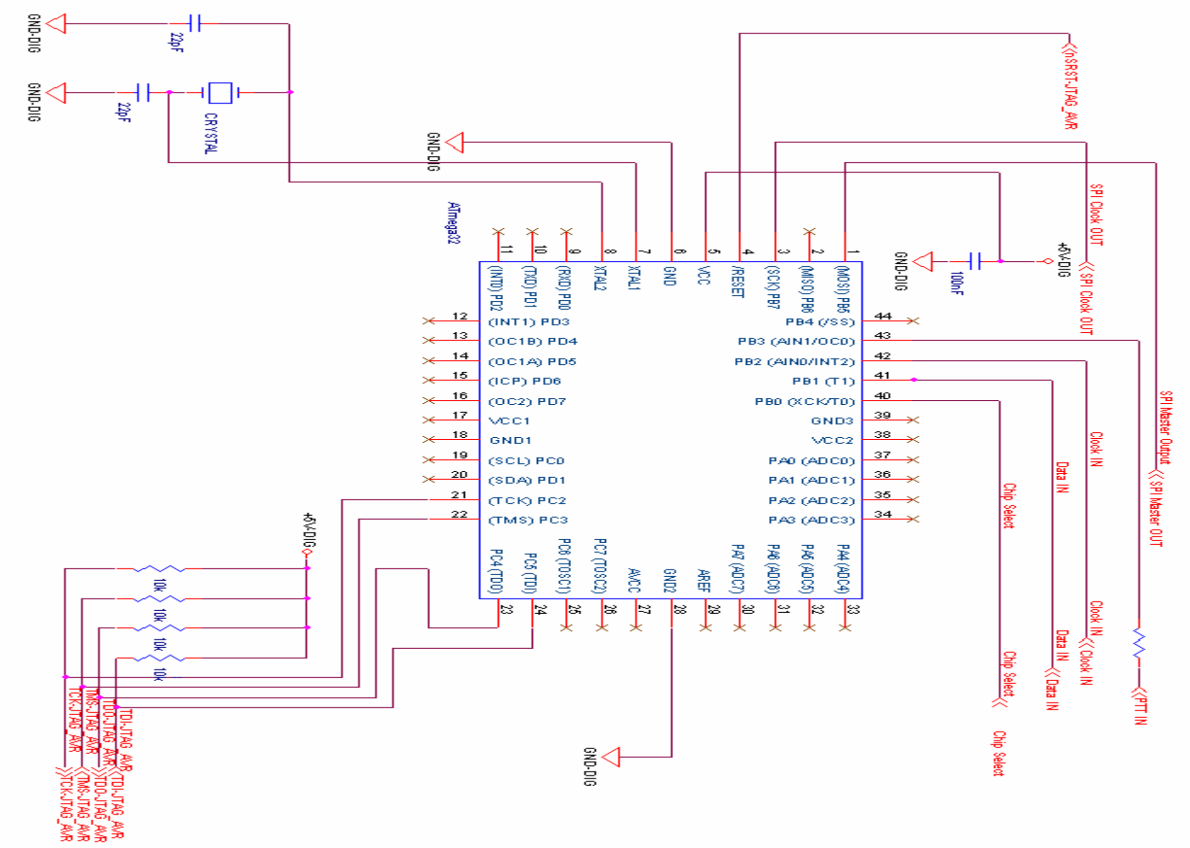


Fig.1 - Microcontroller ATMega32 -

N-Fractional Synthesizer

The core of radiofrequency section is the N-fractional synthesizer, used to generate a direct digital modulation (DDM).
Through a three wire serial interface, this device receive the configuration settings from the microcontroller and drives the VCO to generate the required frequencies.
For technical data of this device and instruction for its configuration, please refer to the datasheet of SKY72302

Schematics

In Fig. 2 the schematics parts related to the main synthesizer used for this application are shown and highlighted.

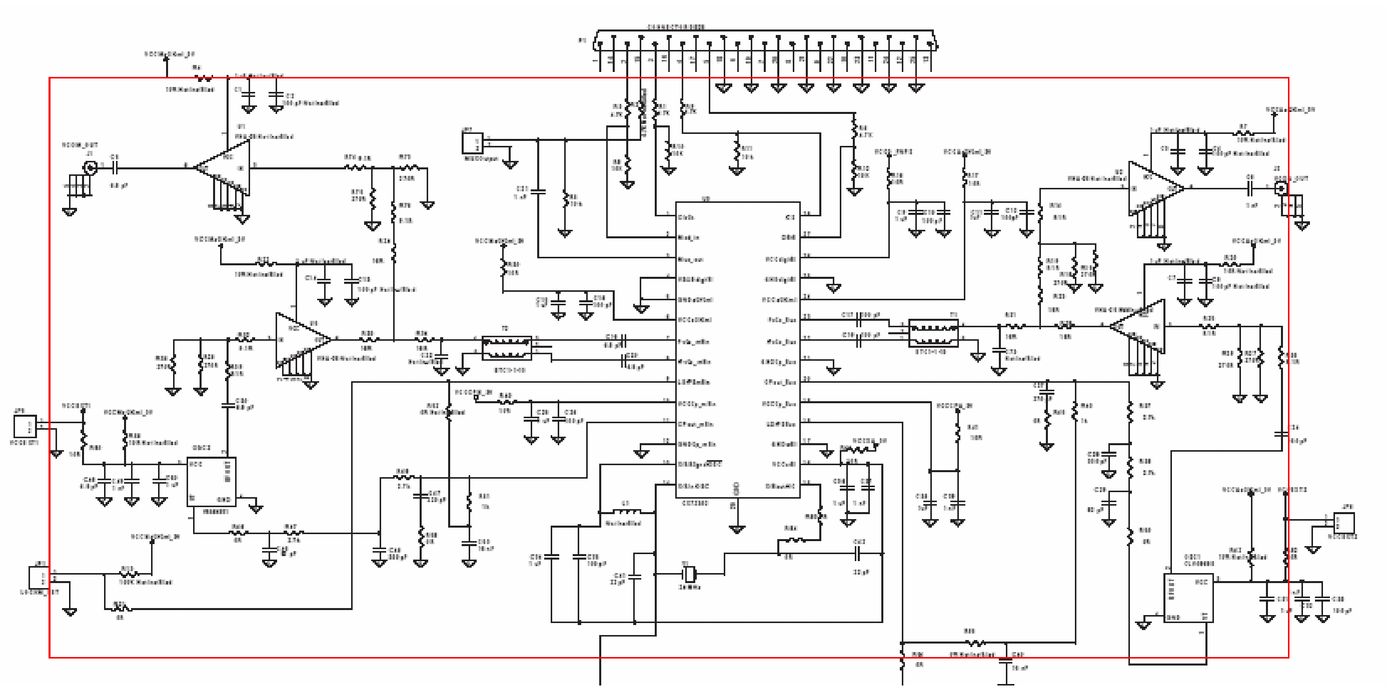


Fig.2 – SKY72302 synthesizer schematics – [2]

The remaining part of the circuit concerns the secondary synthesizer, not used by this modulator. Complete schematics are available on synthesizer's evaluation board datasheet produced by Skyworks

The output of the main synthesizer charge pump drives the loop filter which controls the main VCO frequency.

With the board default configuration, the main VCO output is approximately during the tests, from –20 dBm to -6 dBm. If a larger output level is required, a Mini-Circuits VNA-25 amplifier can be installed [5]

For what concerns the serial interface, signal lines coming from the connector are passed through simple resistive dividers to lower the voltage from +5 VDC to +3 VDC.

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
Power Consumption						
Total power consumption	P_{TOTAL}	Charge pump currents of 200 μA. Both synthesizers fractional, F_{REF_MAIN} = 20 MHz, F_{REF_AUX} = 1 MHz		54		mW
		Auxiliary synthesizer power down		39		mW
Power-down current	$I_{CC\text{-}PWDN}$			10 (Note 1)		μA
Reference Oscillator						
Reference oscillator frequency	F_{OSC}				50	MHz
Oscillator sensitivity (as a buffer)	V_{OSC}	AC coupled, single-ended	0.1		2.0	Vpp
Frequency shift versus supply voltage	F_{SHIFT_SUPPLY}	2.7 V ≤ V_{XTAL} ≤ 3.3 V			±0.3	ppm
VCOs						
Main synthesizer operating frequency	F_{VCO_MAIN}	Sinusoidal, –40 °C to +85 °C	400 (Note 2)		6100	MHz
Auxiliary synthesizer operating frequency	F_{VCO_AUX}	Sinusoidal, –40 °C to +85 °C	100 (Note 3)		1000	MHz
RF input sensitivity	V_{VCO}	AC coupled	50		250	mV_{peak}
Main fractional-N tuning step size	ΔF_{STEP_MAIN}		4 × $F_{REF\_MAIN}/2^{18}$ or $F_{REF\_MAIN}/2^{10}$			Hz
Auxiliary fractional-N tuning step size	ΔF_{STEP_AUX}		$F_{REF\_AUX}/2^{10}$			Hz
Noise						
Phase noise floor	P_{nf}	Measured inside the loop bandwidth using 25 MHz reference frequency, –40 °C to +85 °C		–128 + 20 Log (N)		dBc/Hz

Example of configuration

Modulator settings are:

- Central frequency: F_{VCO_main} = 2380 MHz
- Bit Rate: R_b = 38400 bps
- FFSK modulation (deviation from central frequency: $\Delta F = \pm R_b/4 = \pm 9600$Hz)

On the board a reference crystal with F_{ref}= 24 MHz is installed.
For a higher step resolution, a Reference Frequency Divider of 3 is used, obtaining a reference frequency F_{ref} of 8 MHz.
Following the indication on synthesizer's datasheet, the following design equation are obtained:

1) $F_{div\_ref} = \frac{F_{ref}}{3} = 8\,\text{MHz}$ <u>PLL comparison frequency</u>

2) $N_{fractional} = \frac{F_{VCO\_main}}{4F_{div\_ref}} = \frac{2380}{4 \cdot 8} = 74.375$ <u>Fractional division factor</u>

3) $N_{reg} = \lfloor N_{fractional} \rfloor - 32 = 42$ <u>Divider Register</u>

4) $Dividend = \lfloor 2^{18} \times (N_{fractional} - N_{reg} - 32) \rfloor = 98304$ <u>Dividend Register</u>

5) $Step\_Size = \frac{F_{div\_ref} \cdot 4}{2^{18}} = 122.07\,\text{Hz}$ <u>Synthesizer resolution</u>

6) $\Delta F/Step\_Size = 9600/122.07 = 78.64$

7) $$Modulation\,Word = \begin{cases} 79 \text{ per "1"} \\ -79 \text{ per "0"} \end{cases}$$

However, during the test phase an offset on the central frequency has been observed, causing a deviation from the desired 2380 MHz. To solve this problem, a new value for the Dividend Register (95624) was introduced, based on empirical observations. In other words, this value corresponds to a different central frequency but, because of this offset, this is the only way to center the desired nominal frequency.
Another step for the configuration comprises the setting up of synthesizer's internal peripherals.
In particular, using the Control Register 1 (address 0x06), it is possible to set the Lock Detect signal (not used in this version of the circuit) and gain for charge pump.
On the other side, through the Control Register 2 (address 0x07) it is possible to set:

- Mux_Out output enable;
- Copy of serial data sent to Mux_Out output; it has been useful during tests;
- Auxiliary synthesizer power down to avoid interferences and limit power consumption of non-used components;
- Main synthesizer set to work in 18 bit fractional mode;
- Main synthesizer set to work in N-fractional mode;
- Main synthesizer power up;
- Main power down disable.

Then, all these values are inserted in the relatives registers following the indications reported in datasheet.

Atmel ATMega32 Firmware

Modulator firmware is organized to operate through interrupt; at every serial clock signal rising front, the level of data line is acquired and, according to the detected level, the modulation control register is written to obtain a backward or forward frequency shift.
When the device is turned on, the microcontroller SPI is configured at first:

SPCR = 0x50;
SPSR |= 1;

The SPI port is set as Master (SPCR-Bit4), enabled (SPCR-Bit6) and set to work at the $f_{osc}/4$ (SPCR-Bit1/0) frequency; then it is set to work at double speed (SPSR-Bit0), obtaining a final clock speed of 8 MHz with a microcontroller clock of 16 MHz.
After serial configuration, the synthesizer setup can start:

transmit(0x00,0x2a);
transmit (0x11,0x75);
transmit (0x20,0x88);
transmit (0x50,0x22);
transmit (0x60,0x3f);
transmit (0x71,0x50);
transmit (0x80,0x00);
transmit (0x90,0x00);

First of all, it has to be noted that the synthesizer requires data packet of 16 bit, while SPI is only capable of sending 8 bit words at each time; to avoid this problem, every 16 bit message is split in two parts and sent with two successive operations, keeping the synthesizer's chip select enabled.
This job is performed by the function transmit, which receives the values to be sent.
Registers 0 to 9 are configured in the order; they correspond to Main Divide, Main Dividend MSB, Main Dividend LSB, Reference Frequency Dividers, Control Register 1 and 2, Modulation Control and finally, writing it to zero, Modulation Data Register.
Written values are those obtained in the previous section for the configuration.
At this point, it is possible to configure and enable the interrupt routine:

```
MCUCSR|=0x40;
GICR|=0x20;
__enable_interrupt();
```

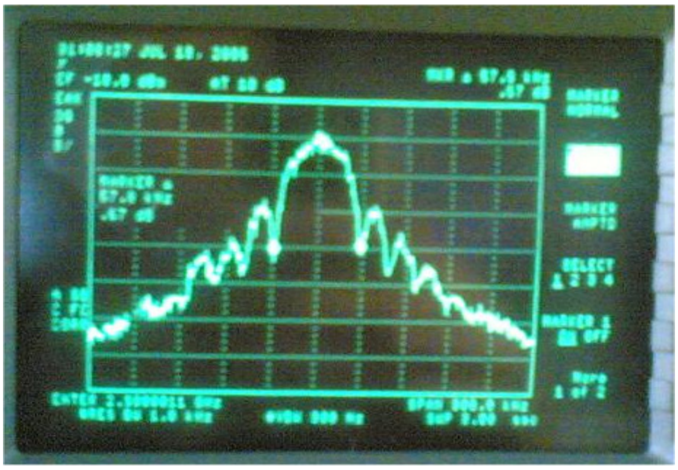
Through the MCUCSR and GICR registers, interrupts over the INT2 pin are enabled; the serial clock signal is connected to this pin. When the execution of the interrupt routine is enabled, the modulator is ready to work.
The time elapsed from the startup of the microcontroller to the end of execution of all these instructions must be considered as a delay to be taken into account to synchronize the enabling of PTT signal with the beginning of serial transmission.
At every serial clock cycle, the following interrupt routine is run:

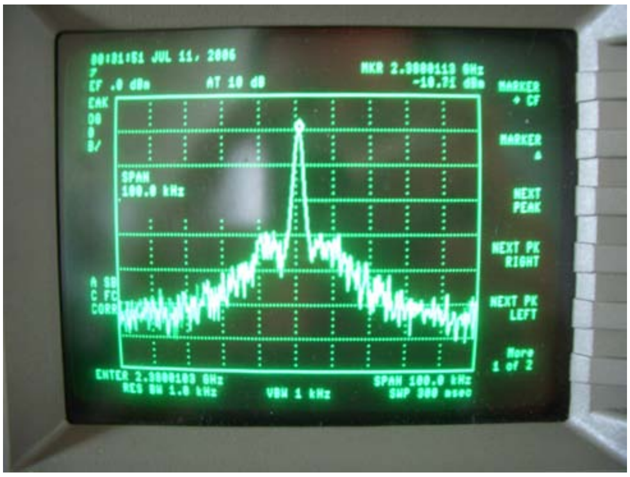
```
if (PINB&0x02)
   transmit(0x90,0x4f);
 else transmit(0x9f,0xb1);
```

If the value read on the third bit of the B port (PortB_Bit2) corresponds to "1", then the register at address 0x09, Modulation Data Register, is written with value 79; on the other hand, value -79 is sent otherwise. This value refers to the number of steps that the synthesizer has to count with respect to the central frequency. In this particular case, +/-79 steps mean a deviation of about 9600Hz.
Then, the program will wait the next interrupt within an infinite loop.

Possible improvements

The simple and flexible architecture of the selected solution allow to have a solid increment in performance basically at zero cost and to introduce new functionalities.
In this optic, it would be interesting to develop a communication protocol between the microprocessor and the modulator, capable not only to transmit data to send, but also to configure the modulator itself: in this way, it would be possible to configure the modulator "on the fly", for example to correct frequency deviation due to Doppler effect or thermal drift using the fine step of the synthesizer.
Also, it would be also wise to implement an automatic compensation system of oscillators' thermal drift: through a temperature measurement system, maybe using the already implemented telemetry, it should be introduced a correction in synthesizer configuration to counteract the oscillation frequency change of crystals.
Finally, changing the VCO it would be possible to set any desired central frequency (50 - 6.100 Mhz)





correct spectrum obtained for a 38400bps random

References

[1] Datasheet SKY72302 http://www.skyworksinc.com/products_display_item.asp?did=5132
[2] Evaluation Board SKY72302 http://www.skyworksinc.com/products_display_item.asp?did=4731
[3] Designer Information http://www.skyworksinc.com/products_display_item.asp?did=4719
[4] Atmel ATMega32 http://www.atmel.com/dyn/resources/prod_documents/doc2503.pdf
[5] Mini-Circuits VNA-25 Amplifier http://www.minicircuits.com/pdfs/VNA-25+.pdf

About the author

Giulio Pezzi ***IZ4FVW – AB2VY*** (AMSAT-NA 36417 Member) has been working with RF circuit and system design since 1991. He award a Diploma of RF Telecommunications Engineering . From 2004 to 2007 he is a team member of the AlmaSat Microsatellite Laboratory of the University of Forlì (Italy) where he collaborated at the realization of the RF Subsistems of the satellite
Now he has been an independent Consultant and Entrepreneur . He is the founder of *CesenaRadio Laboratory – Radio Communication Solution* - ITALY, a company specializing in the design of RF products and Ground Station preparation. Appel also enjoys writing software for modeling RF systems and circuits.
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Suitsat-2/Radioskaf-2: The second Amateur Radio Space Suit project and stepping stone to future small amateur satellites.

ABSTRACT.
This paper describes the plans for the second Suitsat satellite. The first Suitsat captured the attention of people the world over including many who were not radio amateurs. The second Suitsat will make many improvements as well as serving as a test bed for future satellite systems. This paper includes revisions that describe the latest plans for Suitsat 2

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

The little satellite was such a success that plans were developed to produce a second SuitSat/Radioskaf. To do this, the international Amateur Radio on the International Space Station (ARISS) team discussed it at their delegates meeting in July 2008 in Moscow. The team discussed the Suitsat 2 project with Energia management and Mr. Alexander Alexsandrov, RSC Energia is the Russian team leader with Sergey Samburov, ARISS, RSC “Energia”the manager.
Mr. Alexsandrov stated that the SuitSat-2 program must be a serious program and not simply a toy. This is consistent with the approach that is being taken with Suitsat 2 by the U.S. team.

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

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

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

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

Enhanced Capabilities of SuitSat-2/RadioSkaf-2

SuitSat-2/Radioskaf-2 has a special new job added to it's mission that is considered very important to the amateur satellite community. That new addition to it's mission is to be a prototype and test bed for testing new concepts in building amateur satellites. In addition to that goal is the use of Suitsat 2 as a platform for real scientific experiments. The Kursk University experiment meets that goal.

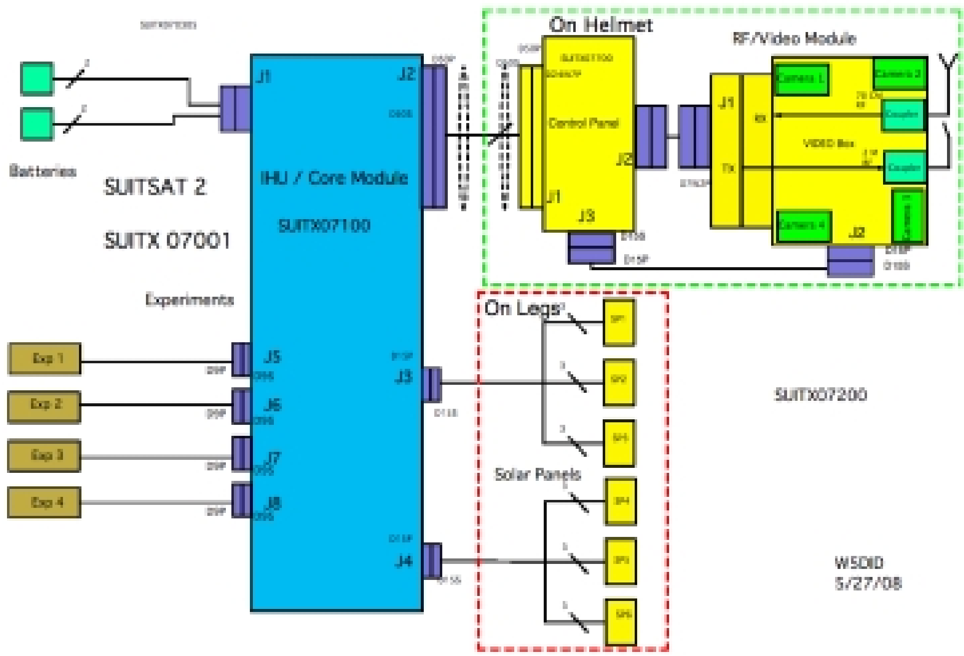
SuitSat-2/Radioskaf-2 has all new electronics. It includes all the features of SuitSat-1/Radioskaf-1 and all the features that were planned but could not be included on SuitSat-1/Radioskaf-1 due to the launch time pressures. In addition to those features, SuitSat-2/Radioskaf-2 will have solar panels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

Primary objective

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

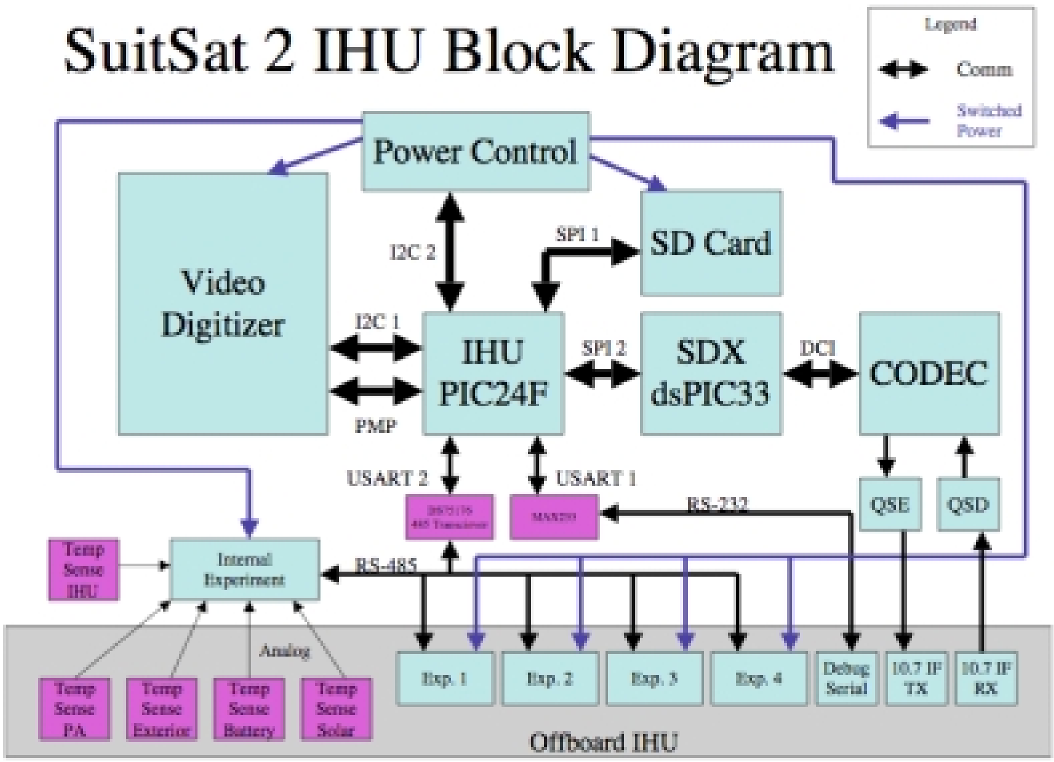
SuitSat-2/Radioskaf-2 will build upon the SuitSat 1/Radioskaf-1 design.

The safety interlock system designed and approved for SuitSa-1t/Radioskaf-1 will be incorporated into SuitSat-2/Radioskaf-2. There will be a new transmitter and receiver designed to incorporate a down converter that will convert the 70 cm signals down to a 10.7 Megahertz (MHz) intermediate frequency and then an up converter to convert the 10.7 MHz intermediate frequency up to the 2 meter transmit frequency. This RF system design will be reusable on future small satellite designs. This system is depicted in the block diagram in Fig.1.



This is similar to the system used on larger satellites so it will be a stepping stone for the amateur satellite community that fits well with AMSAT's and the ARISS' teams desire to utilize this opportunity to test new designs for future satellites.

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

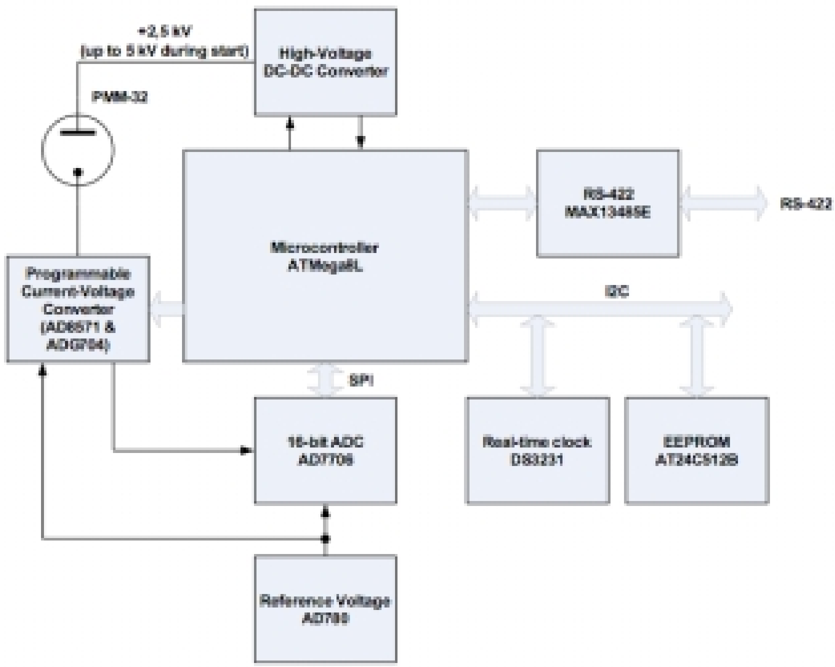


The IHU will also include the same safety interlock circuit that was included in Suitsat/Radioskaf-1. This circuit performed flawlessly on SuitSat-1/Radioskaf-1 and has been through the NASA safety approval process. The IHU board will also include circuitry to implement the Video and Slow Scan TV (SSTV)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

Experiments

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

The Kursk University Experiment is the most significant experiment. It is designed to measure the vacuum environment in the vicinity of Suitsat 2. A Block diagram of the experiment is shown in Figure 3.



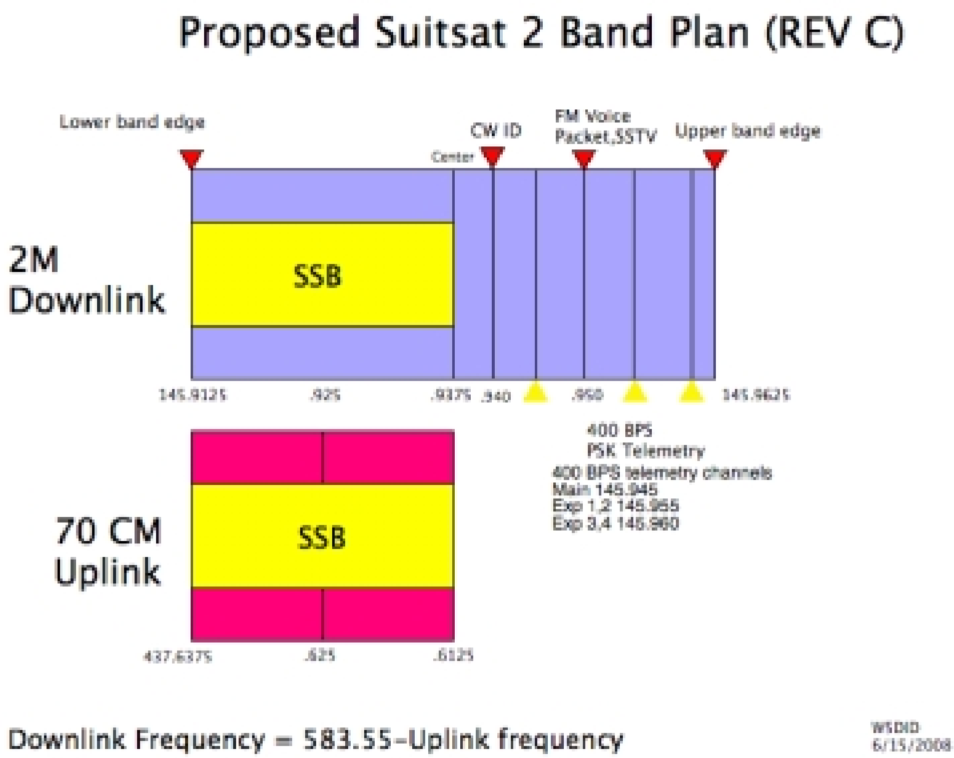
Radio

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

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

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

The DSP processor receives the 10.7 MHz signal from the receiver down converter and processes it and outputs a 10.7 MHz signal to the transmitter upconverter. The DSP can also inject signals such as the cw ID, telemetry, audio and packet signals as determined by the software on the DSP. The proposed Suitsat/Radioskaf-2 band plan is shown in figure 4.

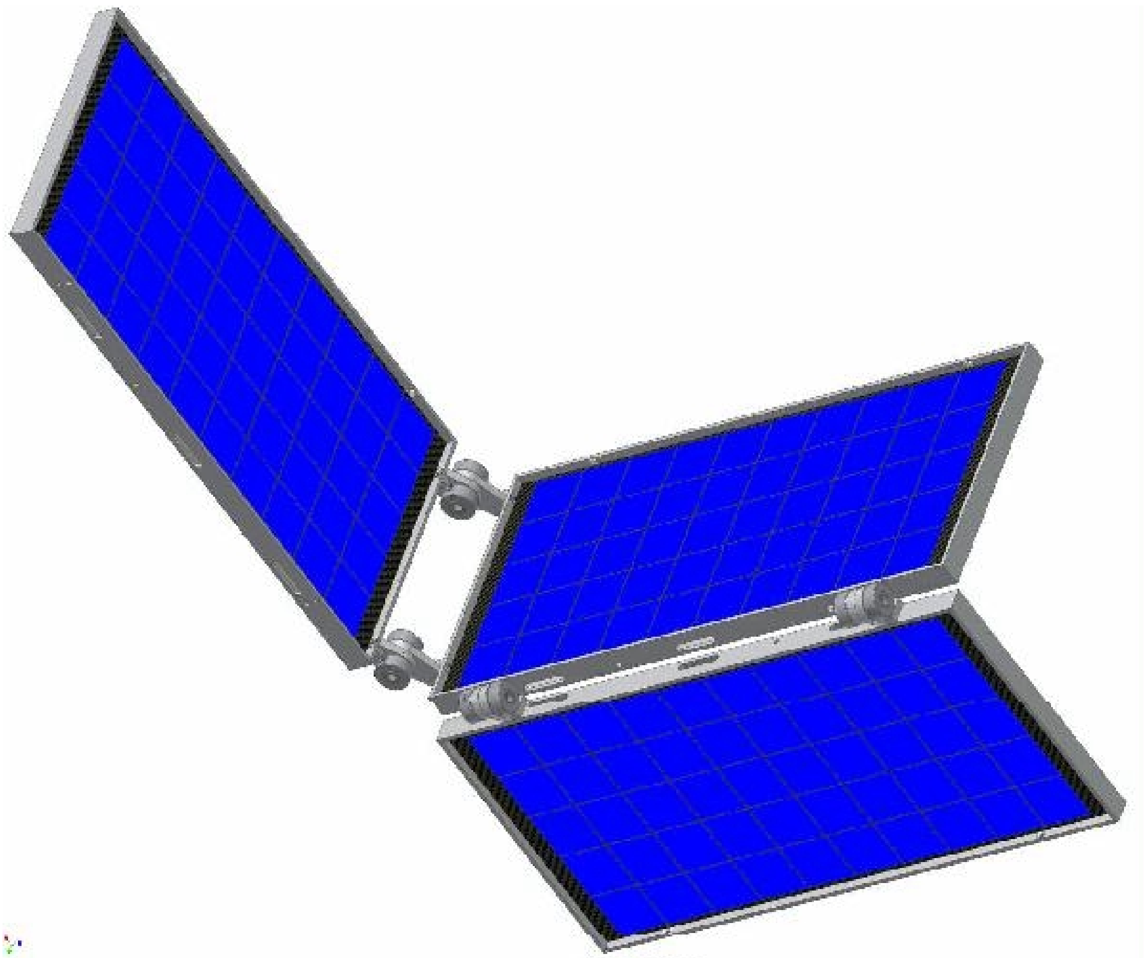


Solar Power System

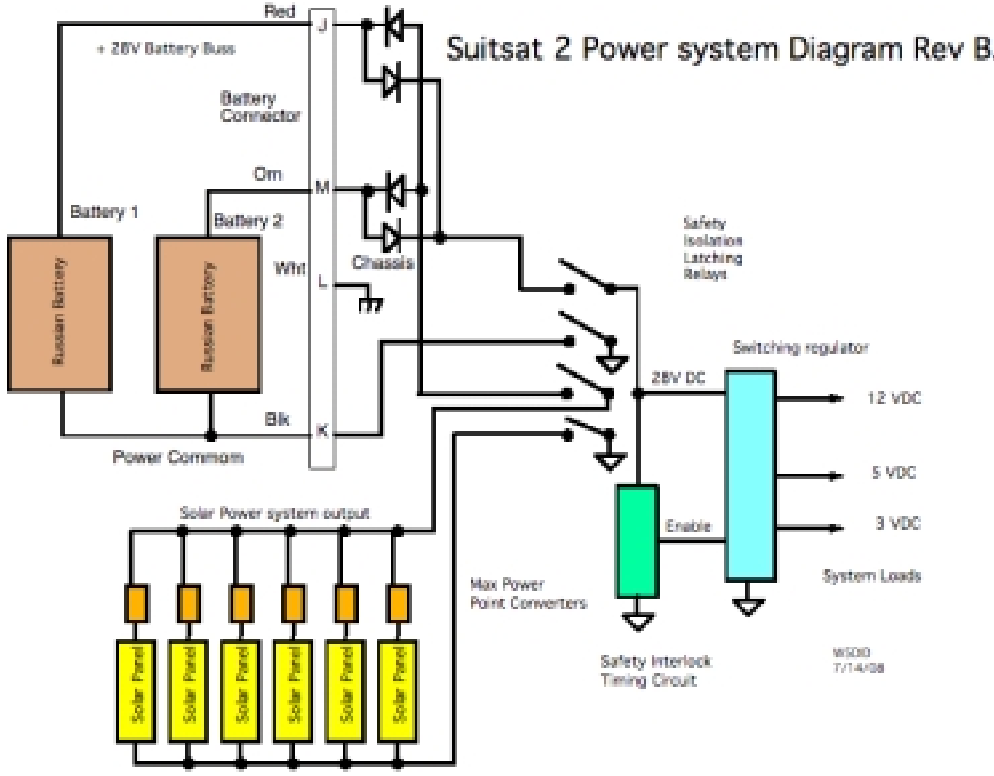
The Solar Power System consists of three major systems. The solar panels, the Maximum Power Point Converter and the batteries.

The solar panels are NASA developed panels that have flown on several NASA satellites. They were intended to be used as generic panels that were available to any new satellite being developed for the NASA Small Explorer (SMEX) program. When the program was in operation, these were state of the art panels. The SMEX program is no longer operational and these panels are surplus for NASA. They are in excellent shape and are being made available for SuitSat-2/Radioskaf-2. The panels will be mounted on the exterior of the Russian Orlan suit. There will be six panels mounted. Each needs to be facing a different direction so that power is received regardless of the orientation of the suit. . The idea is to fabricate a frame similar to a picture frame out of 3/4 inch angle aluminum.

The panels will be mounted inside the frame which is hinged to another frame. The two will fold together similar to a dual picture frame with a third panel attached also. The panels will face each other in the closed position. Velcro double sided straps will be threaded through slots in the frame behind the panels. The panels will be held closed using all straps until ready to be installed onboard ISS. After taking the suit outside, the velcro straps will be used to secure the solar panels to the suit. The cable will feed through the hole in the center of the hinges and through the side of the panel frame.



This concept is illustrated in Figure 5. This method of mounting the panels is still under discussion and may be changed during the discussions with the Russian team.



A block diagram of the power system is shown figure 6.

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

Operating Modes

The SuitSat-2/Radioskaf-2 software will determine the operating mode based on available power from the batteries.

Continuous Wave Identification (CW ID)

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

400BPS Telemetry

The 400 bps telemetry will be receivable by those who have an AO-13 or AO 40 telemetry decoding program or equivalent hardware decoder.

Slow Scan Television (SSTV)

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

Commands

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

Educational Outreach.

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

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

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

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

Accomplishments Specific to Education

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

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

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

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

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

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

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

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

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

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

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

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

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

Accomplishments Specific to Public Outreach

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

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

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

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

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

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

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

SuitSat-2/Radioskaf-2 development and project responsibilities

At a meeting at the Russian space facility in Moscow, the joint Russian and American teams agreed to the following list of responsibilities:

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

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

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

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

The Russian team will supply two used 28VDC battery of the same type that is certified for use on the Russian Orlan suit for SuitSat-2/Rdaioskaf-2.

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

The U.S. team with inputs from the Russian team is responsible for defining all commands and telemetry.

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

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

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

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

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

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

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

The Russian team has a proposed experiment from Kursk University that will be accommodated in the Suitsat 2.

Both the Russian and the U.S. team will investigate methods of stabilizing the attitude of Suitsat 2 in order to obtain more power from the solar power system.

Schedule

U.S. team will deliver hardware to Energia in Spring 2009.

AubieSat-1: A Student-Designed CubeSat developed at Auburn University

Richard Chapman, KC4IFB
Jean-Marie Wersinger KI4YAU
Thor Wilson
John Klingelhoeffer WB4LNM

I. Introduction

AubieSat-1 is a CubeSat project of the Auburn University Student Space Program (AUSSP). The AUSSP was created by Dr. J-M Wersinger, a physics professor, in 2001 with initial funding from Auburn University and with yearly funding from the Alabama Space Grant Consortium, itself funded by the NASA Space Grant Program [ref?]. The purpose of AUSSP is to attract and retain young people in STEM (Science, Technology, Engineering and Mathematics) disciplines in an effort to address the aging engineering workforce question.

The AUSSP has three main components: small satellites, high altitude ballooning and outreach to high schools. The outreach program lets high school students build experiments that the balloon team launches for them in the spring semester of each year. The balloon team is made mostly of university freshmen and sophomores who may join the satellite team as juniors and seniors. Additionally, graduate students provide management oversight and assistance with technical issues. As such, AUSSP addresses the pipeline issue at many levels. It draws young people to science and engineering and helps retention by providing college students with an opportunity to work in teams, designing and building spacecraft, developing both science/engineering skills while learning the basics of management and systems engineering.

II. Mission

AubieSat-1 has both an educational and a telecom research scientific objective. Scientifically, we hope to demonstrate the ability to determine the changing attitude of the satellite by measuring the polarity of signals received at the ground station. This will be done by building a model of the satellite's attitude with respect to the earth and the sun using changing voltages and currents present on the solar cells on the six faces of the cubesat, and correlating that with the observed polarity of the timestamped signal when it is received at the ground station. We hope to provide research results that will provide suggestions for future ground stations to mitigate the effects of spin modulation and other polarization fading effects. Educationally, our objective is to attract students to science, technology, engineering and mathematics (STEM) disciplines, and to motivate them to enter the space-related workforce. Given that NASA Marshall Space Flight Center and United States Army Redstone Arsenal are located in Huntsville, Alabama, and are annually the destination of large numbers of Auburn University graduates in STEM disciplines, this educational mission is appropriate for Auburn University. Auburn continues to build upon its space system legacy which at least dates back to the building of the video transmitters for the NASA Saturn program in the 1960's.

A. Structure and Overall Design

The design conforms to the CubeSat program requirements [1]. As such, AubieSat-1 is a 10cm cube weighing approximately 1 kg, with an aluminum frame, and a series of internal printed circuit boards. The six faces of the cube are covered with solar cells, except for a small port for testing, battery charging, and checkout. Internally the boards are stacked one on top of the other (see Figure 1), with 2 40-pin headers on opposite sides of each board carrying redundant electrical signals between boards. Other large components inside the cube include a commercial Yaesu VX-2R amateur radio 440Mhz/144Mhz handheld transceiver, which is the main radio for AubieSat-1, two lithium-ion batteries, a permanent magnet to damp rotation, and two Nitinol dipole antennas deployed from diagonally opposite corners of the cube (see Figure 2). An Atmel AVR Atmega 256 [2] 8-bit microcontroller provides control and data handling functionality. The Micro C/OS-II real time kernel [3] is used, providing cooperative multitasking, synchronization, intertask communication, and scheduling capabilities. See Figure 3 for a block diagram of the electrical systems on board.

Figure 1. Aubiesat-1, minus solar panels

B. Electric Power System

The electric power system consists of six sets of solar cells, two lithium-ion batteries, dual MAX8677C battery charger IC's, LTC3533 voltage regulators, and a high-side switch to be used in latch-up recovery and pre-launch power-off modes. A 5V supply powers all on-board electronics. The redundant regulators and chargers provide capability to continue the mission if a single regulator or charger fails, as well as allowing normal operation away from the limits of the devices in terms of current supplied.

C. Communications

AubieSat-1 has two radios on board, a primary communications transceiver, and a secondary receiver. The primary transceiver is used for sending an audio beacon, for receiving commands from the ground station, and for sending telemetry data back to the ground station.

The primary transceiver, a stripped-down Yaesu VX-2R amateur radio handheld [5], will be the main radio for two-way communications with AubieSat-1. The audio input and output of the VX-2R radio are connected to a TNC-X terminal node controller [4], which is connected to the main (Atmega) microcontroller via a serial port. The audio input to the VX-2R can also be fed with a synthesized Morse code message as a beacon for aiding in finding the satellite, or a continuous tone for use in polarization measurements for the science mission.

The secondary receiver can process 4-bit digital commands to execute various functions on the satellite. Most importantly, it fulfills the IARU/FCC transmitter control requirements to turn off power to the primary transceiver if it becomes "stuck" in transmit mode. This function does not rely on the microcontroller.

D. **Command and Data Handling**

Command and data handling chores are managed by an Atmel Atmega 256 microcontroller. This microcontroller was chosen because of its large memory, low cost, and easily available and cheap development tools including the micro-C/OS-II real time kernel, as well as the wide variety of interfaces it supports.

In addition to numerous general-purpose digital I/O pins, the Atmega chip includes support for the Inter-Integrated Circuit bus (I^2C), Serial Peripheral Interface (SPI), two serial ports (USART's) and eight channels of 12-bit analog-to-digital conversion (ADC). This wide variety of interfaces is needed on AubieSat-1 to support four external eight-channel ADC chips used to measure temperatures, voltages, and currents on the satellite, as well as an external Atmel Dataflash memory to store telemetry data for transmission back to the ground station. The I^2C bus is also used for communications with a real-time clock chip, and for driver chips on other boards to control the various relays/switches (antenna deployment, transceiver power, and mic input source) on the satellite. The control and data handling block diagram is shown in Figure 4.

E. Ground Station

The ground station has two components, one for control and data gathering from the satellite, and the other for measurement of polarization of radio signals. The control station is a UHF amateur radio satellite station located in Allison Hall on Auburn University main campus. A circularly polarized antenna with a roof-mount preamplifier on a custom-built tower with altitude-azimuth computer controlled rotator feeds an Icom 910 transceiver via LMR400 feedline. Nova tracking software is used to control the antenna rotator. The tower also has a 2m circularly polarized antenna on the boom, used for training ground station personnel in receiving existing satellites, such as the mode K amateur satellites. A Kantronics TNC feeds a Linux computer running software developed at Auburn for AX.25 decoding, command processing, and data logging.

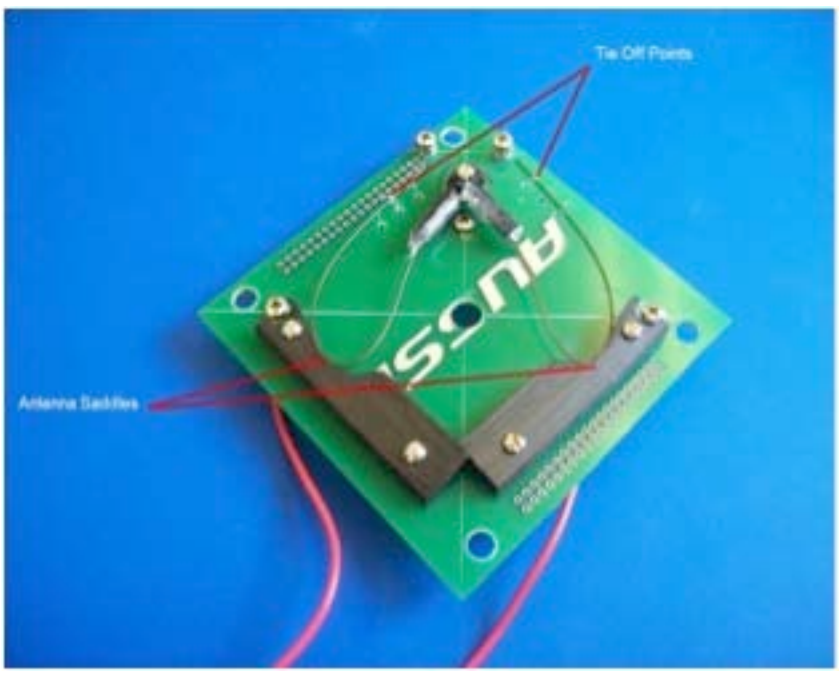


Figure 2. Antenna deployment mechanism board

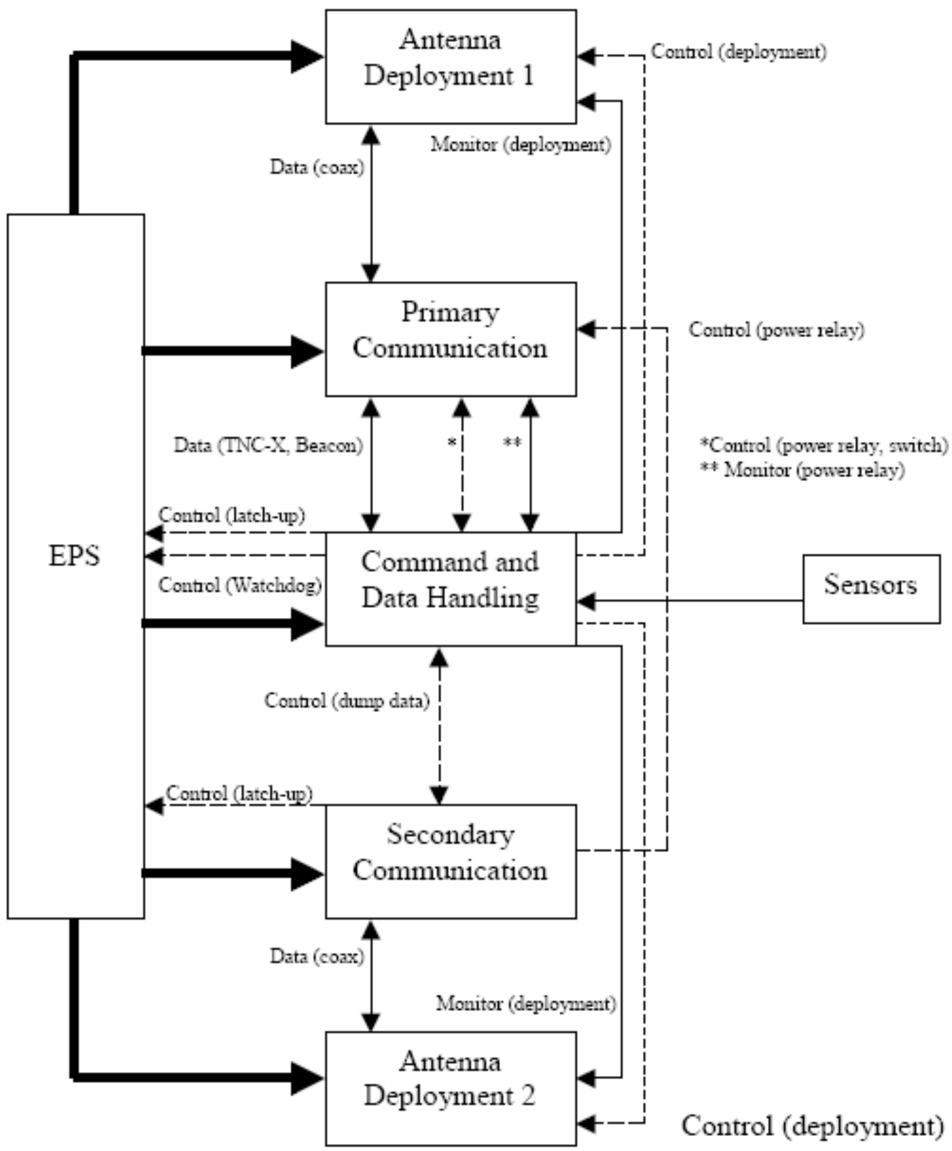


Figure 3: Electrical Systems Block Diagram

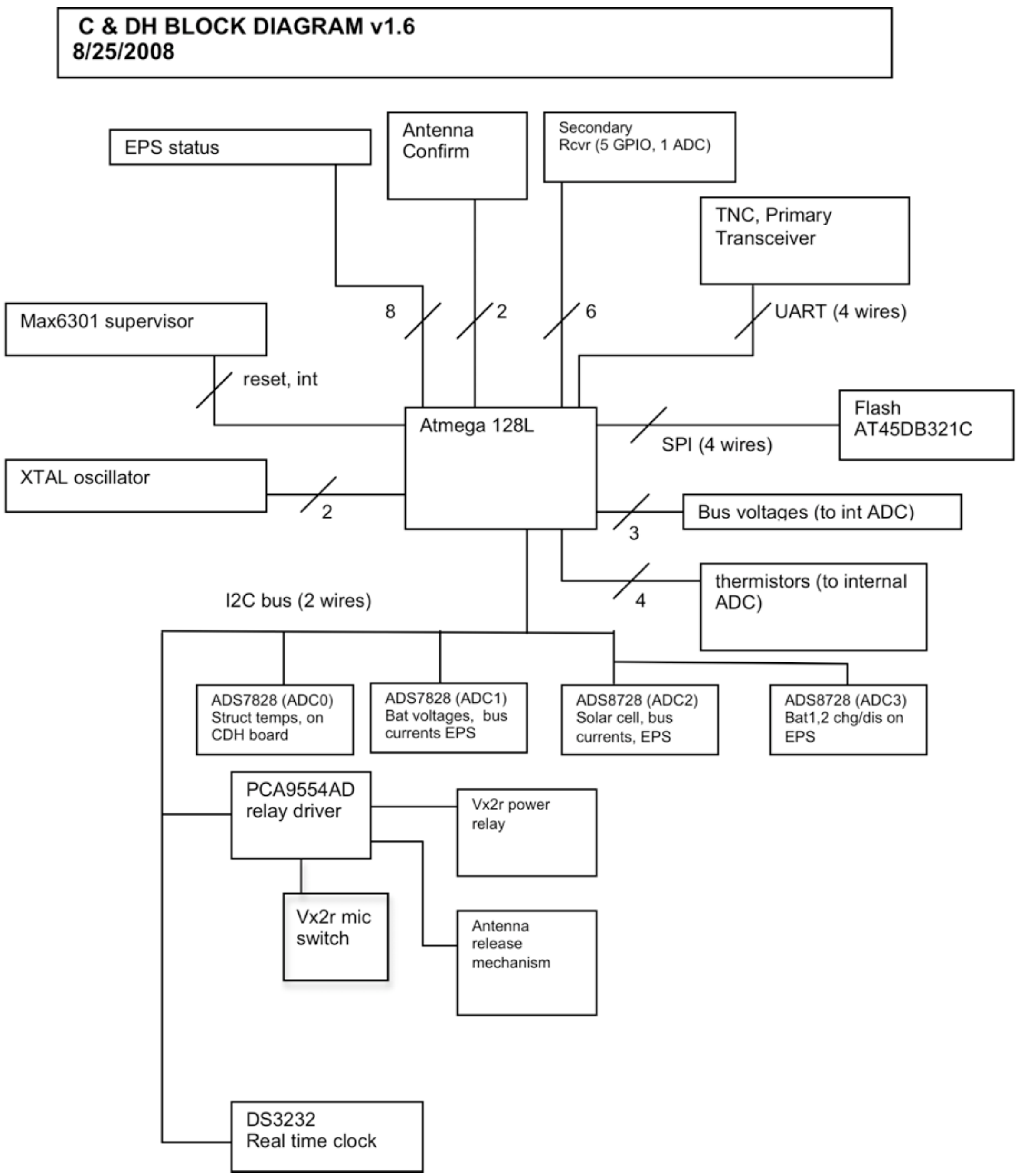


Figure 4. Control and Data Handling block diagram

Figure 5. Ground Station Operating Position

III. Management and Systems Engineering

The AubieSat-1 approach to management has evolved over the years to the current system of teams for each subsystem, with a student team lead and a faculty advisor for each team. The core of student leaders comes from the Physics department. Students for the communications team have primarily come from the Electrical and Computer Engineering Department, control and data handling from the Computer Science and Software Engineering Department, and the structural team from the Mechanical Engineering Department. A recent addition has been a team of systems engineers from the department of Industrial and Systems Engineering. This team provides quality assurance, risk management, configuration management, and development lifecycle assistance. As well, the project has been fortunate to have several technical advisors with significant industrial experience, including Mr. John Klingelhoeffer, WB4LNM, a retired president of Intelsat General and Comsat General Corporations, a long-time AMSAT member, and Mr. John Cook, a retired Lockheed Martin Vice President and manager of the Viking-I Mission. The student participants include volunteers, undergraduate students receiving credit for their capstone design course in the engineering disciplines, and graduate students using the AubieSat-1 project as part of their research.

IV. Conclusion

AubieSat-1 is Auburn University's first attempt to build and launch a student-designed satellite. A date of May 1, 2009 has been set to send the satellite to California Polytechnic University (Cal Poly) for acceptance testing and eventual launch.

V. References

[1] http://cubesat.atl.calpoly.edu/pages/documents/developers.php. Cal Poly CubeSat Program requirements for developers

[2] Atmel Corp, *8-bit AVR Microcontroller with 64K/128K/256K Byte In-system Programmable Flash, Atmega 256*, datasheet rev. 2549-AVR-08/07, August 2007

[3] Labrosse, Jean, *Micro C/OS-II: The Real-Time Kernel,* 2nd edition, CMP Books, 2002.

[4] Hansen, John, " TNC-X: An Expandable Microcontroller-Based Terminal Node Controller", *Proceedings of 22nd TAPR/ARRL Digital Communications Conference,* Sept 19-21. 2003.

[5] Yaesu, *VHF/UHF Ultra Compact Dual-Band Transceiver with Wide Band Coverage VX-2R*, 2003, Vertex Standard Co, Ltd

Using Iridium's satellite network for amateur satellite communications in Low Earth Orbit

Florida International University

Department of Electrical and Computer Engineering
Department of Arts and Sciences
Author: Christian J Rodriguez (KJ4DOI), Henric Boiardt
Mentor: Kenneth Furton

Abstract

Amateur satellite communications are limited by overhead transmissions that last around 15 minutes twice a day. Using Iridium's satellite network as a gateway, amateur satellites in low earth orbit (LEO) may achieve near continuous communications with earth. This paper discusses the use of the Iridium network for amateur satellite communications. Specifically, the paper focuses on Florida International University's (FIU) Florida University SATellite (FUNSAT) payload submission, named Pico Panther. An introduction to the network and hardware is presented. Furthermore, an analysis of cost, Doppler effects and possible uses is performed.

I. Introduction

The iridium satellite network is a constellation of 66 satellites that allow for worldwide communication of information, pole to pole. American embargos limit the use of this constellation in North Korea, Iran and Sudan. The satellites orbit from pole to pole in around 100 minutes at an inclination of 86.4 and an altitude of 780 km. The satellites operate on an L-band spectrum and have channels that operate in a bandwidth of 31.5KHZ, compensating for Doppler shifts.

There are currently two leading ways of using the Iridium satellite network, with a 9522A L-Band Transceiver or a 9601 Data Transceiver. The 9522 provides voice data and internet services to an iridium subscriber.

II. Iridium Hardware

The Iridium 9522A is capable of sending files via File Transfer Protocol (FTP) at a fixed monthly price. The dimensions of the 9522A are 19.64cm x 8.26cm x 3.9cm. The dimensions limit the use of the 9522A to a custom satellite or a 3U CubeSat design.

Figure 1: Iridium 9522A

For smaller satellite applications, such as a standard CubeSat, the Iridium 9601 transceiver is the ideal option. With dimensions of 10.64cm x 5.62cm x 1.3cm, the 9601 can fit into small applications with minor modifications.

Figure 2: Iridium 9601 Transceiver

To fit into a standard CubeSat design, the aluminum case must be removed and the antenna connector must be modified to sit perpendicular to the transceiver. These modifications reduce weight and more importantly, allow the transceiver to fit inside a 10cm cube.

Figure 3: Iridium 9601 out of case

L-band antennas come in a variety of sizes and shapes. The smallest of these antennas is 4cm x 4cm x 1cm and can fit in small applications. Both transceivers must be interfaced to a processor. The protocol to communicate to the transceiver is the Hayes (AT) command series. Any processor or microcontroller with serial capability can use the transceiver. Also, the 9601 uses 1.5 watts of power and the 9522 uses 4 watts of power. Both power levels can be achieved on different types of amateur satellites.

Florida International University's design entry into the Florida University SATellite (FUNSAT) competition uses a dsPIC chip from MicroChip to communicate to a 9601 transceiver.

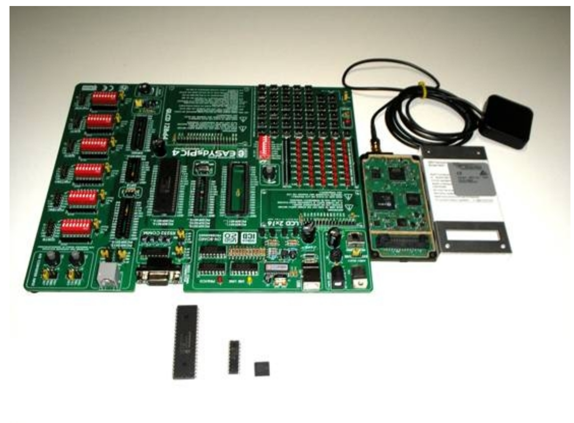


Figure 4: dsPIC development board and Iridium 9601 transceiver with antenna.

III. Orbital parameters

FUNSAT satellites are sent into retrograde polar orbit. Since Iridium satellites also operate at a polar orbit, there are many chances to downlink at the poles. Moreover, since Iridium's network is less dense by the equator, dead zones lasting up to 15 minutes may be encountered. As inclination is increased, the amount of dead zones increase, but the time spent in them decreases since a satellite would be crossing more of Iridium's orbits.

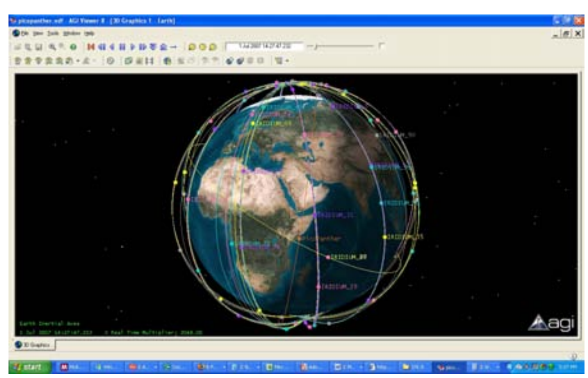


Figure 5: STK analysis of orbital trajectories

IV. Doppler effect Considerations

Doppler shifts happen when there is a relative velocity present between a source and destination and as a result there is a perceived frequency shift in a signal. The equation that relates a Doppler shift for a speed of light transmission such a radio is:

$$F' = F + \frac{FV_{t/r}}{C},$$
$$V_t = V_r + V_{t/r}$$

F' is the new observed frequency, F is the original frequency, V is the velocity of the transmitter relative to the receiver, and C is the cosmological constant.

1. Calculations for an earth transceiver and an Iridium satellite.

Frequency range of Iridium 9601:
1616 MHz – 1625 MHz
Velocity of Iridium satellite at 780 km:
7.46 km/s
Velocity of Earth:
465 m/s or .465 km/s
Relative velocity in same direction:
6.995 m/s
Relative velocity in opposite direction:
-7.925 m/s
Change in frequency in same direction at 1625 MHz:
37.88 kHz
Change in frequency in opposite at 1625 MHz:
-42.927 kHz

Note: Iridium transceiver can accommodate +/- 37.5 kHz swing inherently,

2. Calculations for a space based transceiver and an Iridium satellite.

Frequency range of Iridium 9601:
1616 MHz – 1625 MHz
Velocity of Iridium satellite at 780 km:
7.46 km/s
Velocity of Cube Sat at 700 km:
7.51 km/s
Relative velocity in same direction:
.05 km/s
Relative velocity in opposite direction:
-14.97 m/s

Change in frequency at 1625 MHz:
270 Hz
Change in frequency at 1625 MHz:
-81.087 kHz *Never occurs.

Note: The Iridium transceiver can accommodate +- 37.5 kHz swing inherently, orbital simulations show that Iridium and Pico Panther move in same retrograde direction, therefore a -81.08 kHz shift does not occur.

The calculations show that when moving in the same direction as an Iridium satellite, an amateur satellite with an Iridium transceiver will have a Doppler shift of 270Hz. When moving against Iridium's network the amateur satellite will have a -81.087 KHz shift. The Pico Panther never moves against Iridium's network so it will never experience a -81.087 KHz Doppler shift.

V. Cost and Subscription

A 9601 transceiver costs $500 dollars with an antenna. The 9522A costs $1,400 dollars. When compared to a simple 2 meter amateur radio transceiver costing less than $200 dollars, these costs seem great. In satellites systems doing data analysis, the cost would most likely not be justified. But, if a satellite system were developed that could be provide valuable information if it had near real-time feedback capability, the cost could be justified.

The monthly contract to use either transceiver ranges from $14-$24 dollars a month. The 9601 carries an additional charge depending on the number of bytes a customer sends.

Subscription	Cost
Iridium monthly cost	16.00
256 bytes every hour @ .0015 dollars per byte	$276 per month
Total subscription:	**$292.00 per month**

Table 1: Cost of sending 256 bytes an hour

Sending 256 bytes an hour, the total for a user would be $292 a month. A ten byte per hour cost would be $26.80. Ten Bytes provide enough for 1024 status codes, in the event real-time monitoring is needed on an hourly basis. A feedback of 256 bytes provides many more.

Subscription	Cost
Iridium monthly cost	16.00
10 bytes every hour @ . 0015 dollars per byte	$10.80 per month
Total subscription:	**$26.80 per month**

Table 2: Cost of sending 10 bytes an hour

VI. Conclusion

Earthquake predictive satellites, Space weather research, atmospheric weather, and Artic and Antarctic polar satellite surveyors are just a few research areas that would benefit from amateur satellites with near real-time messaging capabilities. Iridium's network offers a gateway for amateur satellites to communicate nearly continuously with earth.

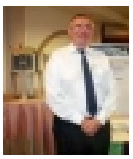
By interfacing Iridium's 9601 transceiver with a microcontroller, FIU's Pico Panther will be capable of near real-time communications with earth. Doppler effects were proven to be negligible and a reasonable set of data plans were presented that would allow a cost effective communication.

VII. Acknowledgement

This paper has been realized thanks to Dr. Kenneth Furton. Without Dr. Furton, the FIU FUNSAT entry would never have been able to compete in this challenge. Dr. Furton's support of student programs and increasing FIU's role as a research institute is admirable and appreciated.

KiwiSAT A communications satellite for New Zealand

http://kiwisat.org/index.html



Presentation Provided by
Kiwisat Project Leader
Fred Kennedy (ZL1BYP)
AND HIS TEAM

Presented by
Bill Ress N6GHZ
for AMSAT-ZL

Presentation for the AMSAT- NA Space Symposium
24 - 26October 2008

Topics:

- Concept of a NZ KiwiSAT Satellite
- The proposed NZ KiwiSAT satellite systems
- Launch proposals and availability
- Questions

KiwiSAT Project

A New Zealand communications satellite
for Low Earth Orbit

KiwiSAT – Review

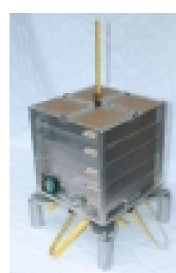
- **KiwiSAT –** the first satellite from New Zealand
  (c/o AMSAT-ZL!) - CubeSAT or MicroSAT?
- CubeSAT – 100 mm cube 1 kg investigated - rejected.
- MicroSAT - 230mm cube accepted for development
- Basic communications fit approved and 90% complete
- Science package determined and under construction.
- Launch agency – SLC Kosmotras (Russia) selected.

Basic design

- A MicroSAT class spacecraft cube shaped weighing 10 - 12 kg.
- Six solar panels – one on each surface
- Measuring tape antennas for VHF.
- Stub Monopoles for UHF plus phased folded dipoles for 1.2 GHz receive converter
- Patch antenna for GPS

KiwiSAT
Physical structure

- A stack of five fabricated aluminum trays each 244mm x 244mm + an 'attic' (Reverse tray!)
- The height of each tray varies from 25 - 45mm making a total of 244mm also.
- Nominal useful internal area in each tray is approximately 210mm x 200mm
- 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.
- 70% of 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 – Modules

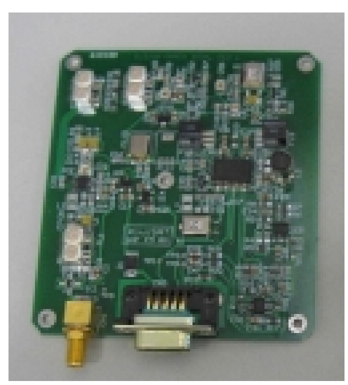
From the top down –

- Receivers on 70 cm and 23 cm and sensors. (+ GPS)
  Science package – ADAC using Geomagnetic Field
- IHU (Integrated Housekeeping Unit – Command Computer) includes 1200 and 9600bd modems
- Battery tray
  NiMH battery 4.0 Ah 12 volt
- Battery Charge Regulator (BCR)
- 2 m transmitters (Linear and FM) + U Band Beacon and target Sun Sensor.

Receivers Linear and FM (& GPS)

Linear – UHF (30 kHz bandwidth)

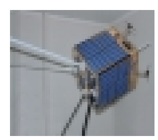
FM - UHF
(2 off)



U Band Beacon.

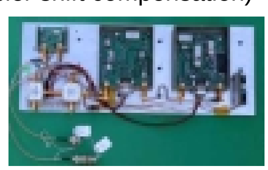
- Needed for Faraday Rotation and TEC measurements for Science Package
- Design/ Schematic is complete.
- PCB layout by Mark (ZL3JVX) is in hand

TRANSPONDER ON TEST!



- The KiwiSAT linear flight transponder is now "on the air" from the Whangaparaoa area with beam antennas pointing South.

  * Transponder: Inverting type (Orbital Doppler shift compensation)
  * Transmit Power: 2 Watts PEP.
  * Beacon frequency: 145.885 MHz
  * Uplink: 435.265 to 435.235 MHZ **LSB**
  * Down link: 145.850 to 145.880 MHz USB
  * 30 Khz transponder bandwidth



- **Note**: A trial transmission on 435.2544 **LSB** comes out at 145.860 **USB**

Planned Operating Frequencies

(Subject to licensing confirmation.)

- **Linear Transponder Downlink** :
  Frequency: 145.850 MHz to 145.880 MHz.
  Output Power: 2 Watts PEP.
  Radiated Power: 2 Watts (+33dBm) EIRP PEP.
  Bandwidth: 30 KHz. Emission Type: Depends on Uplink: CW, SSB etc.
  Antenna pattern: Omni directional in all planes.

- **Linear Transponder Uplink 1** :
  Frequency: 435.260 MHz to 435.230 (Inverting Transponder).
  Bandwidth: 30 KHz.
  Noise temperature: 273 degrees K.
  Emission Type: typically CW, SSB.
  Antenna Pattern: Quarter wave whip on +Z face (Omni in X-Y plane, Null in +Z and -Z direction).

- **Linear Transponder Uplink 2** :
  Frequency: 1268.880 to 1268.850 (Inverting Transponder)
  Bandwidth: 30 KHz.
  Noise temperature: 273 degrees K.
  Emission Type: typically CW, SSB.
  Antenna Pattern: 4 Dipole array (Omni in X-Y plane, +3 dbi Gain in +Z and -Z direction).

Planned Operating Frequencies (Cont.)

(Subject to licensing confirmation.)

- **FM and Data Transmitter** :
  Frequency: 145.865 MHz.
  Output Power: 1 Watt.
  Radiated Power: 1 Watt (+30dBm) EIRP.
  Bandwidth: 20 KHz.
  Emission Type: 9600 bps data (G3RUH Packet standard) Telemetry and Data (various modes) scheduled with FM Voice or 1200 bps AFSK packet telemetry.
  Antenna pattern: Omni directional in all planes.

- **F.M Receiver Uplink 1**:
  Frequency: 435.245 MHz.
  Bandwidth: 20 KHz.
  Noise temperature: 273 degrees K.
  Emission Type: 9600 bps data, FM Voice,
  Antenna Pattern: Quarter wave whip on +Z face (Omni in X-Y plane, Null in +Z and -Z direction).

Planned Operating Frequencies (Cont.)

(Subject to licensing confirmation.)

- **F.M Receiver Uplink 2**:
- **Frequency: 1268.865 MHz.**
  Bandwidth: 20 KHz.
  Noise temperature: 273 degrees K.
  Emission Type: 9600 bps data, FM Voice,
  Antenna Pattern: 4 Dipole array (Omni in X-Y plane, +3 dbi Gain in +Z and -Z direction).
- **Beacons:**
- **Beacon 1:**
  CW Beacon Attached to Linear Transponder:
  Frequency: 145.885 MHz.
  Emission Type: CW standard morse code.
  Power: 50 mW (+17 dBm) EIRP

  Beacon 2 (Data Beacon):
  Frequency: 145.865 MHz.
  Output Power: 1 Watt.
  Radiated Power: 1 Watt (+30 dBm) EIRP.
  Bandwidth: 20 KHz.
  Emission Type: 9600 bps data (G3RUH Packet standard)
  scheduled with 1200 bps AFSK packet telemetry.

  Beacon 3 (UHF Beacon):
  Frequency: 437.425 MHz.
  Bandwidth: 20 KHz.
  Emission Type: 9600 bps data (G3RUH Packet standard).
  Radiated Power: 100 mW (+20 dBm) EIRP.
  Antenna pattern: Quarter wave whip on -Z face. (Omni in X-Y plane, Null in +Z and -Z direction).

L Band Converter

- In hand – Terry (ZL2BAC)
- Awaiting components
  to complete PCB population.

Proto IHU – Computer and RAM Disk

Flight unit is being assembled by Assembly Specialists Ltd. – our only electronics commercial involvement.
To complete end October 08.

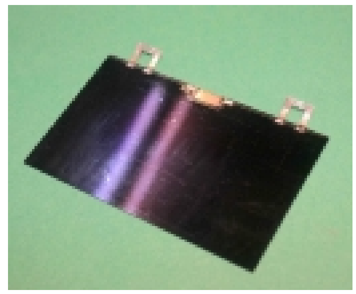
Power System

Comprises:-

- **Power generation**
  GaAs photovoltaic cells will be used.
- **Battery**
  10 x 4.0Ah NiMH cells with a nominal battery voltage of 12 V DC.
- **Battery Charge Regulator (BCR)**
  to manage battery charge and protection.

Solar Cells for Flight

Spectrolab 28% Triple Junction Cells selected and nearly 30% of the cost -which was approx. US$24,000- was fundraised in NZ.
It was “chopped” by ITAR Jan 2005!



We will fly 22% GaAs ex Tecstar cells (US$850 for 200 by way of Ebay!!!!)

Our thanks to
Dave (G0MRF) – for spotting ‘em.
Bill (N6GHZ) – for nerves of steel bidding for ‘em and
Reinhold – of The Aerospace Corp for sorting out the (free) export details.

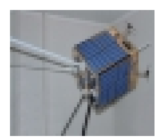
(We owe you, Guys!)

Suitability confirmed and individually rated

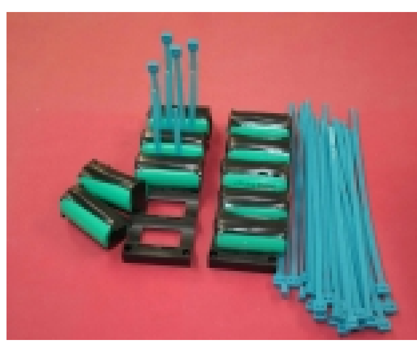
(Where physically possible we ‘hands on’ test and trial everything)

And with the real power source!

Flight Battery

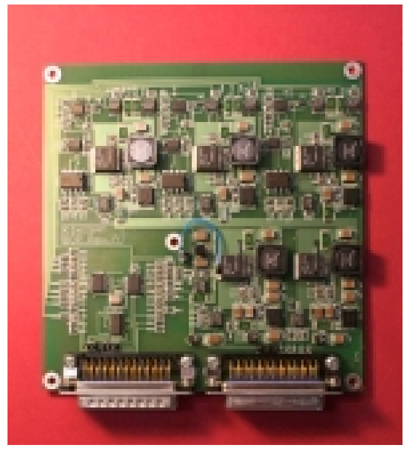


- Capacity requirement – 4.0 Ah at 12 Volts
- Flight ready set of NiMH from AMSAT-DL
- Cells to be stripped, re sleeved with Kapton tape.
- Tefzel ties and Delrin trays fully baked and outgassed.



Battery Charge Regulator (Flight Unit.)

- Switching design by Hans (ZL1HB) - 89% efficiency.
- Operates autonomously.
- CPU to fine-tune default parameters.

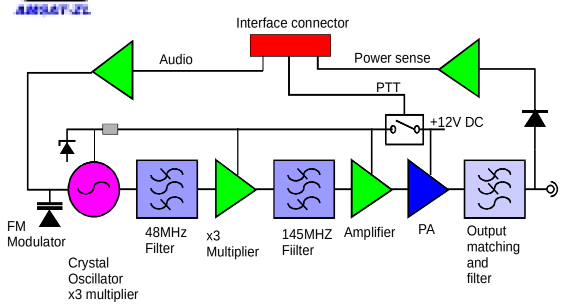


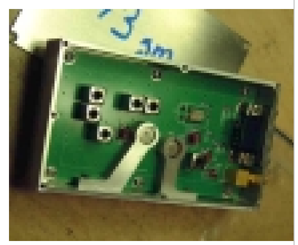
Transmitter Linear (Mk 1)

Linear – VHF
(30 kHz bandwidth)
4 Watts.

By Dr Phil Wakeman of

Transmitters FM





- Frequency 145.865 MHz
- Xtal frequency 16.2072 MHz
- Output power 1W
- Spurious outputs -35 dBc
- DC input 12V at 260 mA
- Modulation FM up to +/-5 kHz
- Temp range -20 +60 degrees C
- Freq stability over temp range +/-10 ppm (1.4 kHz)
- Audio input frequency DC – 15 kHz (-3 dB)

Science Package

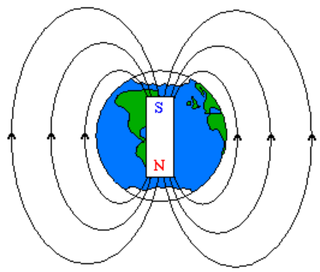
supported by_

Massey University Auckland

- An Attitude Determination and Control (ADAC) system using the geomagnetic field plus
- a Faraday Rotation and an ionosphere total electron content experiment.

Science Package Attitude Control System.

- 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.



Attitude Control Test Rig with Magnetometer

Attitude Control Test/Demo. Rig - draught protected!

27

Remote controller.

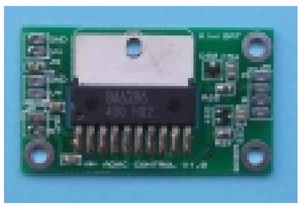
Torque Coils – X and Y

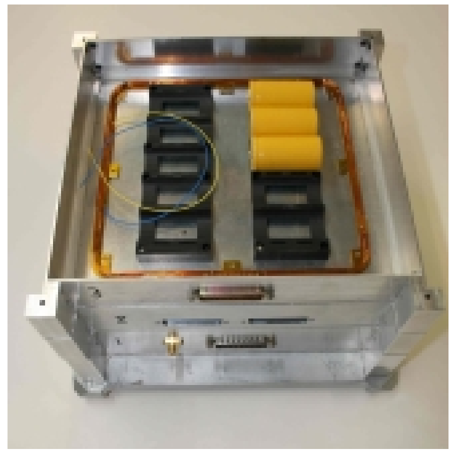
on engineering mock-up

28

Torque Coil - Z

Located in Tray (No 3) with the Battery and the three (X,Y and Z) Coil Driver PCB's (below) attached to the tray walls.

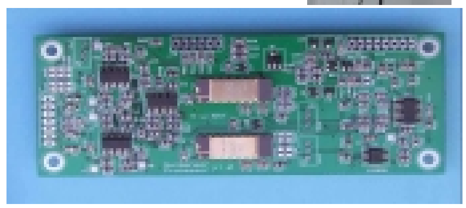




Science Package
Attitude Determination Sensors

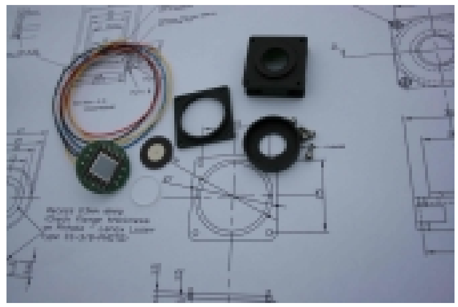
- Sun and Earth/Horizon sensors will provide reference information to 'fix' the satellites position/attitude in space.
- A 3 Axis Magnetometer will record attitude information using the Earths magnetic field.
- A (high speed/altitude) GPS receiver is to be flown for both positional and time data.
- A CMOS fixed focus camera to confirm the attitude -using a horizon image - is being flown.

Sun Sensor Processor

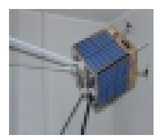


- Based on an original circuit by Alan (N1AL) for use in Phase 3D.
- PCB and assembly by Clayton (ZL3TKA)

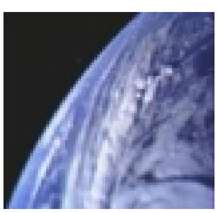
Sun Sensor Head

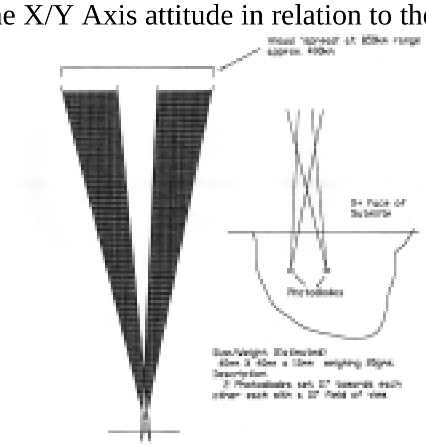


Earth/Horizon Sensors – Fields of view – I/R and Visible



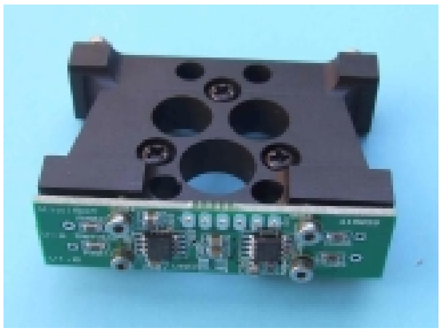
Required to establish the X/Y Axis attitude in relation to the Earth.



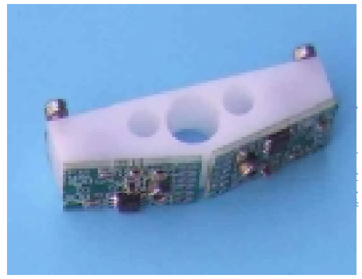


Earth / Horizon Sensors

Heads with sensors for visible and I/R wavelengths.



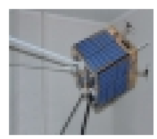
Visible light head



I/R Sensor head

Mounted in the Attic wall on X+ face adjacent the camera.

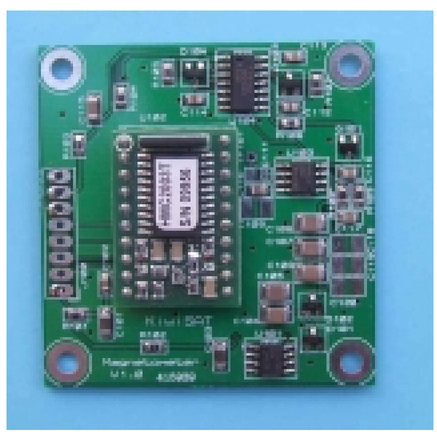
Magnetometer



Based on the HMC2003

3 Axis unit from Honeywell

Adjacent ferrous metal affect test rig,



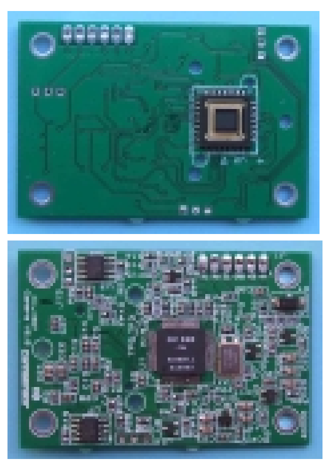
Flight GPS Rx

1. Availability of suitable GPS investigated. NZ $14,000! (plus ITAR if unit from US!)
2. Out of the question!
3. Three ‘old’ Navman ‘sport’ units with duplex port access were found.
4. Enter:
   Kelvin (ZL3KB) (Navman)
   and programmer Mark (Navman)
5. Dwell a short pause.
6. A fully simulator proven High Altitude, High Speed Flight Unit and two spares ready for thermal vacuum and vibration testing.

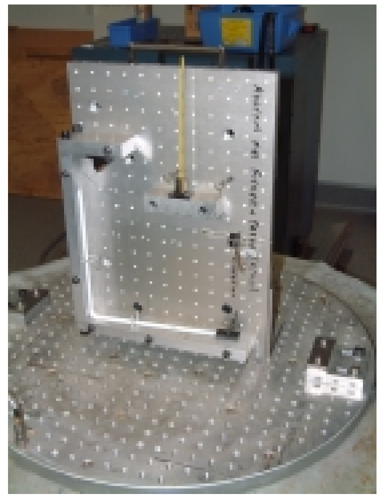
It Passed! **GPS will fly!**

Science Package - Camera

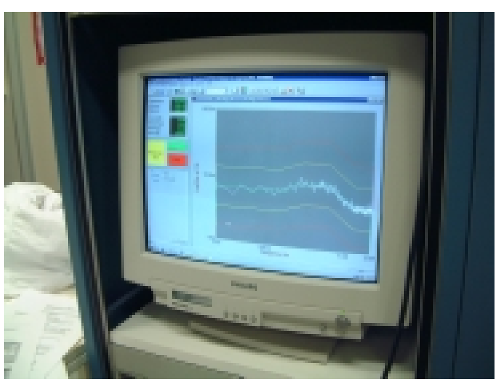
- A small colour camera module has been located via the University of Tokyo. Used on their first CubeSAT XI – IV.
- Re engineered by Clayton (ZL3TKA)
- Camera body – by Fred(ZL1BYP) to follow!!!!

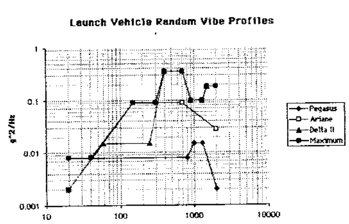


Test Equipment - Vibration



Test Equipments.
Vibration Profile

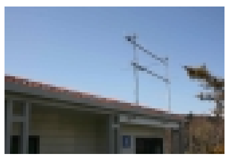


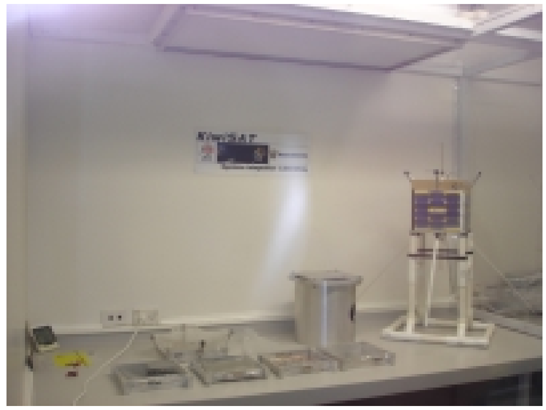


Actual ‘lift-off’ profile for Dnepr LV – 35 secs duration.

Clean Room

- First moves towards a “flat-sat” using the engineering trays.
- Currently the linear transponder is operating 24/7 using the clean room antennas. (below)





(The “sat” on the assembly stand is the model – sorry!)

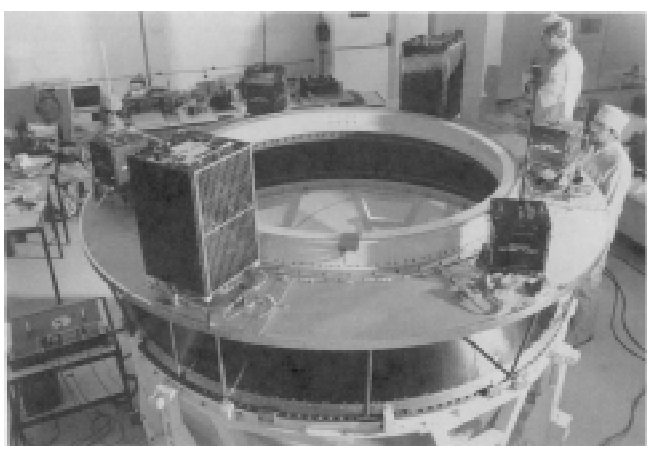
Test Equipment. Vacuum/Thermal Chamber

Massey University

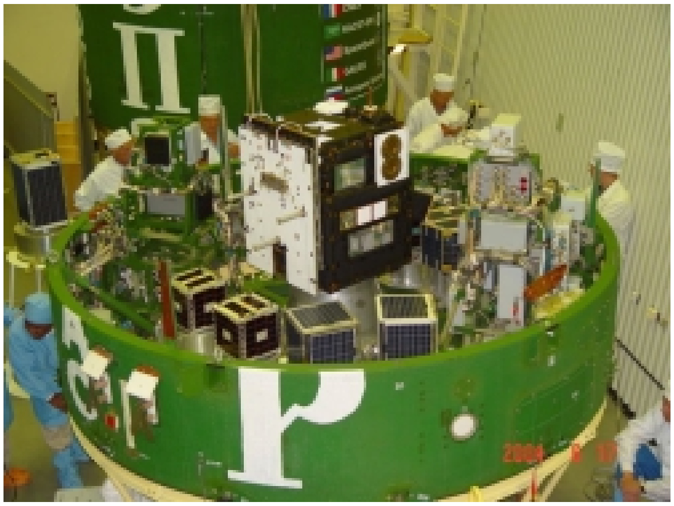
KiwiSAT – Launch proposals.

Russian DNEPR
Space launch system

Multiple launch (1990)



Multiple launch (2004)

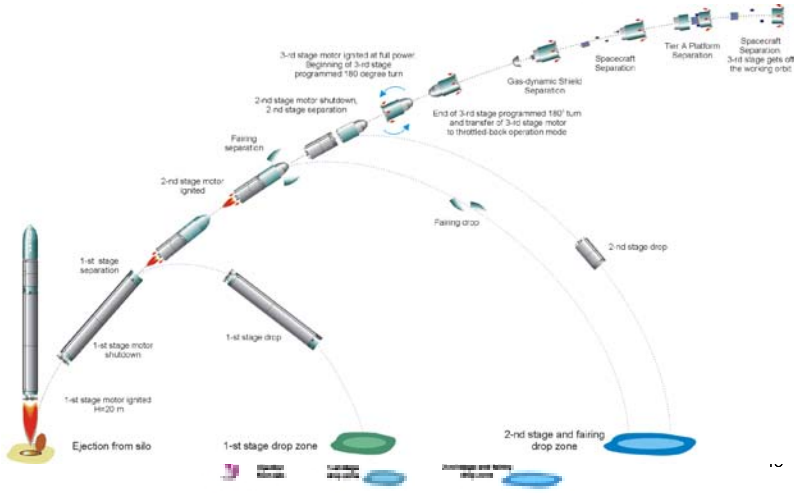


43

OSCAR 51 pre launch fit check

44

KiwiSAT
Launch Sequence



DNEPR
Lift-off!

AMSAT-ZL Would Graciously Accept and Appreciate Your Donation To KiwiSat

Donations to help fund the various stages of KiwiSAT development can be made by mail to the Treasurer of AMSAT-ZL at:

The Treasurer, AMSAT-ZL
894 Ponga Road
RD 4
Auckland 2584
New Zealand

Or via PayPal on their web site at http://kiwisat.org/funding.html

Thanks and Now For Your Questions

Space Radio for Windows

By Anthony Monteiro, AA2TX
AA2TX@amsat.org

Abstract

Space Radio is a very low-cost way to receive the voice and data transmissions from the International Space Station on the 2-meter band. It can also be used to receive the packet data satellites that operate on this band. Using about $15 in parts and free, open-source software, Space Radio could offer an attractive entry point for students, hobbyists, and amateur radio operators interested in exploring space communications and software radio technology.

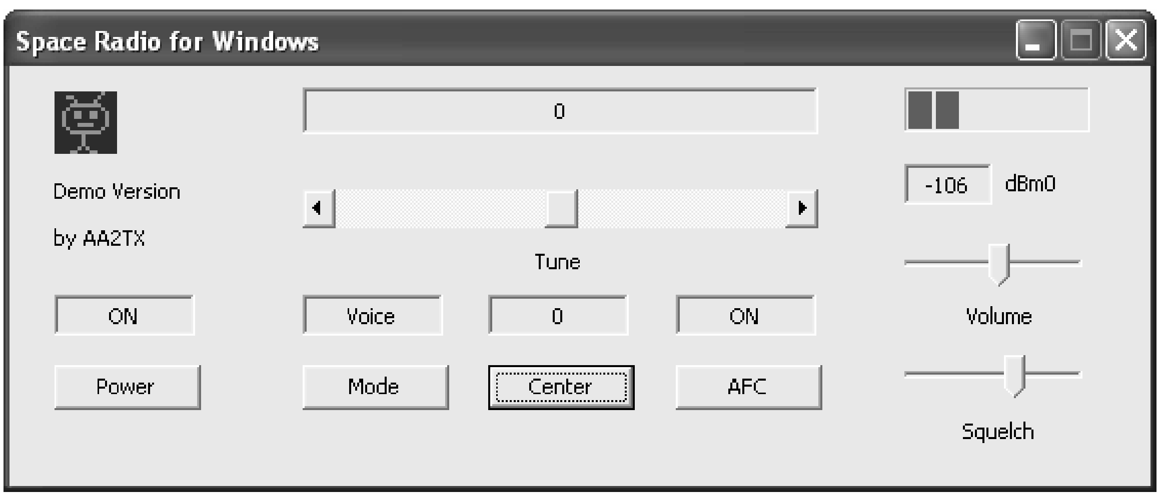


Figure 1. Space Radio for Windows Control Panel

Introduction

The Amateur Radio on the International Space Station (ARISS) school contact program has been an outstanding success with hundreds of schools participating and providing an enriching science experience for thousands of students. But, what happens next? No doubt, the afterglow of excitement lasts for several days or even weeks. But once the ham volunteers pack up their equipment, the majority of students will likely have little or no continued exposure to ham radio, space communications or ARISS.

And while the hundreds of school contacts are an impressive achievement, there are more than 160,000 elementary, middle and high schools in the USA alone[1]. This means that only a very minute percentage of students will ever be able to participate in the school contact program. The goal of this project was to investigate the potential of software radio technology to make ARISS communications more accessible.

Software radio technology has historically been driven primarily by common carrier and military applications where the higher costs of a software-based radio has been offset by the desirability of higher performance and increased flexibility and this has generally been true of amateur radio applications as well. But Space Radio uses the exact opposite approach. It employs software radio technology as a way to *reduce* costs while providing sufficient but modest performance and flexibility.

ARISS and Packet Satellite Communications

The transmissions from the ISS and packet data satellites on the 2-meter band use narrow-band, frequency modulation (FM) with a channel bandwidth of 16 KHz. Packet data is modulated on the FM downlink as audio frequency shift keying (AFSK) at 1200 bits per second using the BELL 202 modem standard.

Table 1 provides the key characteristics of the downlink of the ISS and some representative packet satellites. Due to the Doppler-shift, the downlink carrier frequency shown in the table will be seen at the ground station to vary by about ± 3 KHz.

Satellite	Mode	Carrier Frequency (MHz)	Transmit Power (Watts)	Satellite Antenna Type	Estimated Antenna Gain (dB)
ISS	Voice	145.800	5-25	¼-wave whip	0
ISS	Packet	145.825	5-25	¼-wave whip	0
PCSAT	Packet	145.827	3	½-wave dipole	2
RAFT	Packet	145.825	1	Short whip	-2

Note that RAFT has re-entered and is listed only for reference

Table 1. ISS and Packet Satellite Downlink Summary

The signal level seen at the ground station depends upon the satellite range, (the ISS being included as a satellite,) its transmitter output power, its antenna gain and the gain of the receiving antenna. Based on the information available, the nominal received signal levels of each satellite were calculated. This calculation assumes the lowest transmit power available is used and that the receive antenna is polarity matched with a gain of 0 dB. The results are shown in Table 2 for satellite elevation angles of 0 degrees, 20 degrees and 90 degrees (i.e. overhead.)

Satellite	Altitude (Km)	RX Signal 0 degrees (dBm0)	RX Signal 20 degrees (dBm0)	RX Signal 90 degrees (dBm0)
ISS	360	-105	-98	-90
PCSAT	800	-109	-104	-97
RAFT	360	-114	-107	-99

Note that RAFT has re-entered and is listed only for reference

Table 2. ISS and Satellite Receive Signal Levels

As can be seen from the table, the signal from the ISS is fairly strong. Using the International Amateur Radio Union (IARU) recommendation for S-units, the ISS would be received between S-7 and S-9 so the receiver sensitivity should not need to be very high to hear the ISS signal. The packet satellites are up to 10dB weaker so they would require higher receiver sensitivity or a gain antenna to allow decoding the AFSK data.

It is important to note that the antenna polarities will generally not be matched due to Faraday rotation unless using a handheld antenna that can be manually pointed. The table provides a starting point for estimating the receive signal levels but the real levels will depend upon the actual receiving antenna system.

Major Project Goals

The main purpose of this project was to test and demonstrate the feasibility of using software radio technology to create a low-cost, 2-meter FM receiver capable of monitoring ARISS voice transmissions. The target audience was intended to include high school and perhaps advanced middle school students as well as electronics hobbyists and ham radio operators. This wide audience constrains certain aspects of the project.

First of all, the required circuit would have to be very easy to build. This was taken to mean no surface-mount parts could be used. The circuit would need to be as simple as possible keeping the parts count low and the parts had to be readily available as well. Since this project could be offered in a kit form, there was not a hard requirement to have parts available in single unit quantities however, this was a secondary goal.

Next, the costs had to be kept low. The electronic components cost goal was $25 or less but not including any battery, enclosure, cables etc. Additionally, all software including all development tools were required to be free. This would allow anyone to re-use or re-design any aspect of the hardware or software if they were interested. The Space Radio for Windows source code will also be freely available in keeping with the above.

Finally, Space Radio was intended to be sufficiently sensitive to allow monitoring ARISS voice transmissions using only an omni-directional antenna. A secondary goal was to allow sufficient tuning range and sensitivity to allow receiving packet data transmissions from the ISS and digital satellites with at most a small hand-held beam.

System Design

Any system design requires making tradeoffs. The key design tradeoffs for Space Radio included trying to minimize the circuit complexity and component cost while maintaining adequate performance. The following system parameters were established:

1. Sensitivity: 10dB Noise Figure or better. This is needed to allow receiving ISS voice with an omni antenna
2. Input impedance: 75 ohms. This allows good performance using cheap RG-6 TV coax and a dipole antenna but will also work fine with 50 ohm coax.
3. Intermediate frequency: 8.82 KHz. This IF is approximately in the center of a typical PC sound card pass-band and is conveniently 1/5 of the max sample rate.
4. Use simple (not image-reject) mixer. With the low IF, the image is in the adjacent channel. Since the ISS and satellites are in the space sub-band, there should be little or no activity in the channel adjacent to the ISS or satellites.
5. Use free-running tunable oscillator with automatic frequency control. This keeps costs down and allows automatic Doppler correction once the signal is acquired.
6. Radio will be completely controlled from the PC without even an ON/OFF switch. This is cheaper and more convenient.
7. Use a COM port for PC control of radio. USB would be better but is not reasonable without using surface-mount parts.
8. Use LINE-IN or MIC port on PC for radio IF signal. As above, USB would be better but is not reasonable without using surface mount parts.
9. Radio audio plays through PC speakers.
10. Battery operated with optional AC adapter.

Circuit Design

The Space Radio circuit was designed to meet the system design parameters specified above. Please see the schematic diagram of the Space Radio circuit shown in Figure 2.

The antenna is connected to J1, a 75 ohm F-connector. C1, C2, and L1 provide a match from 75 ohms to the input impedance of U1 as well as providing out-of-band signal filtering. U1, an SA-602A, is a double-balanced mixer IC in an 8-pin dip package. This device provides a noise figure of around 6 dB and about 15 dB of conversion gain. It also includes an extra transistor that is used in this circuit as a Colpitts local oscillator. The base local oscillator frequency is determined by C4, C5, and L2. L2 has an aluminum tuning slug which is adjusted for a nominal local oscillator frequency of 145.813 MHz.

Note that L1, the RF input coil, also has a tuning slug. The RF circuit bandwidth is wide enough so that it does not need to be precisely tuned. However, tuning L1 will pull the

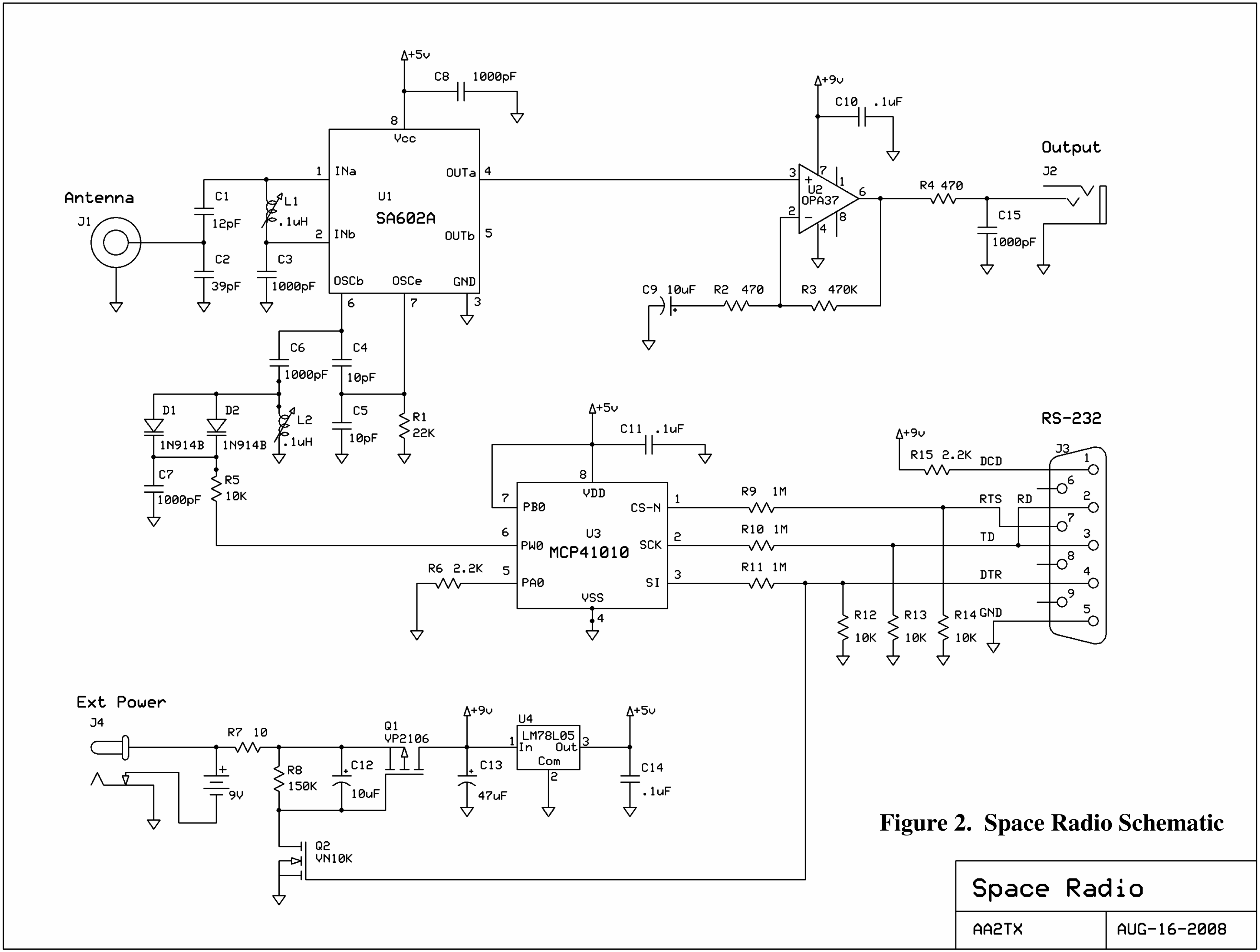


Figure 2. Space Radio Schematic

local oscillator frequency by several kilohertz. This effect is employed to ease setting the base local oscillator frequency without requiring an extra trimmer capacitor.

D1 and D2, a pair of ordinary 1N914 diodes, are used as variable capacitors to provide radio tuning. The circuit provides about +/- 25 KHz of tuning range. The local oscillator is normally tuned 8.82 KHz above or below the received signal. This provides an intermediate frequency (IF) centered at 8.82 KHz at the output of U1.

The IF signal is applied to U2, an OPA37 low-noise op-amp in an 8-pin dip package. U2 and its associated circuitry provide 60 dB of gain over the range of 50 Hz to 20 KHz. The output of U2 is fed to a 3.5 mm stereo jack making it convenient to connect it with a standard patch cable to the LINE-IN jack on a PC sound card. Only the LEFT channel is used (i.e. the TIP.) If a LINE-IN jack is not available, the MIC jack may also be used but this may result in lower fidelity of the received audio.

The tuning of Space Radio is accomplished by changing the bias on the tuning diodes via U3. U3 is an MCP41010 digital potentiometer in an 8-pin dip package. The potentiometer side of U3 is at pins 5, 6, and 7 with pin 6 being the wiper. One end of the pot is connected to 5 volts and the other end is connected to ground through resistor R6 to limit the minimum bias to about 0.9 volts. Adjusting the wiper changes the bias on the tuning diodes which changes their capacitance and the local oscillator frequency. The MCP41010 device has a Serial Peripheral Interface (SPI) port to control the position of the pot wiper. This is a synchronous interface with 0 and 5 volt digital levels. Since most PCs do not have an SPI port, Space Radio uses a regular PC COM port with special *bit-banging*[2] driver software to implement the SPI protocol. The COM port RS-232 levels are converted to SPI-compatible levels using the resistor network consisting of R9 through R14.

Space Radio is powered by a standard 9-volt transistor radio battery. It draws less than 10 milliamps when turned on so a battery can last quite a long time when it is used only for ISS voice monitoring. For extended operation, J4 is provided to allow using an AC adapter. Space radio will operate over the range of 7.5 to 12 volts.

Power to Space Radio is controlled by the PC COM port via the DTR lead. When the radio is disconnected or the DTR lead is low (-12V,) transistor Q2 is turned off which turns off pass transistor Q1. When the DTR lead is set high (+12V,) Q2 is turned on which charges capacitor C12. This turns on pass transistor Q1 which connects the 9V supply to the radio circuits. The 9 volts is also applied to U4, an LM78L05 low-power, 3-terminal, 5-volt regulator IC which provides a stable voltage for the SA-602 mixer and the MCP41010 digital potentiometer.

Parts and Assembly

The complete list of the electronic components is shown in Table 3. In order to keep the shipping costs low, almost all of the parts were purchased from one supplier; Mouser Electronics[3].

Part ID	Description	Mouser Part#	QTY	$ Cost Each	$ Cost Total
B1	9V Clips	121-0426/I-GR	1	0.29	0.29
C1	12pF (NPO)	140-50N5-120J-TB	1	0.06	0.06
C2	39pF (NPO)	140-50N5-390J-TB-RC	1	0.06	0.06
C3,6,7,8	1000pF	140-50Z5-102M-RC	4	0.07	0.28
C4,5	15pF (NPO)	140-50N5-150J-TB-RC	2	0.06	0.12
C9,12	10uF/16V tantalum	80-T356E106K016AT	2	0.48	0.96
C10,11,14	.1uF	581-5ZH104MACJI	3	0.14	0.42
C13	47uF/16V electrolytic	647-UVR1C470MDD1TD	1	0.03	0.03
D1,2	1N914B	512-1N914B	2	0.03	0.06
J1	F-Connector	601-25-7630	1	0.92	0.92
J2	3.5 mm stereo jack	161-3507	1	0.71	0.71
J3	2.1mm power jack	163-5004-E	1	0.63	0.63
J4	DE-9 Female	152-3409	1	1.09	1.09
L1	.1uH	434-1012-3.5CS	1	0.61	0.61
L2	.1uH	***** see Note 3 *****	1	3.02	0.00
Q1	VP2106	689-VP2106N3-G	1	0.34	0.34
Q2	VN10K	689-VN10KN3-G	1	0.32	0.32
R1	22K	660-MF1/4LCT52R223G	1	0.04	0.04
R2,4	470	MF1/4LCT52R471J	2	0.04	0.08
R3	470K	660-MF1/4DCT52R4703F	1	0.03	0.03
R5	47K	660-MF1/4DCT52R4702F	1	0.03	0.03
R6, R15	2.2K	660-MF1/4DCT52R2201F	2	0.03	0.06
R7	10	660-MF1/4D52R10R0F	1	0.02	0.02
R8	150K	660-MF1/4DCT52R1503F	1	0.03	0.03
R9,10,11	1M	660-MF1/4DCT52R1004F	3	0.03	0.09
R12,13,14	10K	660-MF1/4D52R1002F	3	0.02	0.06
U1	SA602A	771-SA602AN/01	1	2.25	2.25
U2	OPA37GP	595-OPA37GP	1	2.56	2.56
U3	MCP41010	579-MCP41010-I/P	1	1.70	1.70
U4	LM78L05	863-MC78L05ACPREG	1	0.20	0.20
		Total Cost			**14.05**

Note 1: All caps are 50V ceramic disc unless otherwise noted.
Note 2: All resistors are ¼-watt
Note 3: L2 is a Coilcraft, 5mm, shielded, tunable RF inductor. Part# 164-07A06SL. See the text about free samples.
Note 4: Optional 9V, AC adapter is also available from Mouser Electronics. Part# 552-PLA01A-090-R at a cost of $5.29 each in unit quantities.

Table 3. Parts List

The prices shown in the table are the single quantity prices and were the actual prices paid to construct the prototype unit. In larger quantities, the prices could be significantly lower.

The one part not available from Mouser is the oscillator coil, L2. This part is only available Coilcraft,[4] its manufacturer. This part was selected because it uses an aluminum tuning slug which has a zero temperature coefficient. Fortunately, this company offers free samples in small quantities to students and design engineers. Please see their web site for more details. As an aside, several Coilcraft inductors flew in space on the NO-60 "RAFT" satellite (see Table 1) and they performed flawlessly.

Unfortunately as of August 2008, one of the parts, the OPA37GP op-amp, was back-ordered at Mouser until January 2009. However, Digi-Key[5] had thousands of these in stock as part# OPA37GP-ND at the same price. Another alternative would be the Linear Technologies[6] LT1037CN8 which is an exact replacement. This part is actually cheaper but has a 2-piece minimum order from the manufacturer.

The Space Radio prototype was constructed on a printed circuit board ordered from ExpressPCB[7]. This company offers free schematic capture and printed circuit board (PCB) layout design software which can be downloaded from their web site. Since only a very small number of boards were needed for a prototype, the "MiniBoard" service was used. The prototype boards were ordered without solder masks or silk screening. A photo of the assembled prototype circuit board is shown in photo 1 below.

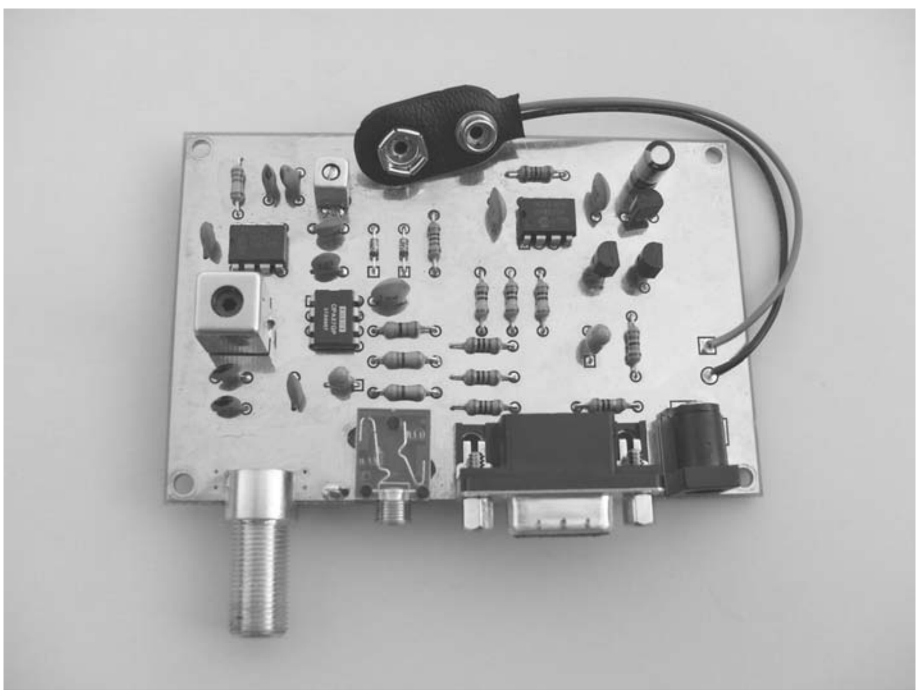


Photo 1. Space Radio Prototype Circuit

Software Design

The Space Radio software is a 32-bit Microsoft Windows application. It requires Windows 2000 as a minimum and will run on any later version as well. All of the software was written in C++ and was developed using Visual C++ 9.0 Express Edition which is available for free from Microsoft[8]. The free Express Edition does not include a resource editor which allows graphically creating and editing icons, dialog boxes, menus, and other visual resources used in a windows program. These can be created using a text editor but it is very tedious. Instead, the free "XN Resource Editor" was downloaded and used from Colin Wilson's Delphi 2006 Website[9].

Please see the software architecture diagram shown in Figure 3. The software consists of four major modules; the User Interface, a WAVE I/O Driver, a KISS-RX Driver, and the IF System.

The User Interface module, like a typical Microsoft Windows application program, includes window controls and display components. These are used to interact with and control the operation of Space Radio. And, like all windows applications, the main window provides the entry point for the program and also ties all the other modules together. Unlike a typical windows application however, Space Radio uses a Dialog Box as its main window. This allows the use of a graphical editor to draw the display area and place the controls which is better suited to a radio "Front Panel."

The WAVE (waveform audio) I/O Driver provides a simple interface to the Windows multimedia Applications Programming Interface (API.) This hides the messy details of the low-level code to drive the sound card and helps simplify the interface to the other modules. The WAVE I/O Driver provides a simple pointer passing mechanism to blocks of PCM samples.

The KISS-RX Driver runs the Space Radio circuit (nicknamed KISS-RX for "keep it simple...") including power and frequency control. It implements the special bit-banging software to run the SPI protocol over the COM port and converts frequency control commands to the low-level SPI operation and parameter codes needed by the digital pot on the Space Radio circuit board.

Finally, the IF System is the signal processing component of Space Radio. It works much like an intermediate frequency (IF) sub-system IC as found in a typical hardware radio but of course all of the signal processing is done in software.

Digital Signal Processing

The signal processing software in the IF System module is the heart of Space Radio. A block diagram is shown in Figure 4. As shown in the diagram, 16-bit, Pulse Code Modulation (PCM) samples arrive from the sound card at a 44.1K samples/second rate. This is the highest rate that a typical built-in sound card will support. Fancy sound cards will do higher rates but they are not generally included with a typical PC.

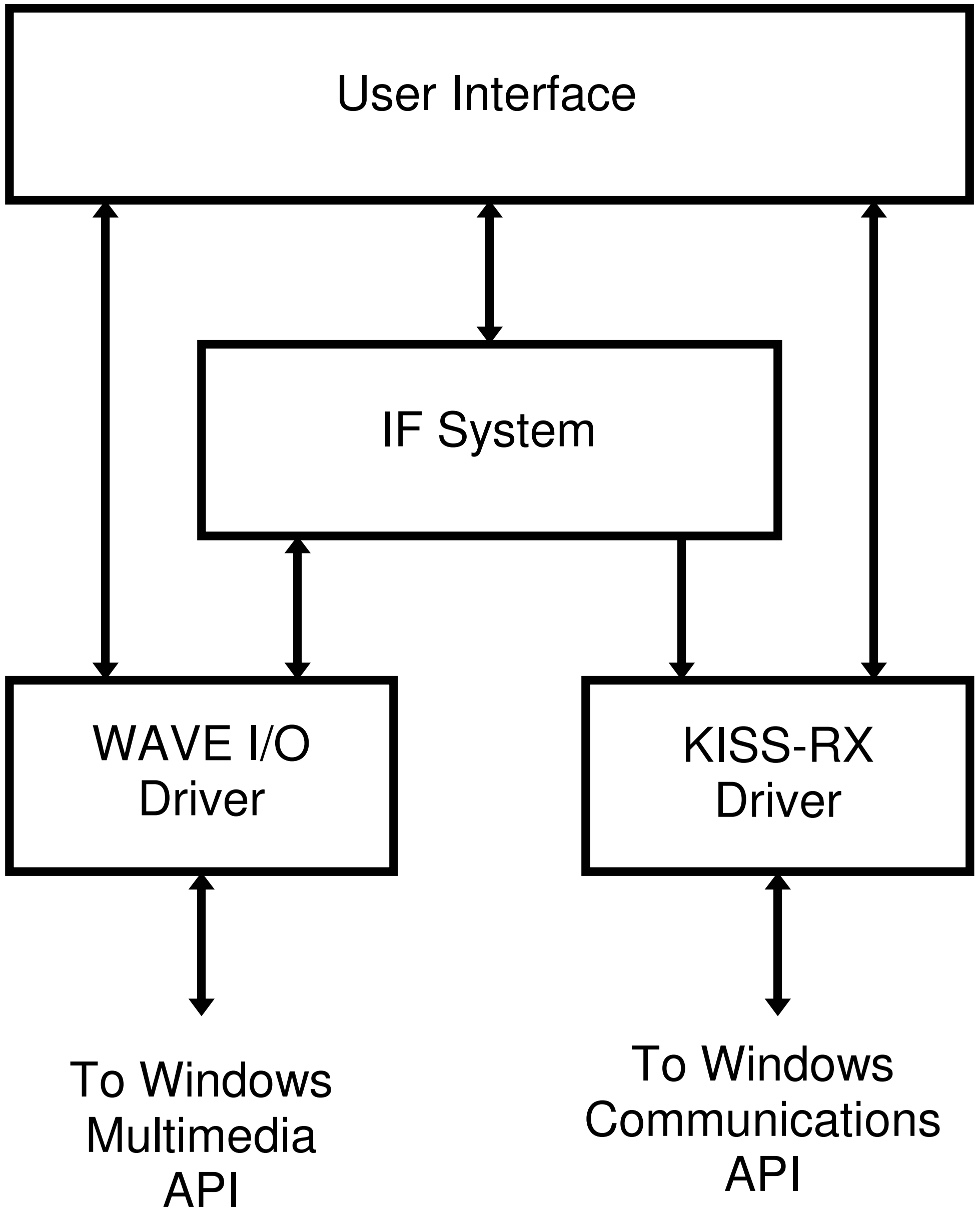


Figure 3. Space Radio Software Architecture

The input samples are passed to the Power Detector which measures the average power in the input signal. The calculated power is converted to decibels and drives the Received Signal Strength Indicator (RSSI.)

The input samples are also passed to a x256 sample rate converter which includes an up-sampler and linear interpolator. This converts the sample rate to a little over 11M samples/sec. This high rate is needed by the FM demodulator block to provide good fidelity FM detection.

The next stage is the FM demodulator and it uses a zero-crossing detector with a period to frequency converter. The zero-crossing detector counts the number of samples in-between signal polarity changes which provides the instantaneous period of the input signal. The period is then converted to the frequency deviation from the IF center frequency. A zero-crossing detector is used because it has excellent noise rejection without needing a limiter stage and is simple to implement.

The output of the FM detector feeds a sample rate converter block which reduces the sample rate back to the sound card rate of 44.1 K samples/second. This block consists of a 2's compliment integrator, a divide-by 256 rate decimator, and an N=10 comb filter. This function is commonly called a combined integrator-comb (CIC) decimator.

The sample rate converter is followed by an N=8, CIC low pass filter which functions as a de-emphasis filter. This filter uses the same integrator-comb structure as the sample rate converter but with no rate decimator. Though it does not have a perfect de-emphasis filter shape, it provides nice crisp communications-quality audio.

The de-emphasis filter is followed by a 3 KHz infinite-impulse response (IIR) low-pass filter. An IIR low-pass filter works much like an analog resistor-capacitor network and it cleans up any left-over, high-frequency digital processing artifacts without affecting the audio quality.

The recovered audio is then passed through a squelch process before being passed back to the sound card. The squelch block will mute the audio if the received signal strength is below the squelch set level. The squelch may be disabled if desired. Note that there is no volume control block needed. Speaker volume is controlled by sending software commands to the PC sound card.

Finally, the Tuning Error block uses the RSSI signal from the Power Detector and takes zero-crossings from the FM detector to create an output signal that corresponds to the average frequency tuning error when a valid signal is present. This is much like the discriminator-meter output from an FM sub-system IC. This signal is used to provide automatic frequency control of the radio's local oscillator. In this way both oscillator drift and received signal Doppler-shift can be compensated for automatically.

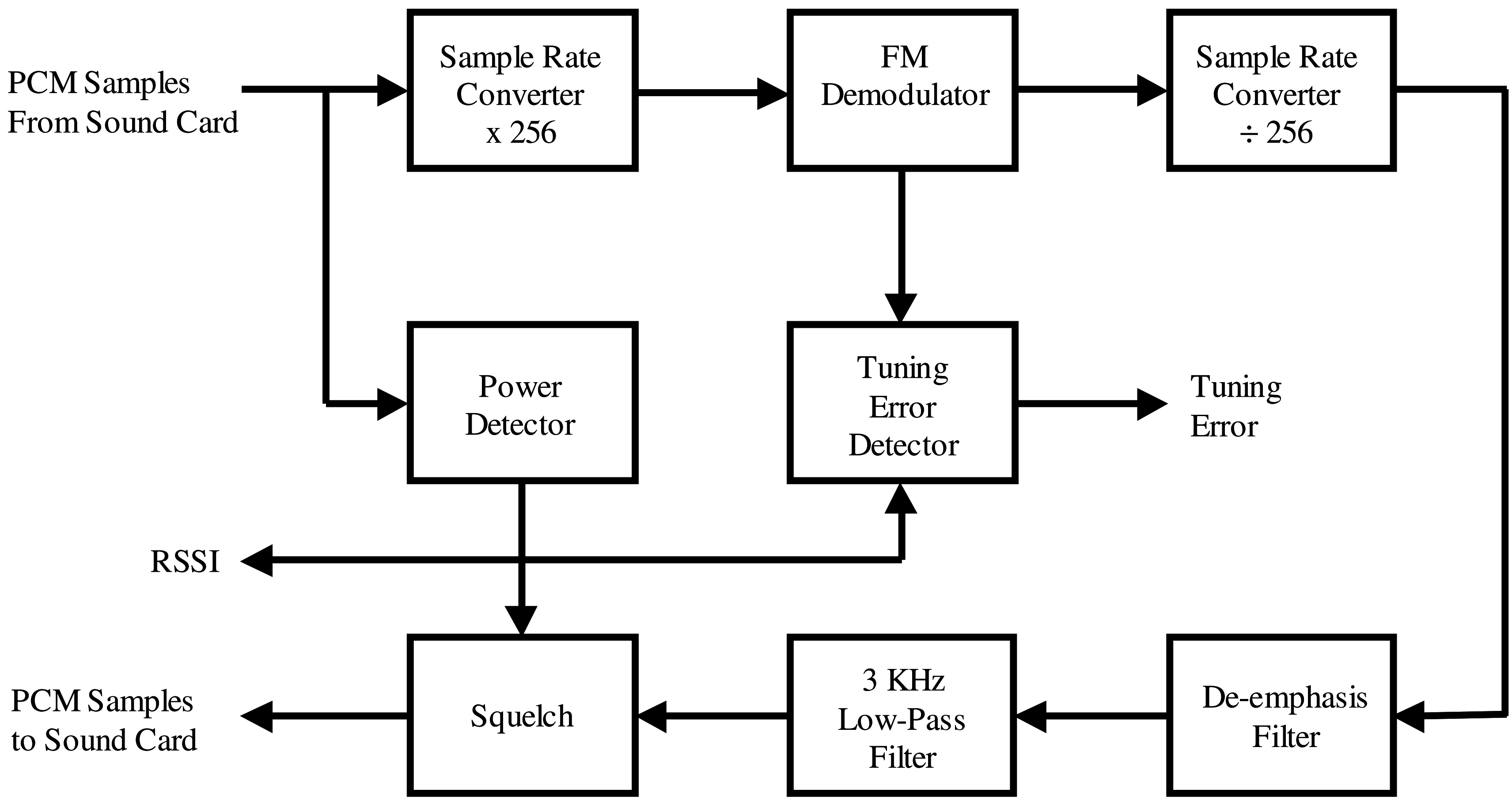


Figure 4. Digital Signal Processing

Operation

Space Radio will run under Windows 2000 or later operating systems. On the author's PC, a 2.3 GHz Pentium R running Windows XP, Space Radio requires around 2% to 4% of the CPU.

Operating the Space Radio control panel is pretty much like operating any other radio. Please see the control panel image in Figure 1. The user controls include buttons for POWER, MODE, CENTER, and AFC. There is a scroll bar for tuning and sliders to adjust the squelch and the volume. An S-Meter shows signal strength and there is a direct digital readout of the received signal power. An "information" bar at the top is used for additional information that was useful during software development. When receiving a signal, it shows the tuning error in hertz. Most of these controls are self-explanatory (i.e. the POWER button toggles the power on and off.)

Tuning Space Radio is accomplished by adjusting the scroll bar labeled "Tune." The box under the scroll bar shows the number of tuning steps from the center frequency. A step is about 200 Hz and the range is +/- 127 steps. The scroll bar thumb can be moved directly by left clicking it and moving it via the mouse. Clicking on the area between the scroll bar ends and the scroll thumb changes the frequency by five steps. Clicking the arrows on the scroll bar ends changes the frequency by one step. The CENTER button returns the scroll thumb back to the scroll bar center position.

The MODE button selects VOICE mode at 145.800 MHz or PACKET mode on 145.825 MHz. The MODE button does not change the radio tuning; it selects high or low side local oscillator injection which allows double the frequency coverage. It was also envisioned that this would activate an AFSK demodulator when in PACKET mode but this software was not completed at the time this paper was written.

The AFC button toggles the automatic frequency control on or off. To use AFC, first adjust the squelch slider to fully mute the audio. Then click the AFC button to turn it on. The radio can then be tuned using the tuning controls. When the radio detects a signal stronger than the squelch level, it will lock on to it automatically. When the AFC is engaged, the software internally saves the squelch level that was set so the squelch slider can be re-adjusted as desired or even disabled and it will have no affect on the AFC action. The AFC will correct for Doppler-shift on a received signal so that no manual re-tuning is normally necessary once the desired signal is acquired.

Lab Testing

The receiver sensitivity was tested using a combination of HP-8903A and HP-8640B test sets. The receiver required 1.8 microvolts at the input for 12 dB SINAD using a 1 KHz modulation tone and 1.67 KHz deviation (i.e. 100% NBFM modulation.) This is equivalent to -104 dBm0 and is well within the expected sensitivity requirement for monitoring the ISS voice and data transmissions with an omni-directional antenna.

On-The-Air

On August 13, 2008, an ARISS school contact was made with the Town of Berkeley Heights, NJ, Summer Playground Camp. This contact was successfully monitored with Space Radio from the Boston, MA area. The antenna was a Lindenblad connected through 200 feet of coax with no preamp.

This pass had a maximum elevation angle of around 45 degrees. Signals from the ISS were detectable at around 10 degrees elevation at 2 minutes into the pass but were very noisy. At 20 degrees elevation, about 3 minutes into the pass, the signals became very clear and fully readable. There were a few short fades during the pass probably due to nulls in the Lindenblad antenna pattern but these were only a few seconds in duration.

The maximum observed signal level was -96 dBm0 and remained fairly constant over the pass between the 20 degree elevation points. This is well within the predicted levels when the antenna elevation gain pattern, mismatched polarity loss and coax losses are considered.

Once the signal was acquired, Space Radio's automatic frequency control successfully maintained the correct tuning over the approximately +/- 3KHz Doppler-shift observed over the pass and no manual tuning was needed.

Since the ISS has not been active in packet mode, it was not possible to test packet data operation on the air. However, the receiver sensitivity measured in the lab test and the performance demonstrated during the school contact appears to be more than sufficient for this to work.

Discussion

This project is not sufficiently developed to consider this paper a construction article. The major purpose was to see if software radio technology could be used to make a really cheap, 2-meter FM radio that could receive the ISS Voice signals. While this was successful, more development work is needed before it could be considered a "turnkey" construction project.

For example, the local oscillator has no temperature compensation. While this worked fine for the demonstration, it is probably not as stable as needed to be really useful. This does not necessarily add anything to the cost but it does require more development work.

Another issue is that the ISS has not been in voice mode very much and the lack of activity reduces the usefulness of Space Radio as a construction project. Perhaps further developing the data capability would make it more interesting as the ISS, PCSAT and a number of other digital satellites such as PCSAT2, RAFT and ANDE, have been much more active on packet in the recent past. Focusing on packet data however might require an increase in the receiver sensitivity as the cubesats are considerably weaker than the ISS. This could be accomplished at a fairly minor cost by adding as RF amplifier stage but there would be in increase in the difficulty of building the circuit. For some satellites, even this might not be sufficient as decoding the data from RAFT and ANDE required having a preamp at the antenna even with an FT-847 radio when using an omni-directional antenna. Perhaps an "active" antenna or a cheap antenna mounted preamp is a better solution.

Yet another issue is the printed circuit board cost. If these were made in at least 100 quantities, the cost would be less than $5 per board even with solder-mask and silk screening added. So, a kit might be a good option but the "MiniBoard" service that was used to make the prototype at $51 for 3 boards, is probably too costly on its own. Another alternative might be to re-layout the board as single-sided only and offer it through a hobbyist oriented supplier like Far Circuits[10].

As long as these issues are kept in mind, anyone who is interested and wants to build a copy of Space Radio to try it out and do their own experiments is encouraged to do so. The Space Radio software, schematics, and printed circuit layout files will be made available to anyone who requests them via email.

Free Development Tools

One of the things that worked very well on the Space Radio project was the reliance on free development tools. All of the tools used can be downloaded via the Internet. Table 4 below provides a list of the tools that were used and their sources.

Tool Use	Name	Web address
Circuit Simulation	LTspice/SwitcherCAD III	www.linear.com
Schematic Capture	ExpressSCH	www.expresspcb.com
PCB Layout	ExpressPCB	www.expresspcb.com
SW Development	Visual C++ 9.0 Express Edition	www.microsoft.com
Resource Editor	XN Resource Editor	www.wilsonc.demon.co.uk

Table 4. Free Development Tools

Conclusions

The goal of the Space Radio project was to investigate the application of software radio technology (SDR) to make space communications more accessible by providing a very low cost entry point. This is unlike typical SDR applications which focus instead on high-performance or enhanced flexibility. The Space Radio experiment was a success. The astronauts on the ISS could be clearly heard during a scheduled ARISS school contact on the prototype radio built using around $15 in parts.

While Space Radio is not sufficiently developed to consider it a construction project, it is hoped that the successful demonstration of the concept would be thought-provoking. There are many areas where a limited performance but really cheap radio could be useful and the basic circuit can be used up through 500 MHz. Some other versions could include an APRS monitor, a NOAA Weather radio, an aircraft receiver, or even just a monitor for a favorite 2-meter repeater. With a small change to the oscillator circuit, it could be used to monitor the university Cubesats that have 70cm downlinks. Comments, discussion and suggestions are welcome.

Tony Monteiro, AA2TX, was first licensed in 1973 as WN2RBM and has been a member of AMSAT since 1994. He started his engineering career as a member of the technical staff at Bell Laboratories and has served as an engineering director at a series of high-tech start-up companies. Contact him at AA2TX@amsat.org.

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[1] Number of public schools from www.publicschoolreview.com. Number of private day schools from www.privateschoolreview.com.
[2] Bit-banging refers to a method of implementing a serial interface by individually setting I/O port bits on and off in software.
[3] Mouser Electronics orders can be placed online at www.mouser.com.
[4] Coilcraft parts available from www.coilcraft.com.
[5] Digi-key parts can be ordered from www.digikey.com.
[6] Linear Technologies parts and information available at www.linear.com.
[7] ExpressPCB software and printed circuit boards available at www.expresspcb.com.
[8] Visual C++ 9.0 Express Edition is available from www.microsoft.com.
[9] XN Resource Editor available from Colin Wilson's Delphi 2006 Website at http://www.wilsonc.demon.co.uk/delphi.htm.
[10] Far Circuits, printed circuit boards at www.farcircuits.net.

Work Satellites with your HT!

Most hams already have the necessary equipment to work FM amateur satellites.
This guide offers all the information you need to "work the birds."

If you can program split frequencies in your HT (transmit on 2 meter and receive on 440), you're set!

In satellite AO-51's main V/U mode, the UPLINK frequency (*to AO-51*) for voice is 145.920MHz. The DOWNLINK freq (*from AO-51*) is 435.300MHz.

First, you need to know WHEN and WHERE the satellite will be passing over your location. There are several commercial computer programs that will tell you. In the home office, I use Nova for Windows[1]. Outside, though, I use PocketSat[1] on my Verizon Treo 650p/755p PDA or Palm TX. On my MacBook Pro, MacDoppler[1] is amazing. These programs are easily updated with satellite tracking data. But completely *free of charge* info is online at...

http://www.heavens-above.com -or- http://www.amsat.org

Plug in your longitude and latitude coordinates on these sites, and you can access amateur satellite pass information.

The one "absolute" for success is to *open up your squelch*. "Working the sats" starts off as a process of finding weak signals, so don't expect the satellite to be anywhere as strong enough to break squelch like your local repeater. Sure, it's a little noisy, but that's part of the process. Noise can also be an aid in locating the satellite because when the frequency starts to exhibit QUIETING, that's a sign that you are capturing the satellite!

Improve your HT's stock antenna. For BNC connectors, Pryme's AL-800[2] will make the difference. For SMA, the Diamond SRH-320a or **Smiley** 270A are good performers. Using an Arrow dual-band[3] Yagi is better. If you prefer to homebrew your antenna, see the Notes[4] for construction article citations.

Set up your radio so you can to tune for the *doppler effect*. Start listening **above** the center frequency[5] - you will hear the satellite sooner and clearer. When the downlink gets scratchy or fuzzy, tune down 1KHz at a time, and reception should be clearer. With low power, only transmit when you can ***clearly*** hear the satellite. Follow the signal down in frequency as the pass continues.

AMSAT

Don't hold your whip antenna upright. Held in a vertical position, your transmitted signal is hitting land-based receivers. You need to tilt your HT's antenna so that it is *perpendicular* to the airborne satellite. The satellite isn't on the ground (which is what HT and vertical antennas were designed for). TILT IT about the same amount as the satellite's **ELEVATION**. You'll quickly get the hang of it!

Ideally, we should all be working the satellites in full duplex mode, where we can simultaneously listen to the downlink as we are transmitting. Although this method is preferred, it is not mandatory: Carefully monitor the downlink, and wait for a break in the conversations to announce yourself. Many operators find using headphones helps - especially if working full duplex.

Knowing your gridsquare - and having a gridsquare map - is a quick way of identifying locations of what you will be hearing. The ARRL and Icom have gridsquare maps: Icom's is free and available at better amateur radio stores[6].

The "three P's" for working amateur satellites: preparation, planning, and patience. Not every pass is workable with an HT — so don't go after the 10 degree passes. Pick your passes, working ones you know will give you the best chance.

When you hear others, try to find a break in the action, and announce your callsign phonetically, grid square, and op mode:

"KILO-SIX-LIMA-CHARLIE-SIERRA, D-M - ONE-THREE, handheld."

Some hams record their sessions for later review. Even if you don't make contacts, it helps to familiarize yourself to the callsigns, voices and personalities of the other operators.

Check the **AMSAT Web site** for the **AO-51 Control Team News** – to make sure AO-51 is in a VHF/UHF mode to work with your HT.

Ask questions! Find an elmer or look up the AMSAT[7] area coordinator for your area. Posting specific questions on the AMSAT bulletin board will also help you find answers.

Clint Bradford, K6LCS
AMSAT Area Coordinator
Email: clint@clintbradford.com
909-241-7666

Updated 07/02/08

Notes

[1] Nova for Windows is available from Northern Lights Software Associates' Web site at www.nlsa.com. PocketSat is available from Big Fat Tail's site at www.bigfattail.com. And MacDoppler is available at www.dogparksoftware.com .

[2] The Pryme AL-800 telescopes to 34" and collapses to 10". It is packaged with a 9" rat tail - which you can use for everyday use. Use caution with this massive, heavy antenna: It has the potential of placing a lot of stress on your radio's BNC connector. Pryme claims gain figures of 3.2 dB on VHF and 5.5 dB on UHF.

[3] Arrow's Model 146/437-10WBP is a dual-band cross-Yagi design, with a duplexer built into the handle. It has three elements on 2M and 7 on 440. See it in action in the December, 2007 issue of CQ Magazine. Arrow's Web site: http://www.arrowantennas.com.

[4] Alex Diaz' Yagi-Uda plans are at http://xe1mex.gq.nu/antenas/yagi.html. The AMSAT "Cheap and Easy" series of satellite antenna articles is at...
http://www.amsat.org/amsat-new/information/faqs/crow/

[5] For example, here's how I have programmed my FT-60R for AO-51:

Ch #	*Name*	*TX Freq*	*CTCSS*	*RX Freq*	*CTCSS*
101	51 -2	145.920	~~67.0~~	435.310	None
102	51 -1	145.920	~~67.0~~	435.305	None
103	51 MID	145.920	~~67.0~~	435.300	None
104	51 +1	145.920	~~67.0~~	435.295	None
105	51 +2	145.920	~~67.0~~	435.290	None

And here's how I have programmed my FT-60R for SO-50:

Ch #	*Name*	*TX Freq*	*CTCSS*	*RX Freq*	*CTCSS*
201	50 -4	145.850	67.0	436.815	None
202	50 -3	145.850	67.0	436.810	None
203	50 -2	145.850	67.0	436.805	None
204	50 -1	145.850	67.0	436.800	None
205	50 74	145.850	74.4	436.795	None
206	50 MID	145.850	67.0	436.795	None
207	50 +1	145.850	67.0	436.790	None
208	50 +2	145.850	67.0	436.785	None
209	50 +3	145.850	67.0	436.780	None

[6] Icom's map is available as a .pdf file on Icom's Web site. Search their Knowledge Base for Article 5BUE54225A at http://icomamerica.com - or at http://www.clintbradford.com

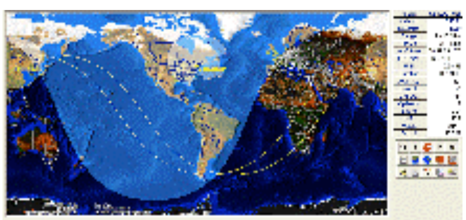
[7] AMSAT *deserves your support!* Membership isn't that expensive, and members are entitled to discounts on AMSAT publications and satellite tracking software!

amsat.org

MacDoppler
dogparksoftware.com

arrowantennas.com

heavens-above.com



Nova for Windows
www.nlsa.com

PocketSat+ for Palm
www.bigfattail.com

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S-Band and X-Band Deep Space Reception

By Paul Marsh - M0EYT.
(pjmarsh@compuserve.com)

Abstract

This paper will give an overview of current deep space transmitters along with equipment needed to build a modest receiver system. Tips on hardware, operating and relevant software are included in order to help the weak signal enthusiast get started.

Introduction

Deep space reception has bubbled away over the past few years, and has been keenly followed by a number of radio amateurs with a deep interest in weak signal work. There are currently around 20-30 amateur deep space receive stations in the world who have X-Band capabilities, and many more with S-Band. Interestingly, most of the amateur-DSN receive sites are in Europe, with only a few being in the USA. If you already have a microwave EME station, you have some of the components needed to explore the deep space network downlink bands. Amateur deep space reception offers some interesting opportunities for learning about extremely weak signals, and receive system optimisation techniques, that can then be applied to other areas of microwave amateur radio.

S-Band receive system

S-Band for the purposes of deep space is defined as the Space to Earth band spanning 2200MHz to 2300MHz. There are some satellites that operate outside of these frequencies which are still classed as S-Band emitters, but they are mostly Russian Military Satellites. S-Band makes an ideal band for entry into deep space reception – receive equipment from AO-40 systems can be re-used along with the relevant tracking methods, either computer controlled or using the arm-strong technique. AO-40 users spent a lot of time optimising feeds for small dishes, and these should work directly, or be easily scaled to operate in the Space to Earth band. Generally the requirements for any receive system should be a) a dish antenna that is as large as is practical, b) a low noise preamplifier, c) suitable receiving equipment capable of tuning the bands of interest, and d) software to aid detection of the signals.

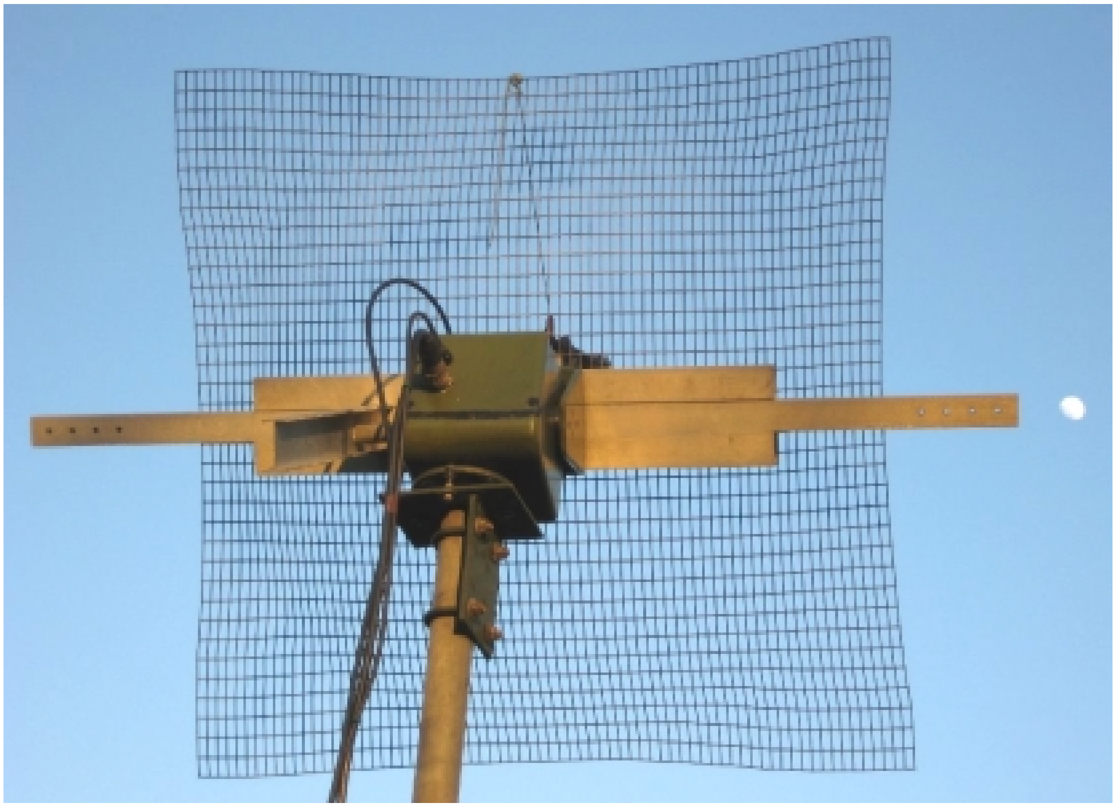
Dish antenna

Starting with the dish, a small 3ft / 1M dish will produce some good results with the closer space probes or satellites. It should be noted that the Lunar Orbiters are extremely simple to copy signals from, even with the most modest of antennas – even a paper-clip can be used!

Here at the M0EYT Earth Station, for S-Band, a mesh antenna around 3ft in diameter is used. In its original application, the mesh antenna was used for a 2.6GHz microwave video distribution network in Southern Ireland. They have recently been resold on eBay as ‘high-gain’ wireless LAN antennas suitable for long distance links.

In order to accurately point the antenna, and taking into account that such a small dish has a reasonably wide beam width, a modified CCTV pan and tilt head is used to point the antenna. The popular G6LVB tracker unit provides the interface between the PC tracking software, and the hardware to move the dish. The other advantage with having a PC controlled antenna is that the S-Band system may also be pointed at the numerous low Earth orbiters for purposes of checking out their downlinks. WX-Track from http://www.satsignal.eu/ can be used to drive the G6LVB tracker and is recommended for its ease of use.

Since the majority of Space to Earth communications at S-Band is right hand circular polarised, an opposite polarity feed is required at the focal point of the dish. For the 3ft mesh antenna, a 3 turn left hand circular helical antenna was chosen to provide the correct illumination of the antenna. As with EME systems, it’s very important to keep all coaxial losses to a minimum, therefore it is recommended that the low noise amplifier is connected directly to the relevant socket on the back of the helical dish feed.



S-Band 3ft / 1M mesh antenna used at M0EYT, shown tracking the Moon

Low noise amplifier.

The choice of LNA is really down to the system builder. It must exhibit a very low noise figure, and enough gain to overcome any LNA to receiver coaxial feeder losses. Many LNA's have been tried at M0EYT, mostly with good results. The two top performers were;

- A 0.45dB NF LNA from SSB-Electronics in Germany, who make a dedicated Space to Earth band amplifier with band pass filtering covering 2200MHz to 2300MHz. The LNA has around 30dB of gain and is mostly immune to adjacent band interference such as cellular services operating at 2.1GHz. The nice thing about these amplifiers is that they come with a noise figure plot. (http://www.ssb.de/)
- The G4DDK VLNA which comes in kit form, and boasts a noise figure of about 0.35 - 0.40dB with 25 - 26dB of gain. (http://www.btinternet.com/~jewell/)

Another LNA that is widely used in the satellite monitoring community is the MiniKits EME-103B which has a 1.6dB NF and 24.5dB gain @ 2400MHz and can easily be optimised for better performance in the Space to Earth band. The MiniKits LNA is the cheapest of the three LNA's mentioned and comes in kit form.

Receivers.

Receiving S-Band signals can be done either directly on the frequency of interest, or by down converting the 2.2GHz signal to something lower. Is it fairly common to use a 2.000GHz local oscillator and then a communications receiver covering 200MHz to 300MHz to tune the IF. Naturally, if building a down converter from scratch, attention will have to be paid to the filters to protect from out of band signals and images. Filtering is especially important if you are located near a cellular base-station, as cell-phone signals tend to get in just about everywhere.

Using a communications receiver such as the AOR AR5000 will allow direct tuning of the 2.2GHz signal and it also has the advantage of being lockable to an external frequency reference source. The important quality of the receiver should be its ability to reject image signals, as this could lead to a non-existent signal chasing exercise.

Signal Detection Software / Hardware.

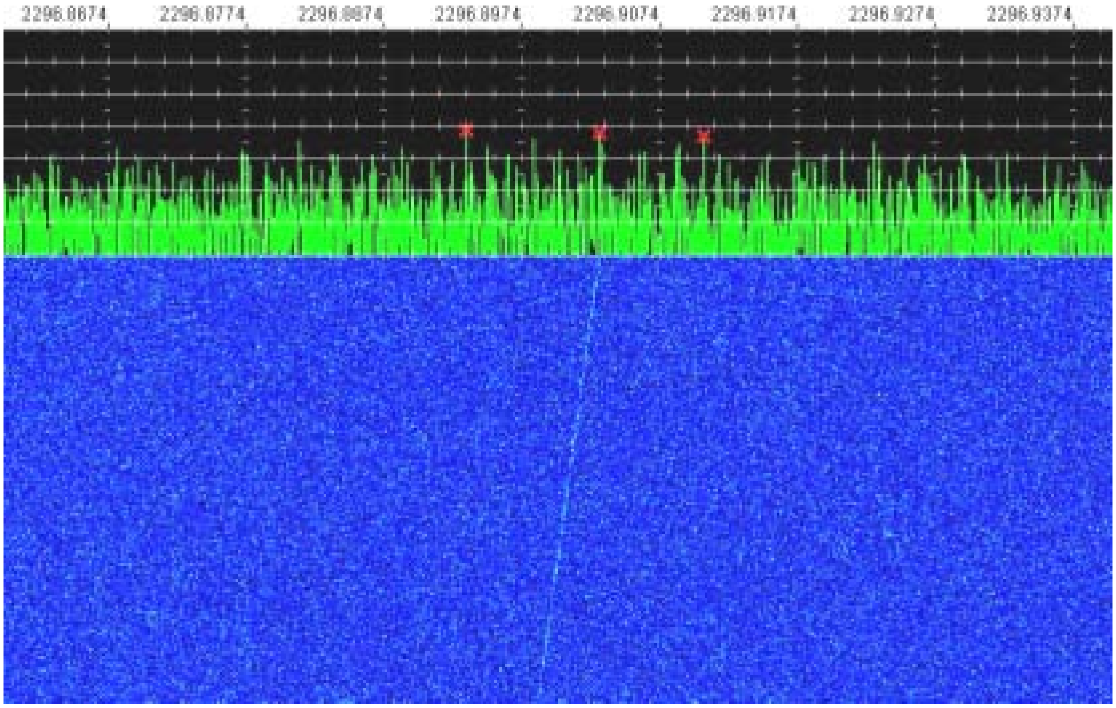
It has to be said that the recent advances in software defined receivers (SDR) has helped weak signal enthusiasts no end. This is certainly the case for deep space monitoring, as there can be some ambiguity in the downlink frequencies, and the ability to see 10's of KHz of RF means that signals can be found providing you are tuned near to the actual downlink frequency. Here at the M0EYT Earth Station, a combination of SDR and digital signal processing software is used. The SDR's are from RF-Space and display up to a maximum RF bandwidth of 4MHz, although most of the time it is sufficient to look at 100KHz to 150KHz when searching for downlinks.

SDR-14 Software Defined Receiver (Credit: RF-Space)

The hardware SDR is connected to the 10.7MHZ IF output of the AR5000 receiver; this is used to display a maximum bandwidth of 4MHz around the frequency of interest. The audio output from the receiver is then processed with ‘Spectran’ which will be familiar to most weak signal enthusiasts.

Taking an example using the Rosetta space-craft which has both S-Band and X-Band transmitters, the S-Band downlink was detected as the space-craft approached Earth for a gravity assisted swing which accelerated Rosetta back out into space. The S-Band signals are generally a lot weaker due to being transmitted from low gain, omni-directional antennas aboard the space-craft. Their purpose being that should the space-craft loose its high gain Earth pointing antenna and communications link, then no matter what the orientation of the space-craft is, S-Band commands can be sent to try and correct the attitude and re-establish Earth pointing of the high gain antenna.

The spectrum analyser screenshot below of the Rosetta S-Band signal was made with an RF-Space SDR-14 connected to the AOR AR5000 IF output. The weak signal with Doppler shift can clearly be seen above the background noise. The Doppler shift here is caused due to the space-craft accelerating towards the Earth in preparation for the gravity assisted swing.



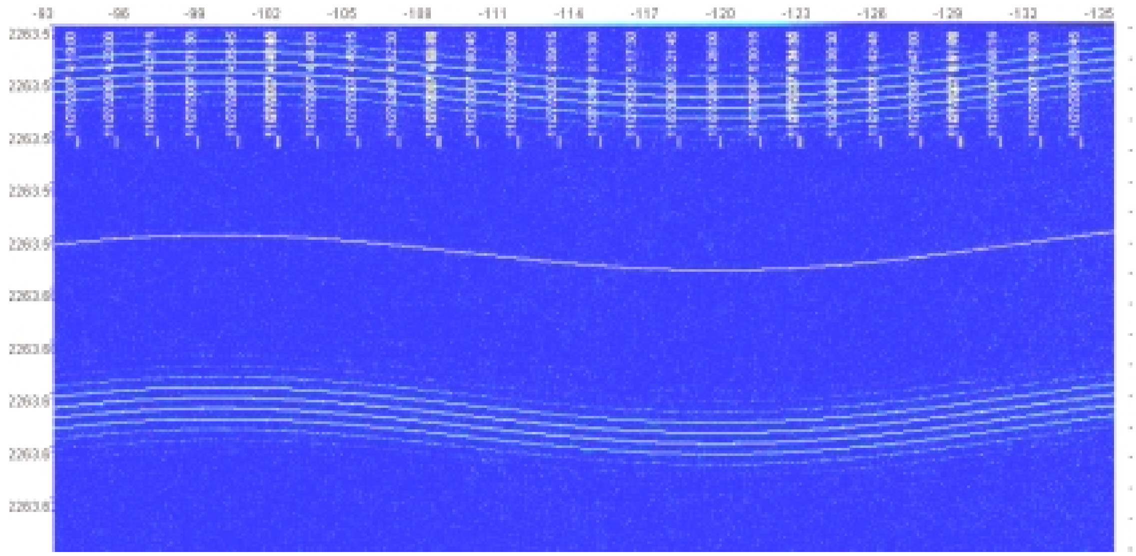
Rosetta S-Band downlink during Earth fly-by. (SDR-14 waterfall)

S-Band downlink frequencies.

S-Band signals from lunar orbiters satellites include;

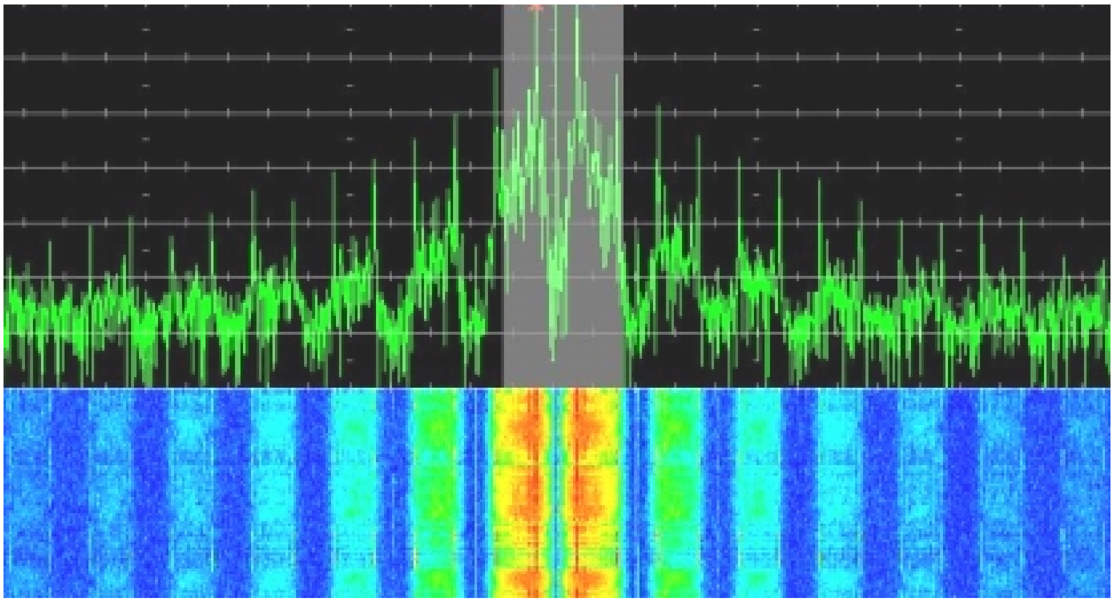
Frequency	Cat #	Satellite Name
2212.000	32054	KAGUYA R-Satellite
2212.000	32054	KAGUYA VRAD-Satellite
2218.000	32054	KAGUYA R-Satellite
2218.000	32054	KAGUYA VRAD-Satellite
2234.533	32274	Chang'e'1 Chinese Lunar Orbiter - not always transmitting
2241.579	32054	KAGUYA R-Satellite
2260.416	32054	KAGUYA R-Satellite
2260.416	32054	KAGUYA VRAD-Satellite
2263.602	32054	KAGUYA Lunar Orbiter main spacecraft downlink – Very strong
2287.313	32054	KAGUYA R-Satellite
2287.313	32054	KAGUYA VRAD-Satellite

The signals from the KAGUYA Lunar Orbiter are loud on even a small antenna. Michael Fletcher OH2AUE from Finland reported hearing the signal using a paper-clip as an antenna! The Lunar Orbiters act as a system sanity check that you can use to ensure your system is optimised before trying some other targets. A huge number of S-Band satellites have been catalogued and appear online at http://www.uhf-satcom.com/sband/



FFT Plot showing KAGUYA Lunar Orbiter Doppler shift during its orbit.

Another suitable target for testing the amateur S-Band deep space ground station is the ACE space-craft which sits at the L1 libration point which is around 930,000 miles from both the Earth and the Sun. From this point, the ACE space-craft observes the Sun and sends a continuous data stream back to Earth. ACE transmits on 2278.377MHz and can be found by pointing your tracking dish at the Sun, and then doing a spiral search up to around 5 degrees off axis.



ACE S-Band downlink signal as received using a 40ft dish. (SDR-14 waterfall)

X-Band receive system

X-Band DSN is the band between 8400MHz and 8450MHz. The band is divided up into 34 channels, starting at 8400.061729MHz and finishing at 8446.234570. Amateur DSN systems operating at X-Band cannot match the performance of the NASA and ESA ground stations, but some interesting experiments can still be performed, and weak signals are pretty much guaranteed. As with the S-Band section, each area of the X-Band system will be addressed.

Dish antenna

Since we're operating at a higher frequency, more tracking accuracy is required. Typical EME systems operating on the upper microwave bands will already have suitably accurate tracking, and where this is not already in place, manual tracking can give good results. For X-Band DSN, a minimum dish size of 4ft to 6ft is recommended, but again, the bigger the dish, the more gain, and the better the signals. Having said that, it can be advantageous having a smaller antenna in some situations. For example, when the STEREO-A and B space-craft were launched, the tracking information was not sufficiently up to date to enable sub degree tracking accuracy, and many DSN stations with larger antennas could not detect signals. Smaller antennas with their wider beam widths were able to find these signals and communicate the frequency and position information to others in the Amateur deep space network.

Considering the professional tracking networks at NASA and the ESA typically have antenna gains around 70dB at X-Band, the amateur DSN station can do fairly well, and it should be possible to receive signals from at least a dozen space-craft, including those orbiting around Mars and Venus. Amateur DSN receive antennas are likely to be more than 20 times smaller than the NASA 70 Metre antennas.

In order to accurately point the antenna, we'll first assume that you have an antenna which is calibrated with either a digital readout for azimuth or elevation, or some other method of accurately positioning it. The antenna in use at M0EYT is positioned manually, and has a 360degree compass rose for the azimuth, and a digital spirit level, or parts of, is used for the elevation feedback.

To get accurate pointing data, the JPL Horizons on-line ephemeris generator is used, which can be accessed online at http://ssd.jpl.nasa.gov/horizons.cgi

The important parameters to input are the observer location, i.e. the lat/long of the antenna, the time span – 10 minute steps covering a 24 hour period is sufficient. The table settings with parameters 4, 20 and 21 will give you the details you need to calculate the Doppler offset and the dish pointing azimuth and elevation. The target body refers to the object you want to track, popular ones being;

```
[-82] Cassini Spacecraft
[-130] Hayabusa Spacecraft [Muses-C]
[-41] Mars Express Spacecraft [MEX] (select Mars)
[-53] Mars Odyssey Spacecraft (select Mars)
[-74] Mars Reconnaissance Orbiter Spacecraft [MRO] (select Mars)
[-98] New Horizons Spacecraft
[-226] Rosetta
[-234] STEREO-A Spacecraft [AHEAD]
[-235] STEREO-B Spacecraft [BEHIND]
[-79] Spitzer Space Telescope
[-248] Venus Express Spacecraft [VEX] (select Venus)
```

The bracketed numbers are the JPL Horizons object identifier, and may be typed directly into the target body field. Where a space-craft is in orbit around another body, i.e. Mars, this should be selected so you end up tracking Mars. The angular difference between Mars and the space-craft is non existent when you consider the distance between Earth and Mars.

Once all parameters have been input, and checked, pressing the ‘Generate Ephemeris’ button will return a long list of parameters after a few seconds of calculation;

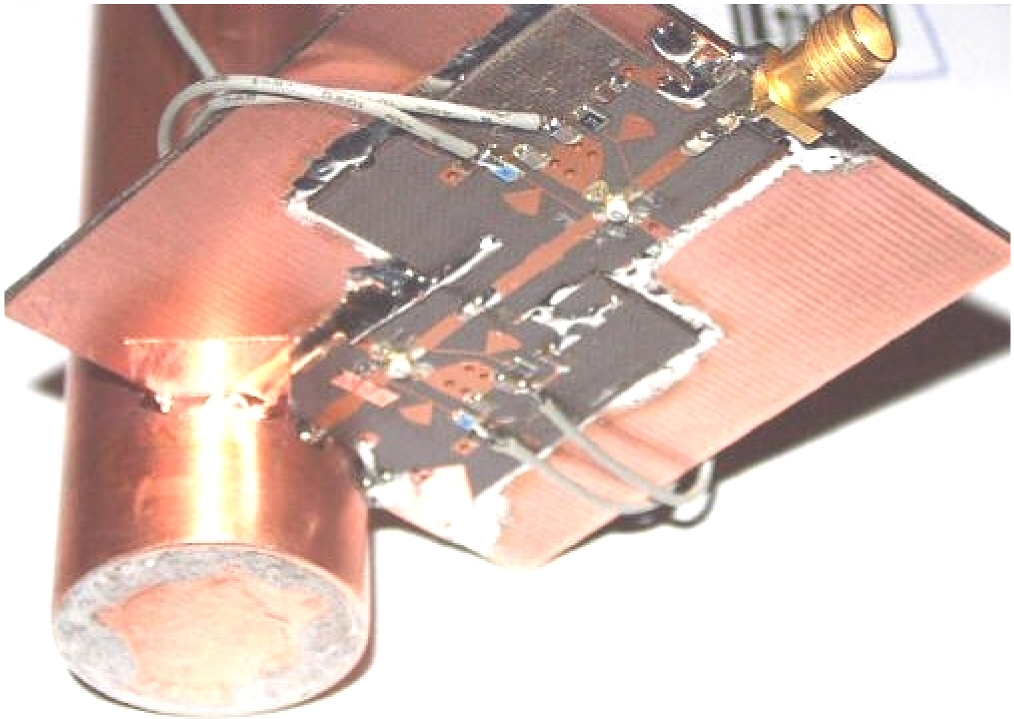
```
*******************************************************************************
 Date__(UT)__HR:MN     Azi_(a-appr)_Elev            delta      deldot   1-way_LT
*******************************************************************************
 2008-Sep-24 20:30 *m  175.8369  34.8880 2.65255403118006  20.6802822  22.060619
 2008-Sep-24 20:40 *m  178.6810  34.9867 2.65263700465997  20.6949273  22.061309
 2008-Sep-24 20:50 *t  181.5293  34.9820 2.65272003691529  20.7095859  22.062000
 2008-Sep-24 21:00 *   184.3725  34.8740 2.65280312794012  20.7242280  22.062691
 2008-Sep-24 21:10 *   187.2017  34.6632 2.65288627760805  20.7388236  22.063382
```

Most of the columns are self explanatory; ‘Azi’ and ‘Elev’ indicate the actual direction you need to point the antenna in. The ‘deldot’ column indicates the speed of the space-craft in Kilometres per second between the observer and the space-craft; this parameter is useful for calculating the Doppler offset. If the value is positive, the space-craft is heading away from Earth, if it’s negative, it’s heading towards Earth. The final column ‘1-way_LT’ is the number of minutes it takes light to travel from the object being tracked back to Earth. This is used to calculate the distance away from Earth that the object currently is. Taking the above table as an example, Rosetta would be 246,211,920 miles from Earth, not bad DX!

Low noise amplifier.

X-Band LNA’s can be sourced directly off the shelf or built. Probably the most well known supplier for off the shelf DSN equipment is Kuhne Electronics based out of Germany. They sell a ready to go X-Band LNA with a super specification, the ‘KU LNA 8000 A’ offers around 0.7dB NF with 24dB of gain, and a waveguide input. Losses at the input to the LNA must be kept to the absolute minimum; some of the signals are a lot weaker than your average EME signal. It is also possible to roll your own X-Band LNA. It does need some patience but good results are possible. Here at the M0EYT Earth Station, a surplus Ku-Band satellite TV LNA board was modified and produces good results, perhaps not quite so low noise as the Kuhne Electronics solution, but certainly good enough to receive most of the reasonably close space-probes.

A photograph of the home-built LNA is shown below. This particular LNA has a noise figure of just under 1dB and a gain of 22dB. The input is circular waveguide (copper water pipe) and the first stage of the LNA is directly coupled to the probe in the waveguide.

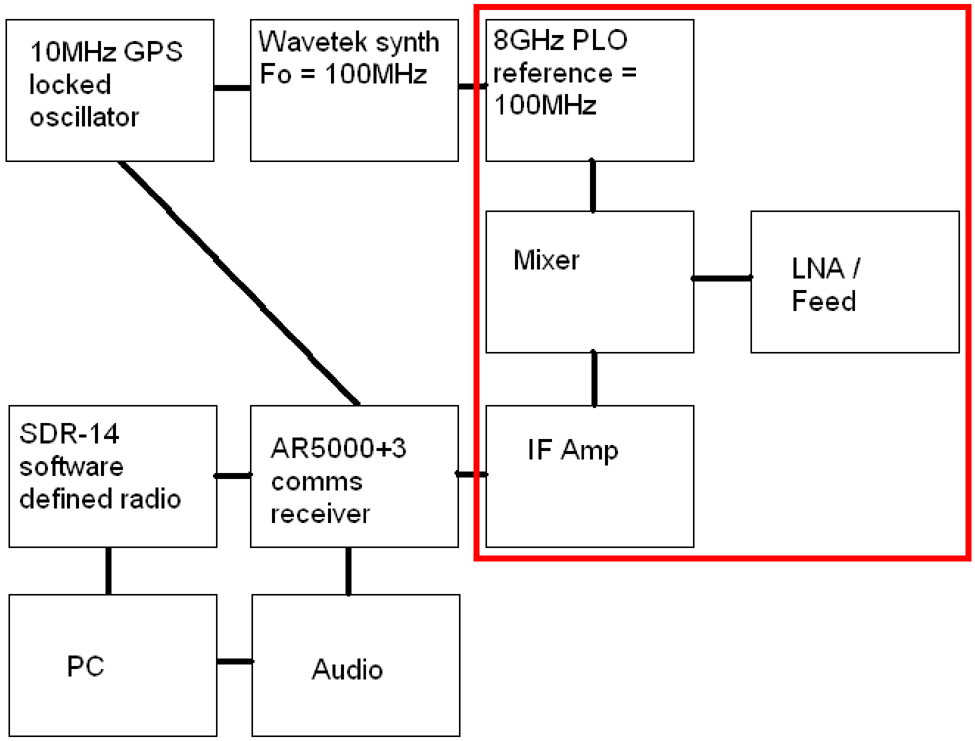


The first LNA’s in use at M0EYT were fairly poor in terms of performance, with around 3dB to 4dB NF, yet signals were easily copied from Venus Express and the Mars Reconnaissance orbiter during their cruise phases. If you have equipment to measure and optimise the noise figure you can build a good LNA. A tip heard many years ago regarding noise figure optimisation stated “Spend no more than 1 hour optimising the NF”, simply because weeks could be wasted to squeeze that extra 0.05dB NF out of an LNA, and this time could be better spent optimising other parts of the receive system.

As well as the LNA, a method of converting the incoming circular polarized signal to linear polarity is also required. There are several methods of performing this polarization conversion, the most popular being to use a dielectric plate as is done often for C-Band television services. Other methods include the ‘squeezed pipe’ depolarizer and the septum feed, although there have been some reports indicating that the septum may not give optimum performance.

Receivers / Down Converters

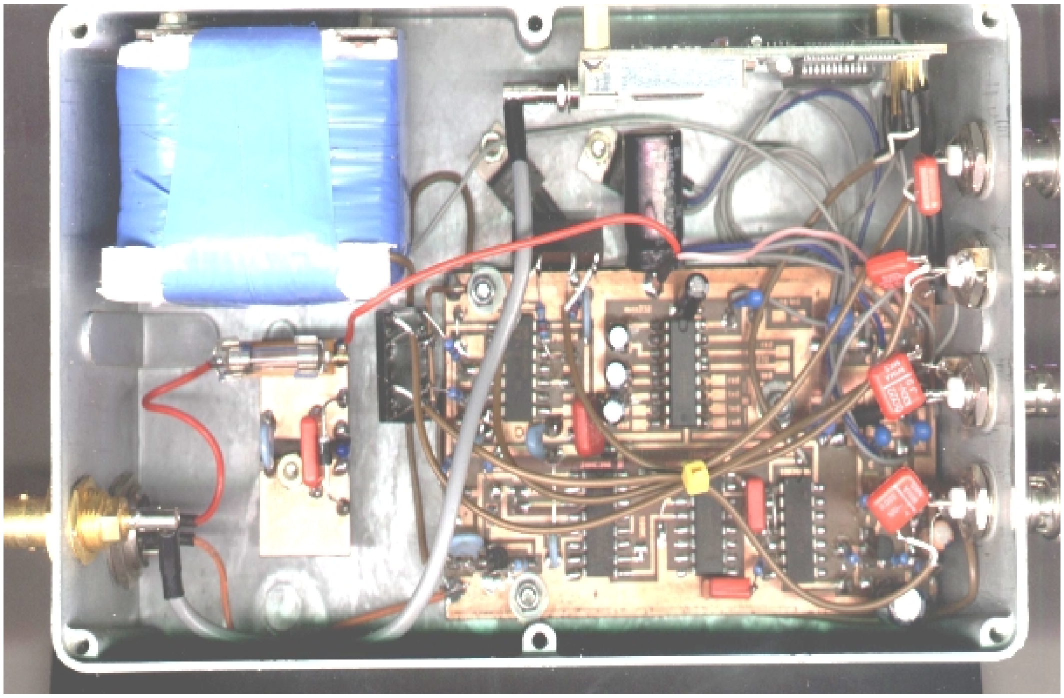
Finding a stable, narrow-band SSB receiver that will work directly at 8400MHz is fairly difficult, if not impossible, so the 8400MHz signal is generally down converted to a lower frequency IF. The frequency of IF depends largely on how the down converter is designed, but can vary between a few tens of MHz and 1300MHz. Off the shelf down converters such as that available from Kuhne Electronics have an IF output from 850MHz to 1300MHz but cover an extended input of 8000MHz to 8450MHz. This particular device uses a local oscillator at 7150MHz.



M0EYT first generation X-Band down converter block diagram

When building your own down converter, the most straight forward method is to find an oscillator module running near 8000MHz that can be locked to an external frequency reference.

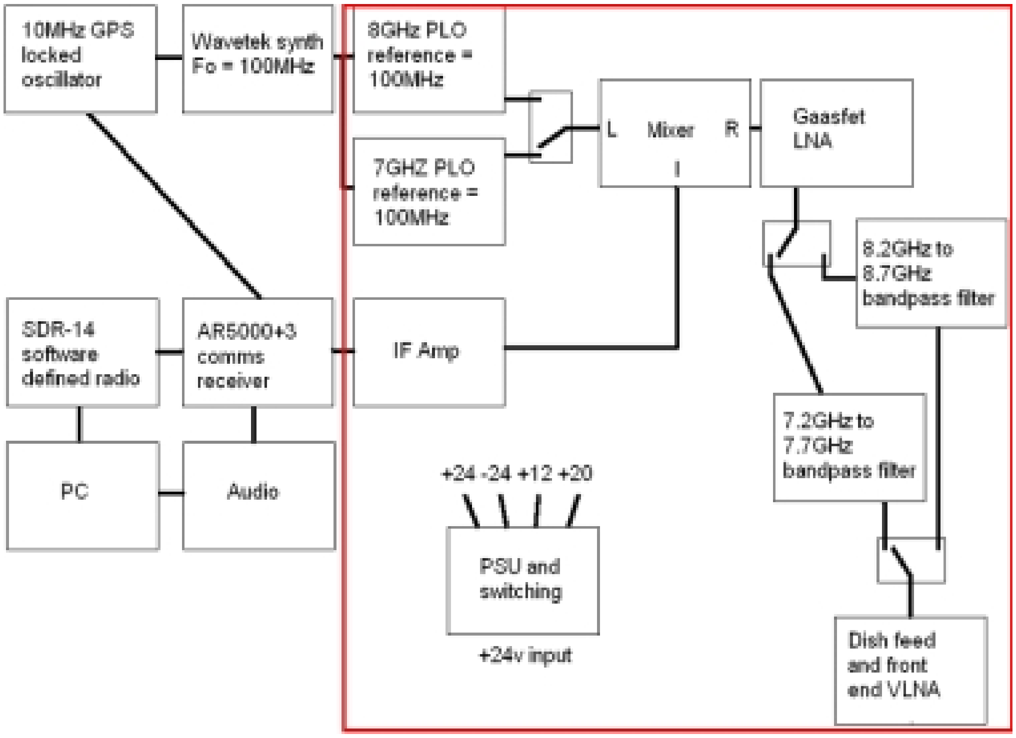
Whilst on the subject of frequency references, it is important that the local oscillator is stable and on a known frequency. Since most of the signals will be at just above the noise floor, it's very important to be able to accurately tune to a frequency, and know that you are receiving it within a few hundred Hertz. Most Amateur DSN systems generate their local oscillator frequencies by locking to a station frequency standard. This can be either a 10MHz Rubidium oscillator, or more likely, a GPS locked 10MHz oscillator. In the USA, there are a fair number of the HP Z3801 GPS locked frequency standards, and these make excellent station references. For those that prefer the home brew approach, there are numerous GPS disciplined oscillator designs from folks such as James Miller G3RUH, Andy Talbot G4JNT and Bertrand Zauhar VE2ZAZ.


An example of a G4JNT GPS disciplined 10MHz oscillator

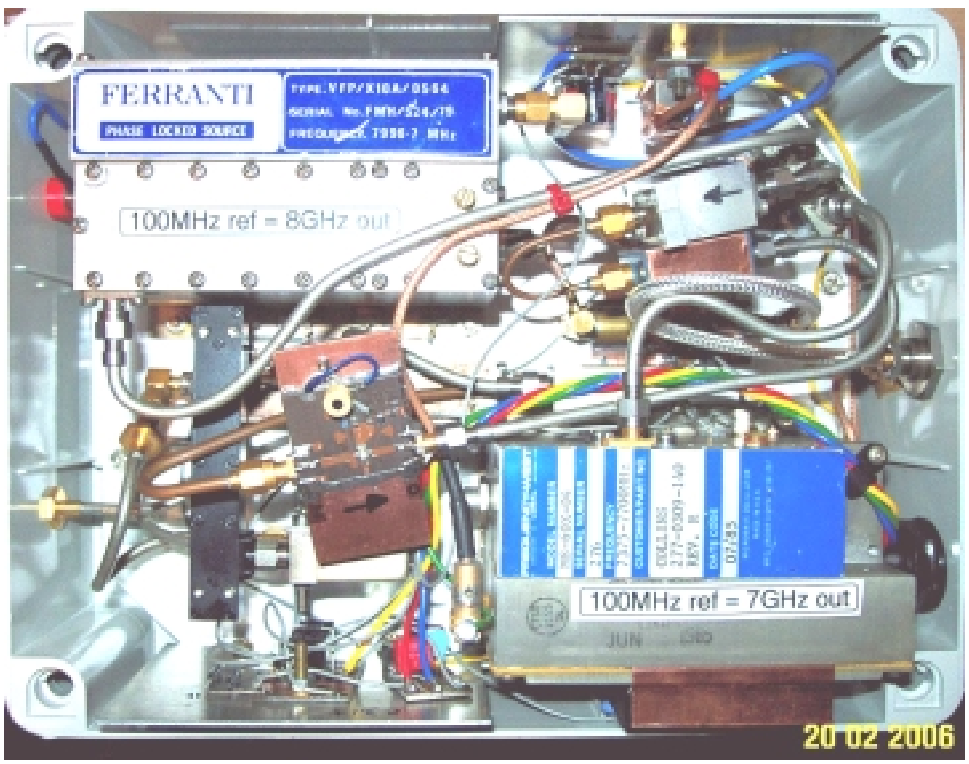
As mentioned, the common 8000MHz oscillator modules are those from Frequency-West, Continental-Microwave, Thompson, etc. Most of these modules use an internal crystal reference running at around 100MHz. In order to generate the accurate 8000.000000MHz signal that we need for our local oscillator, the easiest method is to take the 10MHz station reference, multiply that up to 100MHz, feed this to the 8000MHz oscillator module, and we then have a super accurate local oscillator for use in the down converter.

In addition to the local oscillator, a suitable microwave mixer is required that can operate up to 8500MHz, with an IF of around 400MHz. An IF amplifier connected directly to the mixer will raise the signal level suitable for transfer down coax to your communications receiver. When building the down converter, it may be worth considering adding another oscillator to allow for the reception of 7500MHz signals which are emitted from many geostationary satellites. This can be useful for feed optimisation and alignment, as well as for sanity checking the azimuth and elevation pointing methods in use. As an aside, the signals around 7500MHz are usually huge thereby making reception very easy.

A simple method of converting the 7500MHz segment down to IF is to make use of high side mixing using the 8000MHz local oscillator, using this method requires the use of suitable switchable filters to cover either 8400MHz to 8450MHz or 7250MHz to 7750MHz.



M0EYT 'production build' X-Band down converter.



Hardware inside the X-Band down converter.

As previously mentioned in the S-Band section, it's important to have a receiver that is stable. Since the AR5000 has the facility of being frequency locked to an external reference, it can be connected to the same 10MHz reference that drives the 8000MHz local oscillator in the down converter.

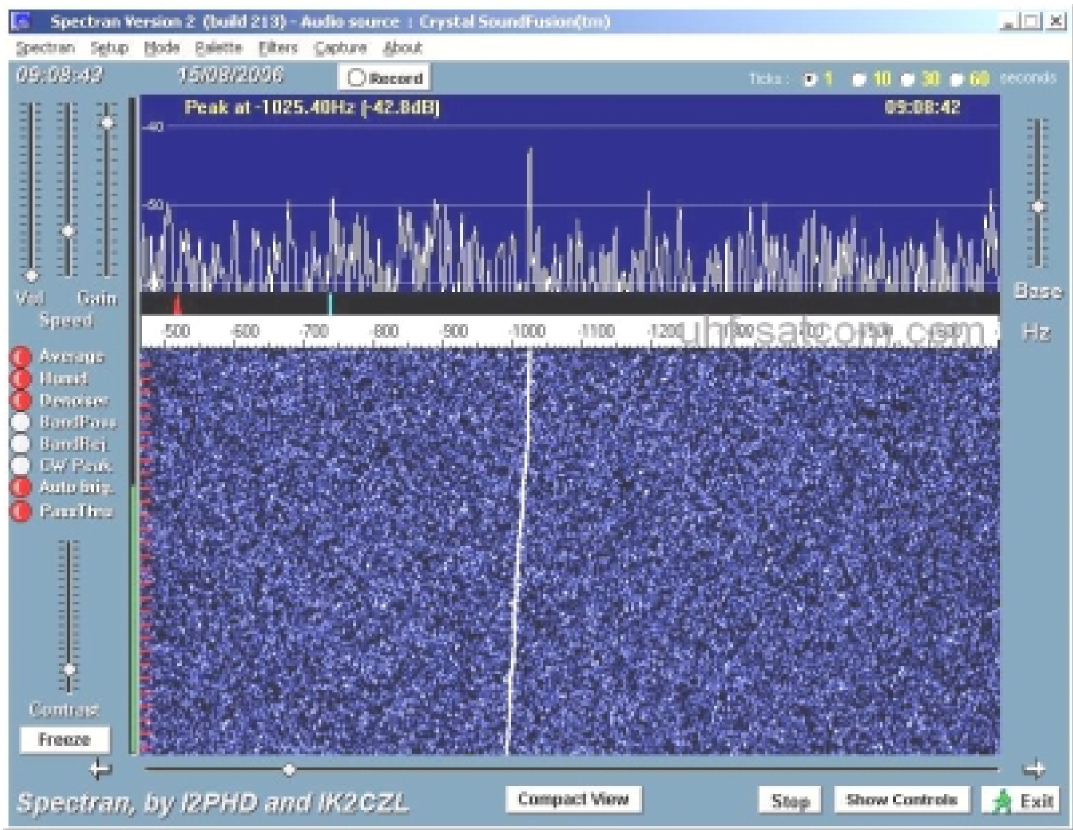
X-Band downlink frequencies.

DSN tracking spreadsheet by Paul M0EYT **Mission Name / JPL Horizons ID**	**Spacecraft TX frequency (MHz)**	**Velocity (KM/s)**	**Doppler corrected (MHz)**	**Tuning Freq (MHz)**
Last updated	**8400.061729**	0.000000	8400.061729	
28/08/2008 18:58	**8401.419752**	0.000000	8401.419752	
Phoenix Lander http://phoenix.lpl.arizona.edu/	**8402.777700**	5.543651	8402.622319	8402.614319
Mars Odyssey -53 (Mars 499)	**8406.851853**	1.552799	8406.808309	
Hayabasu -130 / Ulysees -55	**8408.209877**	-6.715989	8408.398239	
Pioneer -24 / -23	**8410.925927**	0.000000	8410.925927	
Pioneer -24 / -23	**8412.283950**	0.000000	8412.283950	
Spitzer space telescope -79	**8413.626490**	0.026333	8413.625751	
Voyager -31-32 / Stardust -29	**8415.000000**	18.851122	8414.470860	
Venus Exp -248 (Venus 299)	**8419.074073**	-6.131067	8419.246252	8419.251252
Mars Exp -41 (Mars 499) / Voyager -31 -32	**8420.432097**	1.552799	8420.388483	8420.311483
Rosetta -226	**8421.790123**	9.606914	8421.520245	8421.517245
Kepler http://kepler.nasa.gov/	**8423.331100**	0.000000	8423.331100	
MGS (Mars 499)	**8423.177000**	1.552799	8423.133371	
Kepler http://kepler.nasa.gov/	**8424.506175**	0.000000	8424.506175	
Magellan	**8425.864198**	0.000000	8425.864198	
Mars Pathfinder / Cassini	**8427.222221**	23.301314	8426.567217	
Giotto -78	**8428.580248**	0.000000	8428.580248	
Mars Pathfinder / Cassini	**8429.938271**	18.885481	8429.407225	
Mercury Messenger -236	**8432.654321**	6.924454	8432.459548	
DAWN http://dawn.jpl.nasa.gov/	**8435.370372**	3.600319	8435.269069	
New Horizons noncoherent -98	**8437.894737**	34.217271	8436.931665	
NEAR -93	**8438.086418**	0.000000	8438.086418	
New Horizons coherent -98	**8438.181818**	34.217271	8437.218713	
New Horizons coherent (new) -98	**8438.243000**	34.217271	8437.279888	
Mars RO -74 (Mars 499)	**8439.444446**	1.552799	8439.400733	
STEREO A -234	**8443.518520**	1.818612	8443.467300	8443.472600
STEREO B -235	**8446.234570**	0.865834	8446.210176	8446.202876

The chart above shows the currently known X-Band downlink frequencies for space-craft. The online version of this spread-sheet is available at http://www.uhf-satcom.com/DSN.xls and can be modified with current space-craft velocity information in order to get the tuning frequencies.

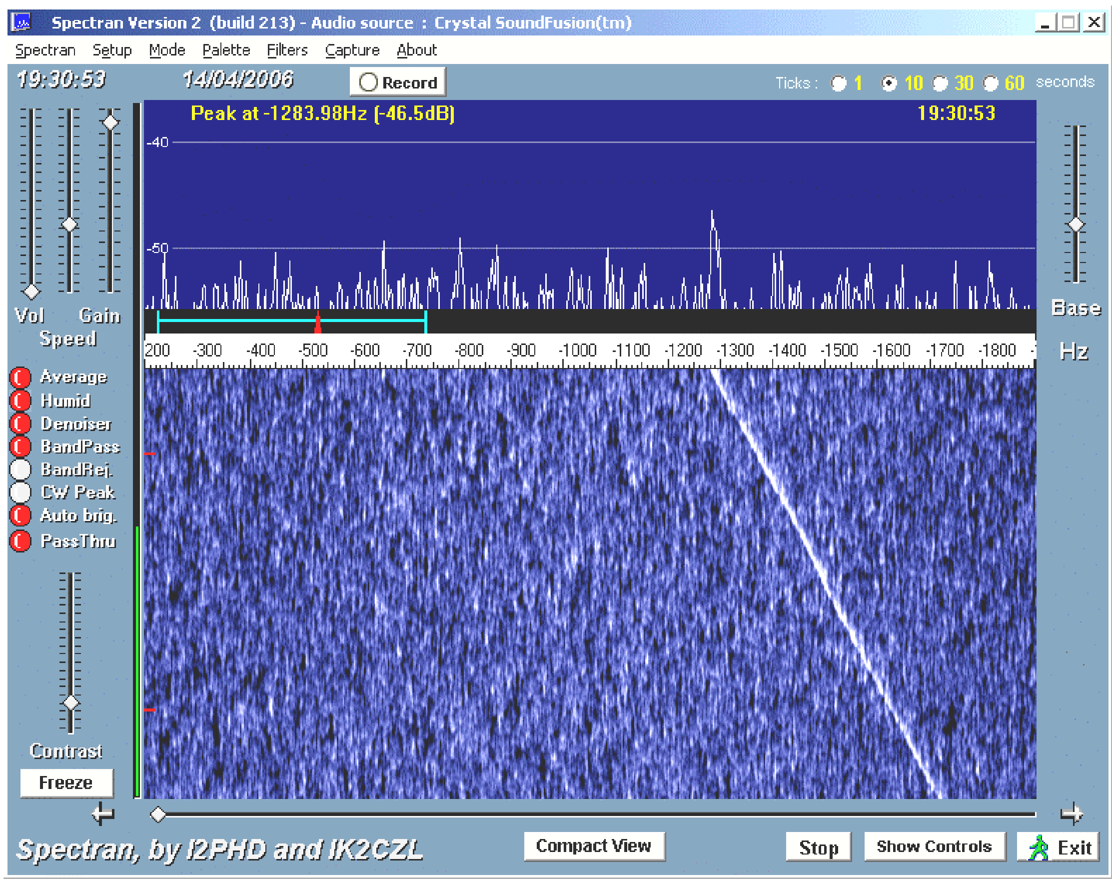
X-Band deep space reception examples.

Smart-1: 250000~ miles away 8453.024225 MHz.
RF: Horn antenna with +9dBm ERP at 8453.024225 MHz



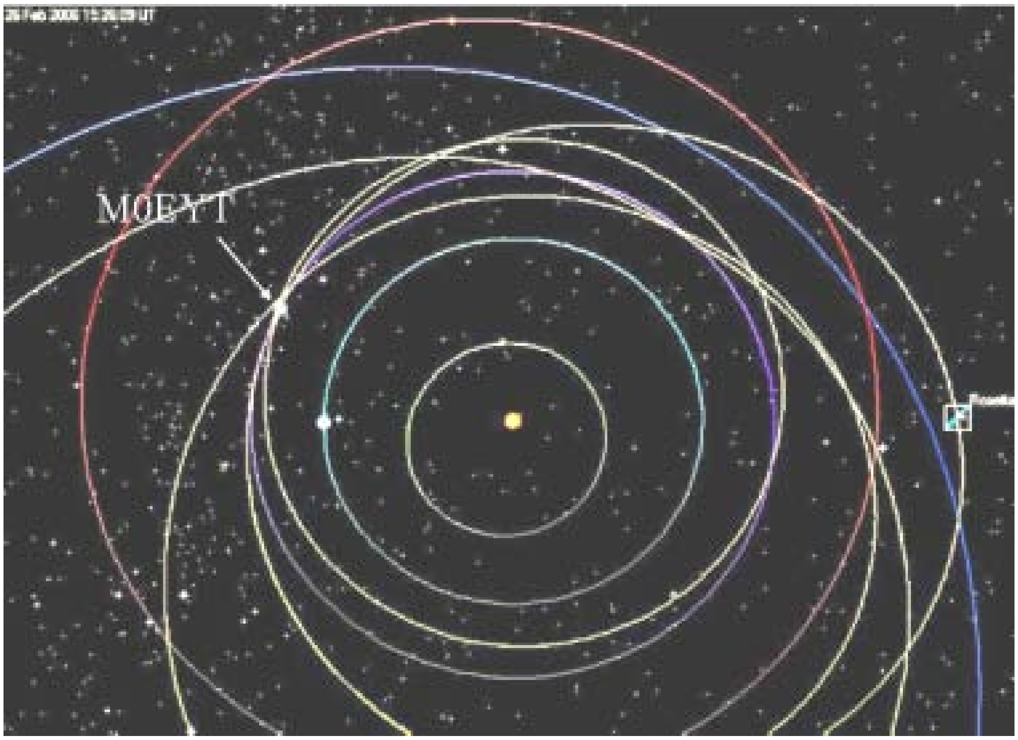
Smart-1 transmit antennas – X-band is a horn antenna with <10mW of RF ERP
(Credit: Swedish Space Corporation)

Mars Global Surveyor: ~180 Million miles away 8417.716050 MHz
RF: HGA is 1.5M with 25 watts of @ 8417.716050 MHz & 8423.148147 MHz, ERP: 199526 watts. Mission ended prematurely due to a software failure.

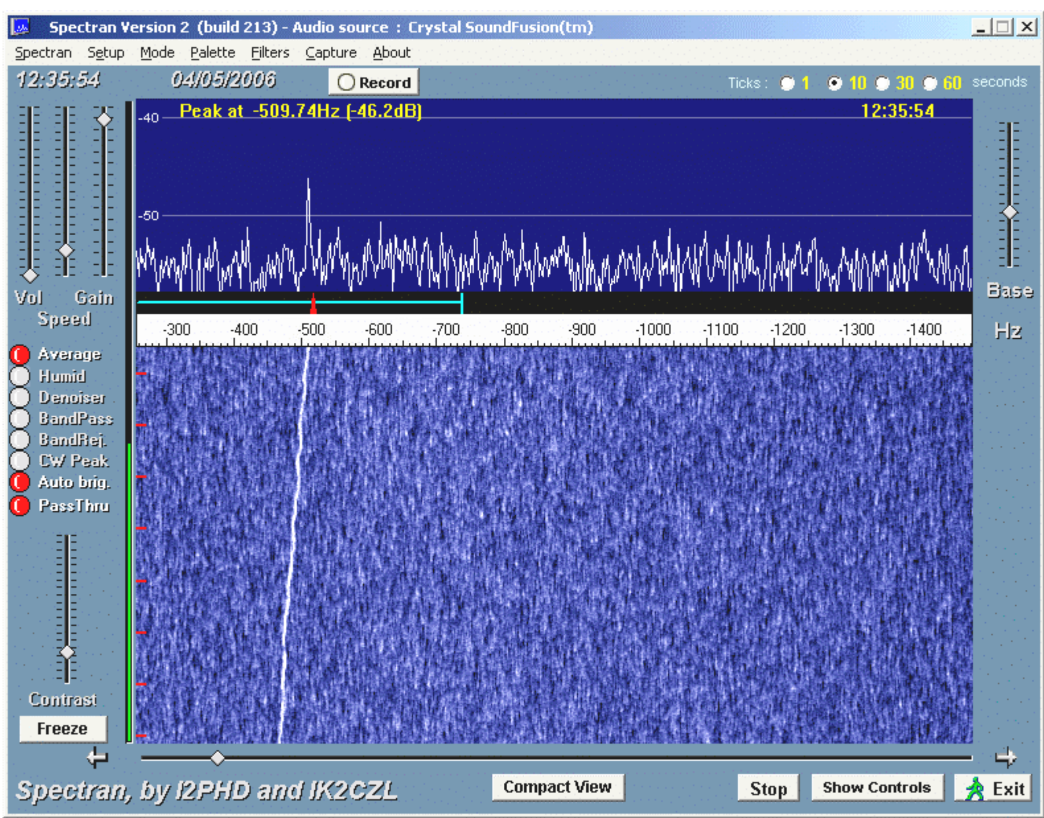


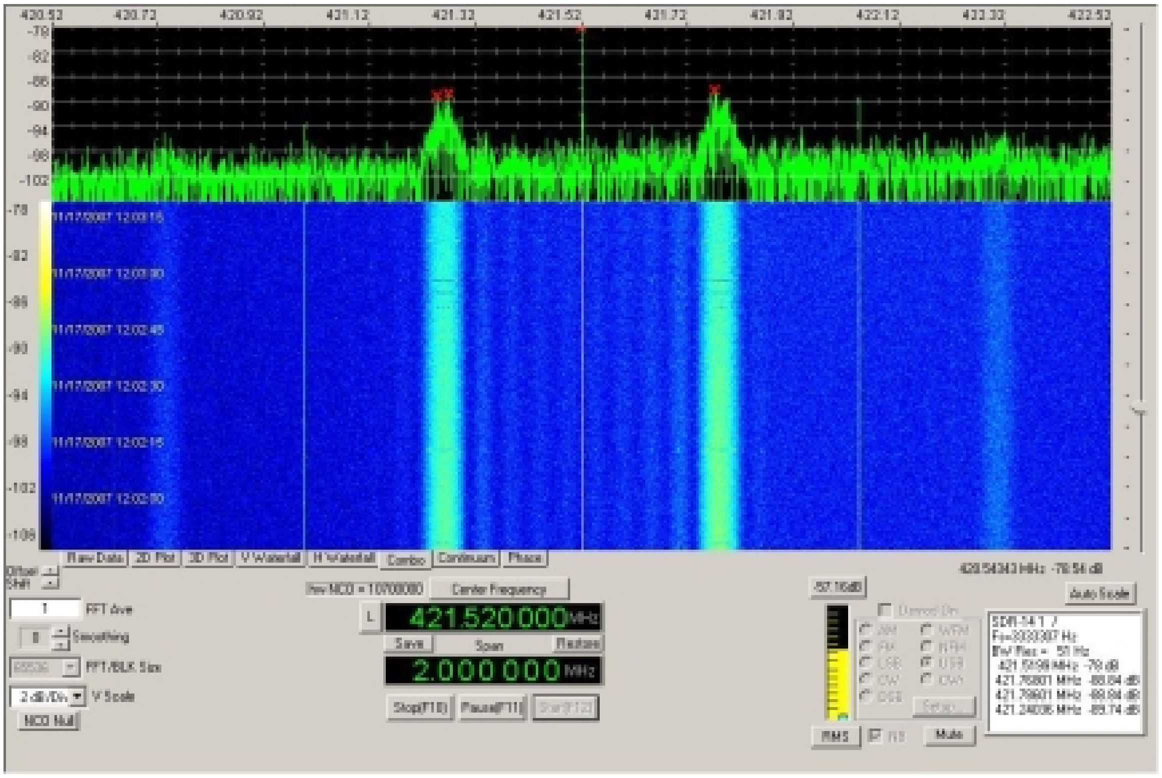
The Spectran FFT display shows a high rate of Doppler shift on the signal caused by the space-craft orbiting around Mars. The signal was loud enough to be copy able in head phones.

Rosetta: ~233 Million miles away 8421.790123 MHz
RF: HGA is 2.2M with 28 watts of power at 8421.790123 MHz, ERP: 467735 watts



An idea of perspective – Rosetta's location. (Credit: NASA)





RF-Space SDR-14 FFT spectrum plot of the Rosetta Earth fly-by (8421.520MHz)

The Future of Amateur Deep Space Reception

As can be seen, Amateur DSN does have a reasonable amount to offer the weak signal enthusiast, but what of the future? An interesting development in Deep Space communications that will open new technical challenges for radio amateurs is the introduction of Ka band downlinks operating around 25GHz and 32GHz. These bands will require the development or modification of existing 24GHz amateur band equipment and new equipment for 32GHz. With the higher frequencies come greater dish pointing accuracy requirements.

Advances in low noise FET amplifiers will assist the Amateur DSN station with pulling even weaker signals out of space, and DSP processing will help resolve continually weaker signals.

References

The Amateur DSN yahoo-group at http://groups.yahoo.com/group/amateur-DSN is an ideal way to pose questions about any aspect of building or operating a DSN station.

http://www.uhf-satcom.com/DSN.xls has the DSN tracking spreadsheet for calculating tuning frequencies for the majority of receivable space-craft.

http://www.rfspace.com/ - Software Defined Receivers including the SDR-14 and SDR-IQ both of which are tried and tested for Amateur DSN purposes.

http://digilander.libero.it/i2phd/ - Spectran FFT display software which is of great help resolving very weak signals.

http://www.kuhne-electronic.de – DB6NT microwave equipment provides off the shelf X-Band down converters and LNA’s of the highest quality.

http://www.jrmiller.demon.co.uk – G3RUH GPS disciplined 10MHz oscillator

http://www.scrbg.org/g4jnt - G4JNT GPS disciplined 10MHz oscillator

http://ve2zaz.net/ - VE2ZAZ A Simplified GPS-Derived Frequency Standard

http://www.ssb.de/ and http://www.btinternet.com/~jewell/ - S-Band LNA’s

http://www.uhf-satcom.com/dsnspace/ - DSN space-craft overview

http://www.kolumbus.fi/michael.fletcher/kaguya.htm - Paper-clip S-Band antenna

http://www.hearsat.org – useful resource for satellite monitoring enthusiasts

<u>Handheld FM Satellite Stations – Meeting FCC Part 97.1 With A Superb Tool For Recruiting New Operators</u>

By Timothy J. Lilley – N3TL
AMSAT Member No. 36820
Athens, Georgia, USA
October 2008

Abstract: Several times a day, American amateur radio operators are using low-cost handheld stations to demonstrate the entirety of FCC Part 97.1, which defines the fundamental purpose of the amateur radio service. These handheld stations are superb tools for use in recruiting new licensed amateurs – especially young people – and, as such, should be at the forefront of efforts to promote amateur radio to the public.

<u>Introduction</u>

There currently are three amateur radio satellites in Low Earth Orbit (LEO) equipped to permit crossband operation using Narrow-band FM. Working these satellites with a handheld station (HHS) provides many benefits to an amateur operator, and all of them are enhanced by the fun and excitement of making contacts in orbit! No licensed amateur should trivialize the remarkable feat that dozens of hams achieve on every pass – they make contact with fellow hams by transmitting a VHF, narrow-band FM signal several hundred km above Earth to a tiny LEO satellite. Each of these satellites – AO-27, AO-51 and SO-50 – serves as a crossband repeater, capturing those 2 meter VHF signals and retransmitting them in the 70 cm UHF band using very low power. This VHF-up/UHF-down crossband operation is designated Mode J.

Satellite	Dimensions	Weight	Apogee	Perigee	Uplink	Downlink	Launched
AO-27	15cm Cube	11.80 Kg	800 Km	789 Km	145.850 MHz	436.795 MHz	26 Sept., 1993
AO-51	24cm Cube	11.14 Kg	818 Km	696 Km	*145.920 MHz	*435.300 MHz	28 June, 2004
SO-50	35cm Cube	10.00 Kg	713 Km	603 Km	**145.850 MHz	436.795 MHz	20 Dec., 2002

* Alternate frequency pair of 145.880 MHz Up and 435.150 MHz Down sometimes operational.

** **CTCSS** Tone of 67.0 Hz required at transmit.

Sources: **www.amsat.org, www.spacequest.com and "Getting Started With Amateur Satellites," by G. Gould Smith, WA4SXM.**

The relatively low cost of building a consistently effective HHS is just as remarkable and significant as the achievement of making contacts in orbit. Notwithstanding the many opportunities to experiment with simple homebrew antennas for HHS operation, a newly licensed amateur who might not feel ready to experiment with antenna design and construction can pick up everything necessary to get an effective HHS on the air for ***less*** than the cost of an Xbox 360 game console and a handful of games to play on it.

The process of preparing for and effectively participating in a pass of any Mode-J satellite calls for HHS operators to develop and use skills that specifically address the fundamental purpose and basis for the U.S. amateur radio service, as outlined in FCC Part 97.1. In the process, they are further refining the talents and skills necessary to provide the most effective communications possible in emergency and other public-service situations.

For these reasons, I believe that handheld satellite stations can and should be key components of efforts to recruit new amateur operators, young and old. The excitement of making contacts in orbit cannot be overstated. Successful HHS contacts with operators across North America and, depending upon location and the footprint of a given LEO-satellite pass, portions of Central and South America (and even western Europe for amateurs in the northeastern U.S. and eastern Canada) will reward and strongly reinforce the investments of time and money necessary to earn an amateur license and get on the air.

The Handheld Satellite Station (HHS)

For the purposes of this report and my accompanying presentation during the 2008 AMSAT-NA Symposium, I define a handheld satellite station (HHS) as a single dual-band handheld radio capable of at least semi-duplex operation and a single handheld antenna. The radio and antenna must accommodate Narrow-band FM transmission on the 2 Meter frequencies noted in the table above and reception of Narrow-band FM on the 70 cm frequencies noted in that table.

As I write this paper, Alinco, Icom, Kenwood and Yaesu all have handheld radios in their current lines that offer at least semi-duplex, crossband operation, which permits Mode-J satellite contacts. The only currently available handheld radio I have used is a Yaesu VX-7R, which is the example featured in this paper. It is not intended as a recommendation of Yaesu or the VX-7R over any other currently available handheld. It simply is the current-model radio I own. Since becoming active on the Mode-J FM satellites, I have purchased a used Icom W32A HT, a discontinued model that offers full-duplex crossband operation. I believe it is important to note that, while full duplex is not essential to effective HHS satellite operation, it is recommended because full duplex reduces multiple/simultaneous transmissions (i.e., operators can avoid "stepping on each other" when trying to make contacts) and a blank downlink. I hope the major manufacturers will consider adding full-duplex-capable models to their current and future lines of VHF/UHF dual-band handheld radios.

The QSL for N3TL satellite contacts includes a photo of my first HHS.

The most popular and high-performance commercially available antenna for HHS satellite contacts is the Arrow 10 WBP, a dual-band yagi with a 10-watt-maximum duplexer that features three elements for 2 meters and seven elements for 70 cm. With elements made from aluminum arrow shafts (thus, the brand name!) and a two-part boom, the Arrow can be assembled and disassembled in a couple of minutes. That being said, there are times and situations when the Arrow might not be preferred for HHS use. In those cases, there are smaller, more convenient options. The Pryme AL800 is a telescoping whip antenna that I have used as part of my HHS for a series of contacts through SO-50 and AO-27. The MFJ 1715 and 1717 are "duck" antennas that also provide useful service as HHS antennas. I learned of the AL800 and the MFJ ducks from AMSAT member Allen F. Mattis, N5AFV. He has an extensive report on his use of the AL800 on his Web site, www.qsl.net/n5afv/. Performance loss when using a whip instead of the Arrow or a similar, homebrew design occurs most notably on the receive side, based on my experiences with all three antennas.

As a licensed amateur, my interest in experimentation and homebrew projects has focused primarily on antennas – especially those that permit consistent operation in portable/emergency situations. When it comes to HHS antennas, operators have a wealth of information and designs available from the Internet. Typing the phrase "Homebrew LEO Satellite Antenna" into a Google search window produced more than 2,000 listings! Here are a couple of links to get you started:

http://www.qsl.net/vk3jed/2m70cmant1html.html

http://members.aol.com/k5oe/

http://www.wa5vjb.com/references/Cheap%20Antennas-LEOs.pdf

It is imperative that *every* amateur satellite station include the most sensitive receiving system an operator can assemble. Amateurs who are new to the satellites must account for the very-low-power signals they are trying to capture from LEO. I like to use SO-50 as my example because it transmits a quarter-watt into a quarter-wave (i.e., 0-gain) antenna mounted on one of its corners. I have worked many passes when stations that are loud, clear and strong into the satellite obviously are not receiving nearly as effectively as they are transmitting. The antennas mentioned in this paper will provide HHS operators with the ability to effectively receive satellite signals. However, that should not keep any amateur from doing everything possible to optimize reception.

Antenna polarization also will affect reception, and it can (and usually does) change during the course of one satellite pass. The HHS antennas featured in this paper are linear-polarized. The Arrow dual-bander provides a 3-element 2 Meter yagi and a 7-element 70 cm yagi mounted at a 90-degree angle to each other on one boom. The AL800 and MFJ duck antennas are verticals. HHS operators will discover quickly that even small changes in these antennas' orientation can make big improvements in reception quality. Anyone interested in learning more about polarization should check out this Web site:

http://www.analyzemath.com/antenna_tutorials/antenna_polarization.html

There have been passes when I have rotated my Arrow antenna through a 90-degree arc to maintain optimum signal quality from AOS to LOS. Making slight adjustments in antenna orientation quickly and easily (i.e., with a slight twist of the wrist) can make the difference in completing a contact.

Earlier, in the introduction, I stated that it was possible to "pick up everything necessary to get an effective HHS on the air for ***less*** than the cost of an Xbox 360 game console and a handful of games to play on it." That statement is based on using one of two radios – an Icom IC-T7H or a Yaesu FT-60R – with a Pryme AL800 whip antenna. I have seen the radios advertised on the Web for $175 and $185, respectively. I bought my AL800 whip for $34.95. That's roughly $210 and $220, plus tax, for either of those radios and the AL800 antenna. As this paper is being written, the lowest advertised retail price I could find for the xBox 360 game console was $299.99. It is possible to buy the IC-T7H and a new Arrow handheld yagi for about the same money as that xBox.

Handheld Satellite Stations and FCC Part 97

FCC Part 97.3-(4) defines the Amateur Service as – *"A radio communication service for the purpose of self-training, intercommunication and technical investigations carried out by amateurs, that is, duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest."*

FCC Part 97.3-(3) defines the Amateur-Satellite Service as – *"A radiocommunications service using stations on Earth satellites for the same purpose as those of the amateur service."*

Before defining what the Amateur Service and its subset, the Amateur-Satellite Service, are, FCC Part 97.1 presents the five principles the U.S. Federal Communications Commission has adopted as the elements of the fundamental purpose of the Amateur Radio Service in America. As noted in this paper's Introduction, I believe that licensed operators using handheld stations for satellite contacts on AO-27, AO-51 and SO-50 are specifically addressing each of those principles every time they activate their stations.

Principle: FCC Part 97.1(a) – *"Recognition and enhancement of the value of the amateur service to the public as a voluntary noncommercial communication service, particularly with respect to providing emergency communications."*

HHS Application: Throughout the 1980s and early 1990s, I served as a member of the Amateur Communications Team that worked with the Johnson County (Kansas) Emergency Operations Department. Serving both as a certified storm spotter in the field, and also as a net control operator, I had an opportunity to learn about and apply the skills necessary for effective, timely communication in an emergency situation. In the field and from the net control chair in the county's Emergency Operations Center, I learned quickly that amateurs who choose to get involved in emergency communications must be able to transmit pertinent information quickly and clearly. Those in the field also must be able to receive information from net control accurately – preferably without the need for repetition.

I dare say that few non-emergency amateur radio situations help operators hone the skills described above like HHS operation. Even though the LEO provides a relatively small geographic "footprint" during a given satellite pass, that footprint still opens communications to a large part of North America. Southern portions of passes also put HHS operators within range of stations in Central and South America. As a result, there are many operators using stations of all kinds trying to access the same satellite for contacts, some even DX. That fact creates opportunities for skills improvement on every pass.

Operators often must deal with conditions that sound as chaotic as any HF DX pileup I have ever heard or tried to work. Successful contacts happen when HHS operators are able to communicate clearly and quickly – not only because they are among many other stations competing for contacts, but also because the operating window for a given pass rarely exceeds 10-12 minutes for the HHS. My experiences suggest that, even in the best of cases, HHS operators will generally acquire the satellite at around 3-4 degrees elevation, and lose the satellite at about the same elevation on the other side of the pass. There are always exceptions, of course, but day-to-day HHS operation rarely will get to even 3-4 degrees. From my home QTH, I have learned that effective contacts require an elevation of at least 8 degrees. I have logged and recorded (via digital recorder) a contact with Clint Bradford, K6LCS, when AO-51 was at 4.1 degrees to my west/northwest. This is a tribute to the effectiveness of the HHS because Clint was in a Tarzana, California, parking lot doing a demo using his HHS. That two-way HHS contact is a great illustration of the potential for HHS operation.

In addition, all operators who attempt satellite contacts must learn about and account for the Doppler Effect in real time. Because of Doppler, the received frequency is higher than the transmitted frequency when a receiver and transmitter are approaching each other. When they are departing from each other, the received frequency is lower. At some point during each satellite pass, the receiver and transmitter are neither moving toward nor away from each other, so there is no Doppler shift. At the uplink frequencies on 2 meters, the Doppler range is lower than the 5kHz bandpass, so HHS operators do not have to adjust their transmit frequency. They do, however, have to retune their receivers during every pass to account for Doppler. Operators who are new to working AO-27, AO-51 and SO-50 should start listening for each satellite at 10 kHz above its listed receive frequency. As a pass unfolds, they should expect to tune down in 5 kHz increments when signal quality begins to deteriorate. By LOS, they will be listening 10 kHz below the satellite's listed receive frequency.

Richard Hackney, N1ASA (SK), wrote a clear and concise explanation of the Doppler Effect, including examples of how Doppler affects the receive frequencies of AO-51 and SO-50, in "'Down-to-Earth' Satellite Communications," which is available online here:

http://www.wku.edu/ksgc/sats.pdf

Clint, K6LCS, also has a great HHS tutorial online at:

http://www.clintbradford.com

Amateurs who choose the HHS for their satellite work inevitably will become better operators, and their improved skills will pay big dividends in any public service/ emergency situation.

Principle: FCC Part 97.1 (b) – *"Continuation and extension of the amateur's proven ability to contribute to the advancement of the radio art."*

HHS Application: This is the critical principle as it relates to using a HHS to introduce amateur radio to the public and newcomers, and to recruiting new licensed operators of any age. For the purposes of this discussion, I will expand the concept of "contributions to advancement" beyond just the "radio art" specified by the FCC.

My decision to begin working the FM LEO satellites with a HHS required more than just finding the frequencies I needed for crossband operation and assembling my Arrow handheld yagi. I had to learn how to find and track the satellites as they moved across the sky, and I had to learn the information necessary to provide my location during contacts. In preparing for my first few HHS satellite passes, I discovered a number of exercises that will expose newcomers to more than just amateur radio. These exercises will definitely help anyone contribute to advancement of more than just radio art because they will expose newcomers to concepts and activities that will expand their knowledge.

I learned quickly that I needed to know my precise location so I could accurately provide it as a maidenhead grid square. I used my handheld GPS unit to find the coordinates of my home QTH, then used grid square calculators on the American Radio Relay League (ARRL) and AMSAT-NA Web sites to confirm my grid square. That proved important because online "lookup" sites, including QRZ and Hamcall, listed me in a different grid square based on my zip code. It turns out that I operate my HHS from just slightly north of the EM83/EM84 boundary, in EM84. I updated my listings at QRZ and Hamcall to reflect this.

Use a GPS reading to determine your maidenhead grid square

I also used my coordinates to generate schedules of the FM LEO satellites on the AMSAT Web site. Later, I added tracking software to the home computer for this purpose, but that step is not necessary for HHS operators who are just starting out. They can get the information they need online from AMSAT, as I did. Those schedules provide the overall duration of a pass, Acquisition-of-Signal (AOS) time and azimuth position, maximum elevation and azimuth position, and Loss-of-Signal (LOS) time and azimuth position.

When I generated my first schedule for AO-51, something clicked. I realized immediately that any new HHS operator had a way to practice and refine the ability to follow the tiny FM LEO satellites as they track across the sky several hundred kilometers overhead. The schedule I printed looked very similar to the one I had been printing for years from the Heavens Above Web site for visible passes of the International Space Station (ISS). Having marveled literally hundreds of times at the silver-white dot racing silently across the night sky above me, I realized that all of those ISS passes were practice for tracking AO-27, AO-51 and SO-50.

I quickly located the orienteering compass that I'd had for more than 30 years. In the days before GPS, a compass like this one and a map helped everyone who spent time outdoors navigate in the wilderness and keep track of their positions. I use it now to get my bearings for and visualize every satellite pass I work with my HHS. I note landmarks that coincide with the azimuths for AOS, maximum elevation and LOS. I then use the markings on the compass to get an eyeball reference on maximum elevation. Having these reference points makes it quick and easy to visualize how the satellite will track as the pass unfolds. This approach has proven itself time and time again as a great way to pick up the satellite quickly and stay on it from AOS to LOS.

Compass, GPS and HHS – everything any operator needs to make HHS satellite contacts anywhere.

Many amateurs around the world are using home stations with wonderfully complex and effective antenna systems that feature azimuth and elevation rotator systems connected to a computer in the shack. They use software like SatPC to not only control the rotators and track the satellites, but also to automatically and accurately tune their radios to account for the Doppler Shift during a pass. I will suggest here that HHS operators develop a more personal understanding of the tracking principles involved, and one that will serve them well in an emergency situation. Finding and reporting their precise location becomes second nature. Finding the bearings they need to point a directional antenna toward net control also becomes second nature.

The very fundamentals of HHS operation require amateurs to not only contribute to the advancement of the radio art, but also to contribute to the art of quickly and accurately finding and reporting their locations, and to using the skills necessary to generate the most effective signals possible.

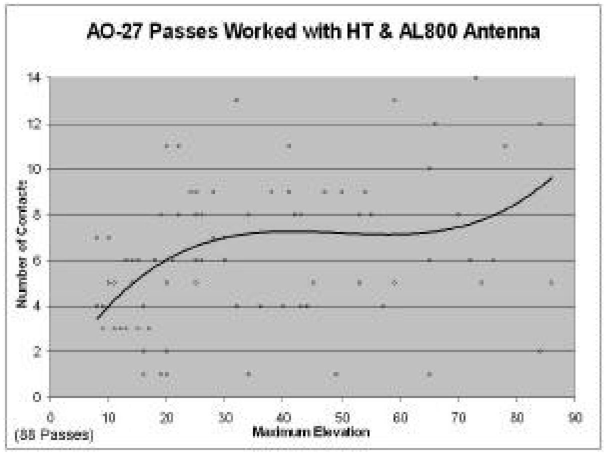
Principle: FCC Part 97.1 (c) – *"Encouragement and improvement of the amateur service through rules which provide for advancing skills in both the communication and technical phases of the art."*

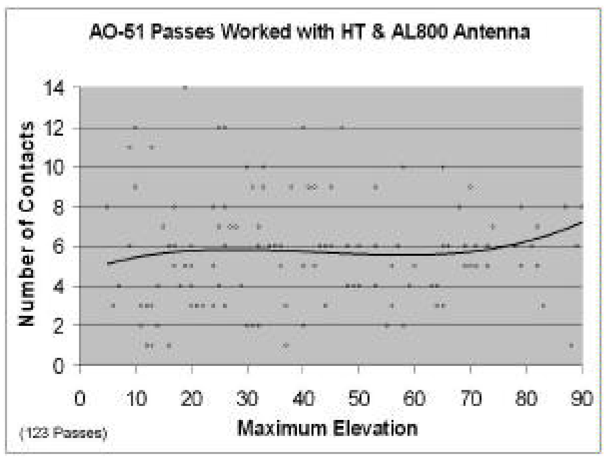
HHS Application: Much of what appears in the last section arguably could be included here. Instead, I choose to focus in this section on two concepts that speak directly to advancing communication and technical skills. The first is HHS operation with very compact antennas. The second is HHS operation using very low power.

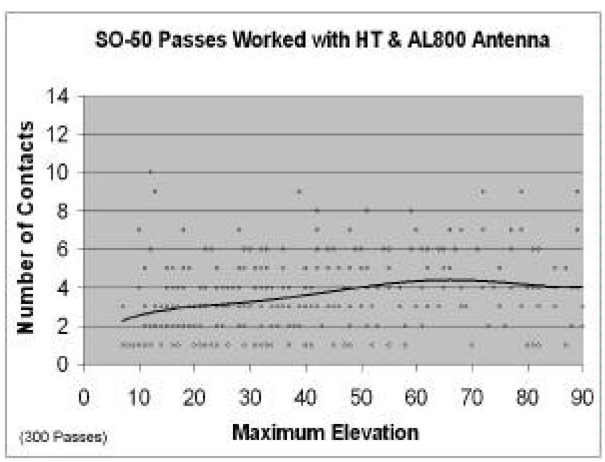
Telescoping-Whip-Antennas for HHS Operation: Allen F. Mattis, N5AFV, has made more than 9,000 HHS contacts on the LEO FM satellites using a handheld transceiver with a Pryme AL800 telescoping whip antenna. Allen has generated significant data on whip-antenna performance in his HHS operation, and it is available on his Web site – www.qsl.net/n5afv/.

N5AFV with his 9,000+ contact HHS. *Photo courtesy N5AFV*

Allen's ongoing research and HHS operation using only a whip antenna is a great example of the ways HHS operators are improving their abilities to prepare for emergency communications by learning the most effective ways to use a whip antenna in HHS satellite operation. I encourage everyone to visit Allen's Web site to learn just how consistently effective HHS satellite work can be with nothing more than a telescoping whip. Such operation undoubtedly will help prepare any amateur to quickly establish effective communication in an emergency situation. Here are Allen's contact summaries, by satellite:



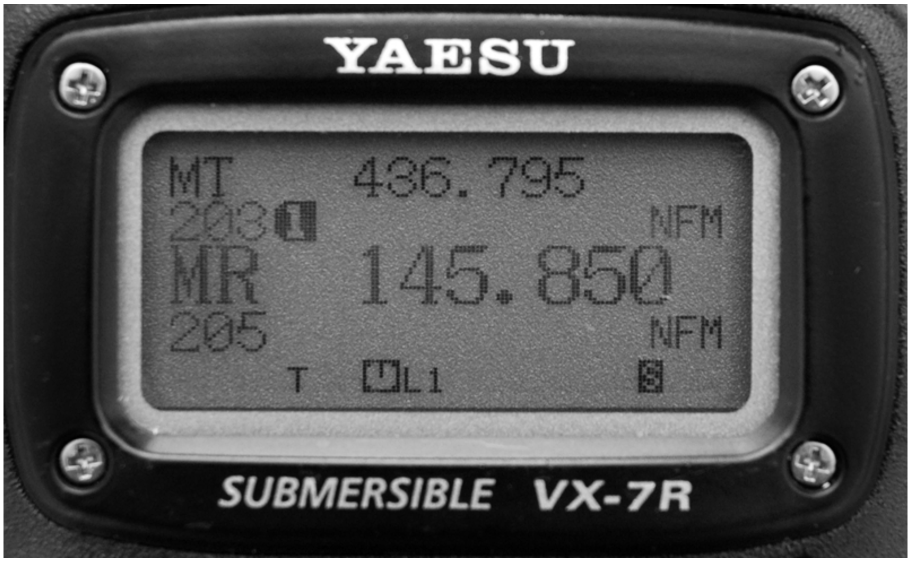




Tables courtesy N5AFV

Very Low Power for HHS Operation: Imagine the worst. Without warning, you find yourself in an emergency situation that demands communication – and all you have for power are alkaline batteries for your HT. Would you be surprised to learn that as few as two AA batteries could enable you to cover hundreds of kilometers with a VHF signal? They can, and they have for the N3TL handheld station. When I began HHS operation on the LEO

FM satellites, I began wondering how low I could go – not in elevation to hear and work a satellite, but rather in output power to reach orbit with an effective signal. That curiosity spawned the “Duracell Experiment.” Included as Appendix A is a report of the 51 satellite contacts I made using one set of two AA Duracell batteries, with the RF output on my Yaesu VX-7R set to 50 milliwatts.



Note L1 at the bottom of the display. It represents a power level of 50mW out on the VX-7R.

Even with the gain provided by the handheld yagi, my rf output was lower than SO-50’s quarter-watt RF out. I will apply for the AMSAT Satellite Communications Achievement Award using only confirmed contacts on 50 mW rf out, having worked 20 states, Ontario, Mexico and Venezuela. Here is a summary of contacts during the “Duracell Experiment,” by satellite:

SAT	CONTACTS	AVG ELEV	AVG RANGE
AO-51	32	37.878 DEG	1274.468 KM
AO-27	13	34.269 DEG	1452.774 KM
SO-50	6	30.850 DEG	1386.619 KM

FCC Part 97.1 (c) pertains to rules which provide for advancing communications and technical skills. I submit that current rules permitting newly licensed amateurs with a Technician license to begin HHS satellite operation are precisely intended to permit the kind of research Allen, N5AFV, and I have undertaken with antennas and very low power, respectively. In the process, any amateur who tries HHS operation with either or both also will improve his or her operating skills.

Principle: FCC Part 97.1 (d) – *“Expansion of the existing reservoir within the amateur radio service of trained operators, technicians and electronics experts.”*

HHS Application: HHS operation is a wonderful tool to recruit new amateur radio operators and, as a result, specifically address Part 97.1 (d). Consider:

- HHS demonstrations take very little time because of the nature of satellite passes.
- The “band **will** be open,” permitting contacts with stations within the footprint of a given pass.
- Those who are unfamiliar with amateur radio will be exposed to the ability to make contacts with stations hundreds, even thousands, of kilometers away using equipment they can hold in their hands.
- The most basic of amateur radio licenses is all it takes to get on the air and into orbit.
- The cost of a very effective handheld satellite station is relatively low – less than the cost of an xBox game system and a few games, as noted earlier.

Clint K6LCS, does a satellite demo using his HHS.
*Photo courtesy K6LCS***.**

Patrick, WD9EWK, works satellite stations during a demo at the Scottsdale, Ariz., hamfest. *Photo courtesy WD9EWK.*

I believe that any licensed operator who is interested in the growth and future of amateur radio should assemble and begin using a handheld satellite station for contacts on the FM LEO satellites. After only a few passes, any operator will have the ability to provide an educational and entertaining demonstration for any group. HHS operation on the FM LEO satellites is one of the best and most important tools we can use to expand our ranks.

Principle: FCC Part 97.1 (e) – *"Continuation and extension of the amateur's unique ability to enhance international goodwill."*

HHS Application: A vast majority of the FM LEO satellite passes I have worked provided a footprint that included portions of South America, Central America or Canada. Admittedly, this is not the same as being able to work that rare DX location on the HF bands, or even working into other parts of the world through amateur satellites in higher orbits that provide much larger footprints. However, being able to use a handheld station to make contacts with amateurs in other countries will demonstrate to anyone the international flavor of ham radio. Recently, I was talking to Rick, WA4NVM, who I first met on the FM LEO satellites. He was looking through some old QSL cards and found one from Cam, HP1AC in Panama, for a satellite contact they had in 1980. That call sounded familiar, and I began looking through my old HF QSL cards. There he was – HP1AC – confirming a QRP contact we made in 1984 on 10 meters. Rick said that he'd looked up HP1AC on the QRZ Web site and sent an email that Cam responded to. I did the same, and rekindled an acquaintance from almost 25 years ago. All of this – meeting Rick and developing a friendship with him, learning from him that HP1AC was still active, and contacting Cam after almost 25 years – happened because of my handheld satellite station. I am confident that many HHS operators have similar stories to share, and all of them relate directly to the international goodwill that is so important to all of us.

Conclusion

I am addicted to HHS operation on the three Mode-J FM LEO satellites. That addiction is providing more enjoyment for me than anything I've ever done in ham radio. It also has picqued my curiosity about using other modes (e.g., CW, SSB, digital) on other satellites. As a result, I am assembling another satellite station that will permit operation using those modes.

I have resurrected and begun to refine skills for determining my location and a given satellite's position during a pass, and for making contacts in tough conditions (e.g., many stations competing for the same contacts and/or running very low power). I have discovered a mode and style of operation that not only addresses every principle outlined in FCC Part 97.1, but also lends itself beautifully to attracting and licensing new amateurs.

None of this would have happened without AMSAT. I encourage everyone to join the organization and support its efforts to keep amateur radio alive and well in orbit! New HHS operators should consider the AMSAT Web site as the online source for everything they need to make memorable contacts in orbit on every satellite pass they work.

Visit the AMSAT Web site today: **http://www.amsat.org/**

My thanks to friends and fellow operators who reviewed this paper and provided input: Don Baughman, K7MX; Stew Haag, W4MO; John Henderson, N4NAB; Gould Smith, WA4SXM; and Rick Tillman, WA4NVM. Thanks, too, to Clint Bradford, K6LCS; Allen F, Mattis, N5AFV; and Patrick Stoddard, WD9EWK, for photos and graphics published in this paper.

Appendix A – Summary of contacts during the Duracell Experiment

CALL	STATE	GRID	DATE	UTC	SATELLITE	ELEVATION	RANGE
KD8ILL*	WV	EM99	8-Jul	20:20	AO-27	78.4 DEG	819.627 KM
KD8ILL*	WV	EM99	8-Jul	20:23	SO-50	40.9 DEG	1018.977 KM
AJ5C	AR	EM36	8-Jul	20:24	SO-50	63.9 DEG	776.516 KM
K4DLG*	FL	EL97	9-Jul	0:04	AO-51	61.8 DEG	809.878 KM
W4TEJ	FL	EL98	9-Jul	0:04	AO-51	61.8 DEG	809.878 KM
VE3DRT	ON/CA	EN93	9-Jul	0:06	AO-51	52.5 DEG	883.771 KM
WA1DX	MA	FN42	9-Jul	0:07	AO-51	35.6 DEG	1132.152 KM
WA4NVM	TN	EM55	31-Jul	0:27	AO-51	39.6 DEG	1027.258 KM
N5ZNL	MS	EM42	31-Jul	0:29	AO-51	64.0 DEG	771.270 KM
W8KHP*	KY	EM79	31-Jul	0:30	AO-51	60.4 DEG	795.206 KM
KD0AR	OH	EN90	31-Jul	0:31	AO-51	42.0 DEG	994.244 KM
WB8LZG*	MI	EN72	31-Jul	12:38	AO-51	37.1 DEG	1207.110 KM
WA4NVM	TN	EM55	31-Jul	12:39	AO-51	57.8 DEG	922.106 KM
K4DLG*	FL	EL97	31-Jul	12:39	AO-51	57.8 DEG	922.106 KM
KB3MBO*	PA	FN21	31-Jul	12:41	AO-51	57.6 DEG	924.311 KM
K5MBV	TX	EM12	31-Jul	14:18	AO-51	14.9 DEG	2027.280 KM
KG7EZ	ID	DN32	31-Jul	14:49	SO-50	12.1 DEG	2036.632 KM
K5MBV	TX	EM12	31-Jul	14:52	SO-50	32.0 DEG	1183.810 KM
WA4NVM	TN	EM55	31-Jul	19:12	AO-27	20.2 DEG	1758.633 KM
KD8ILL*	WV	EM99	31-Jul	19:13	AO-27	26.2 DEG	1516.076 KM
W0SAT	IA	EN32	31-Jul	19:16	AO-27	31.9 DEG	1341.185 KM
WB2OQQ	NY	FN30	31-Jul	19:16	AO-27	31.9 DEG	1341.185 KM
KE5SR	TX	EL29	31-Jul	20:54	AO-27	25.1 DEG	1555.883 KM
YY6KWD	VZ/SA	FJ78	31-Jul	23:48	AO-51	36.2 DEG	1093.280 KM
WX8J	OH	EM89	1-Aug	12:00	AO-51	23.0 DEG	1638.277 KM
W4TEJ	FL	EL98	1-Aug	12:02	AO-51	22.8 DEG	1651.725 KM
W0TUP	ND	DN98	1-Aug	13:38	AO-51	31.0 DEG	1358.062 KM
WB9L	IN	EN61	1-Aug	13:40	AO-51	35.3 DEG	1255.504 KM
ND9M*	FL	EM70	1-Aug	13:42	AO-51	27.7 DEG	1470.268 KM
K5MBV	TX	EM12	1-Aug	13:43	AO-51	21.1 DEG	1729.322 KM
WA4NVM	TN	EM55	1-Aug	23:13	AO-51	15.2 DEG	1844.702 KM
WB9L	IN	EN61	1-Aug	23:13	AO-51	15.2 DEG	1844.702 KM

K0KN	KS	EM28	2-Aug	0:49	AO-51	37.1 DEG	1078.224 KM
W8KHP*	KY	EM79	2-Aug	0:51	AO-51	31.8 DEG	1198.746 KM
WA4NVM	TN	EM55	2-Aug	0:52	AO-51	24.0 DEG	1439.439 KM
WA4NVM	TN	EM55	2-Aug	3:51	SO-50	20.5 DEG	1530.982 KM
ND9M*	FL	EM70	2-Aug	12:59	AO-51	57.9 DEG	923.458 KM
WA5NVM	TN	EM55	2-Aug	14:38	AO-51	8.9 DEG	2450.183 KM
KC9ELU	IN	EM79	2-Aug	14:40	AO-51	8.6 DEG	2482.003 KM
KD0AR	OH	EN90	3-Aug	0:09	AO-51	70.9 DEG	740.738 KM
WB9L	IN	EN61	3-Aug	0:10	AO-51	78.8 DEG	717.516 KM
WA4NVM	TN	EM55	3-Aug	0:11	AO-51	67.1 DEG	760.209 KM
W1AW	CT	FN31	3-Aug	13:58	AO-51	20.6 DEG	1740.135 KM
XE1AO	MX/CA	DK89	3-Aug	14:42	SO-50	15.7 DEG	1772.798 KM
WA4NVM	TN	EM55	3-Aug	19:31	AO-27	42.0 DEG	1120.866 KM
KI4YZI*	AL	EM63	3-Aug	19:32	AO-27	33.1 DEG	1309.628 KM
WA2S*	NJ	FN20	3-Aug	19:32	AO-27	33.1 DEG	1309.628 KM
KB1JAE	NY	FN03	3-Aug	19:33	AO-27	24.1 DEG	1592.870 KM
WB9L	IN	EN61	3-Aug	19:33	AO-27	24.1 DEG	1592.870 KM
WA8SME	CT	FN31	5-Aug	18:32	AO-27	11.6 DEG	2251.175 KM
K4DLG*	FL	EL97	6-Aug	19:44	AO-27	63.8 DEG	876.440 KM

** Two-way HHS contact*

NOTE: Contacts are groups by satellite pass

Summary

SAT	CONTACTS	AVG ELEV	AVG RANGE
AO-51	**32**	**37.878 DEG**	**1274.468 KM**
AO-27	**13**	**34.269 DEG**	**1452.774 KM**
SO-50	**6**	**30.850 DEG**	**1386.619 KM**

Appendix B – Glossary of Terms

The following is not intended to be all-inclusive, but rather to highlight some of the terms used in this paper that amateurs encounter regularly in working satellites.

Terms related to finding and tracking satellites on a given pass

- **AOS –** Acquisition of Signal. The point (usually expressed in time and azimuth position) that a satellite rises above the horizon in reference to an operator's location.
- **Maximum Elevation –** The point during a pass [usually expressed in time, azimuth position and degrees (from 0 to 90)] at which a satellite has reached its highest point above the horizon in reference to an operator's location.
- **LOS –** Loss of Signal. The point (usually expressed in time and azimuth position) that a satellite descends below the horizon in reference to an operator's location.
- **Doppler Effect –** The shift in received frequency caused by a satellite's movement across the sky during a pass. From AOS to Maximum Elevation, the received frequency will drop from about 10 kHz above the center receive frequency to that center frequency. From Maximum Elevation to LOS, the frequency will drop from the center receive frequency to about 10 kHz below that frequency.

Other satellite-related terms

- **AMSAT –** A nonprofit volunteer organization that designs, builds and operates experimental satellites and promotes space education. The organization works in partnership with government, industry, educational institutions and fellow Amateur Radio societies. AMSAT encourages technical and scientific innovation, and it promotes the training and development of skilled satellite and ground system designers and operators.
- **Crossband –** A mode of operation in which operators transmit on frequencies in one amateur band and receive on frequencies on a higher or lower amateur band (e.g., transmitting on 2 meters and receiving on 70 cm).
- **Full Duplex –** A mode of crossband operation in which the receive frequency is not muted during transmission.
- **Mode J –** One of several transmit/receive configurations used in amateur satellite operation. Mode J features a VHF uplink in the 2 Meter amateur band and a UHF downlink in the 70 cm amateur band.
- **Polarization –** The orientation of the electric field generated by a radio transmission. Amateurs working satellites will encounter three types of polarization – Linear, Left Hand Circular and Right Hand Circular. HHS operators generally will be dealing with linear polarization at their stations. A good example of linear polarization is the field generated by a vertical antenna, which radiates at a 90-degree angle away from the antenna. The angle of that antenna's mounting will determine the angle of radiation, or polarization, of the signal and the antenna.
- **Semi-Duplex –** A mode of crossband operation in which the receiver is muted during transmission.
- **UTC –** Universal Time, usually reported in 24-hour format. UTC also is known as Greenwich Mean Time (GMT).

Modeling Robot Control for AO-51 Satellite Follower

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Abstract

Our universities have developed some projects related with ham activities, one of them is AO-51 follower, and this project is composed for many steps to complete all system: antenna design, pre amplifier signal, handy radio, mechanisms and control. For antenna support we design a simple two axis robots that are connected to control system located on embedded card with microcontroller assistance for sensor and actuators. Our main effort is over control of close loop system integrated for motor and encoder link, traditionally use PID technical to solve this problem, but we have knowledge of all positions over a specific referential place, for this reason, fuzzy logic is considerate to be evaluated in this paper. Other steps of all system models are used based in previously designed equipments and integrate them. Another important point is to consider the embedded hardware and software technology to design and improve one modern controlled applied to satellite follower. Additionally, the use of formal design of fuzzy sets and rules are evaluated here

Keynote words: *Mobile robotic, fuzzy logic, digital design, communications and embedded systems.*

1. Introduction

In our country, currently, there are many enthusiasts radio operators of satellite systems of manual procedure satellite detection; they use traditional software platforms that are used to locate every pass in one day. One point detected to make a research of fitness control of these parameters to detect a specific position of antenna is necessary. Our principal interest is to communicate with weather satellite image, but in first instance in this project work with FM voice satellite repeater [1, 2]. For this purpose, we used some prepared parts to use them, for example, the embedded Yagi antenna for VHF/UHF, designed by Alvaro XE2AT, UHF pre-amplifier and handy dual band transceiver. Some works related with fuzzy controllers design are used as reference to decide our algorithm; some references are depicted in [3, 4, 5]. For hardware for controller design we consider a specific embedded card JRex-PM as central processor with two auxiliary microcontrollers as interface with power and mechanical elements to control our robot with two axes. In next sections more specific information is depicted to explain how is currently working this controlled model and their connection with robot. In the first part an introduction is present about satellite followers, in the second part graph bond electromechanical system is presented to know how mobile robot is composed; third part is dedicate to preset all references about embedded technology selected to build our control program; the next part cover all design methodology to implement our fuzzy controller. The nest tow parts are dedicated to results and conclusions about this project. It is important declare that results are partial and continuing working them.

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2. Robot Design

Our robot is designed to support a simple antenna that is mounted over final bond of robot structure; two axes or freedom degrees are considered to complete horizontal and half circumference that cover all displacement world. For horizontal θ1 and elevation angle θ2 only from 0 to 180^o, depending of geographical position horizontal and specific trajectory of satellite pass this robot convert their home position before to start their displacement following to satellite. For specific world an analogy may be spherical form half divided. Our mechanical representation is depicted in figure 1.

For mechanical elements, a simple gear relation to reduce our speed 50:1 to link antenna boom to DC motor with encoder included (servomotor), another is installed between bonds with similar speed ratio. For technical specifications, encoders are absolutes with 8 bits per turn, PWM speed controllable motors.

As controllable system, is necessary to obtain our plant model to do control. For this step based in bound graphs we can identify both variables force and flow of every block that specify all sub modules of this part, additional references may be depicted by Karnopp [2].

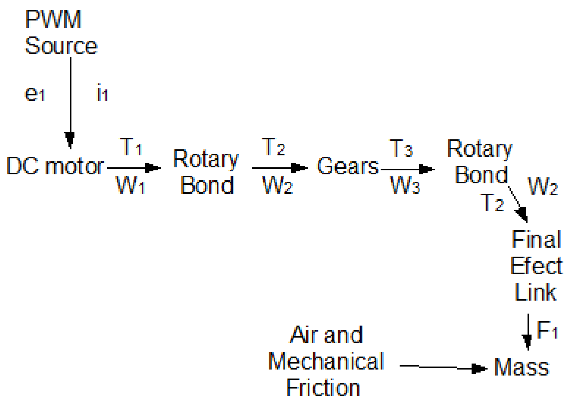

Fig. 1 Bond graph for electromechanical system of robot system.

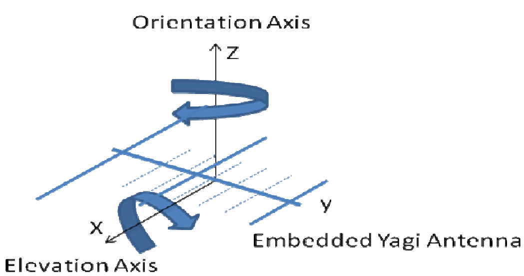

Fig. 2 Cinematic two axis robot model, in this case, antenna is part of 3-D structure as bond.

3. Embedded Design

In this part, one embedded card is considered to use to eject control algorithm of satellite sunflower system developed, as reference we analyze some cards of Single Board Computer SBC type, all with operative system support in this case Linux with C compiler and Java virtual machine. For this application, **JRex** is a member of the 3.5" board family. JRex modules are characterized by the same pin out and interface for 2 x USB 2.0, FAST LAN, Keyboard/ Mouse-socket, Compact-flash™, VGA and COM1. This family feature allows reusing chassis and maximizes design re-use. **JRex-PM** hosts an Intel® Pentium® M or Celeron® M processor. A DDR-RAM-DIMM socket for up to 1 GByte allows the use of standard desktop memory and full ATX power supply is as well a standard feature.
These **JRex-PM** homogeneous features facilitate easy upgrades within the JRex product family. The graphic controller is included in the chipset that performs with up to 2 x 32 MByte UMA. Connection of displays is simplified when using these units which are complete with a JILI-Interface (JUMPtec® Intelligent LVDS Interface). JILI automatically recognizes which display is connected and independently sets all video parameters.

In this case, we start with our main interfaces to connect to robot system, based into RS485 network. One serial TTL port is provided in this card with a simple RS-485 converter, one network is building with other converters to communicate with 16F777 microcontrollers that cover every axis. A simple protocol is used to communication point to point between embedded vs. controller for every servomotor; we use only 5 packets of one byte across physical layer. Data rate used is 9600 bps with asynchronous model with one start and stop bits.

Fig. 3 Embedded Card used to sunflower controller.

4. Controller design

In this part we are designing a simple agent for every axis to make two controllers based into satellite trajectory database, as is depicted in figure 4.

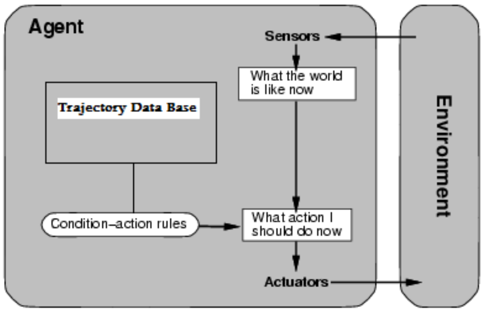

Fig. 4 Simple agent panned to every closed loop system.

Based in this model all actuators and sensors are covered by hardware step, and all info is driven over protocol net, the other parts involved denominated Condition-action rules and Trajectory databases are developed in software, in this case, using C++ as platform to develop al decision routines. The language selection was based in oriented object programming strategy to develop an integration of Xfuzzy code generation and fit this program with hardware embedded card.

The condition-action rules design are based in IA intelligence artificial techniques as Fuzzy Logic to obtain a controller over all trajectory of satellite pass, our fuzzy set variables are linked to characteristics of encoders as input of speed and positional point, as output a certain PWM percentage, this design is repeated for every motor to try to set a simple closed loop system based in position and speed is used as additional input variable to consider final position setting of every angle of junction of robot.

For fuzzy relation in fuzzyfication and desfuzzyfication stage we use three types of function implication: Zadeh, Mandani and Larsen; all are T and S form and their mathematical expression are depicted above.

Table 1. Implication function used.

F. Implicación	basada en	T	S	expresión
Zadeh	$(p \wedge q) \vee (\neg p)$	min	max	$\mu_{Rm}(x, y) = \max\{\min[\mu_A(x), \mu_B(y)], 1 - \mu_A(x)\}$
Mamdani	$p \wedge q$	min	-	$\mu_{Rc}(x, y) = \min[\mu_A(x), \mu_B(y)]$
Larsen	$p \wedge q$	prod.	-	$\mu_{Rp}(x, y) = \mu_A(x) \cdot \mu_B(y)$

For simplicity, all fuzzy graphs of this model considerate only triangular and trapezoidal form, all was planned to easier hardware implementation. For fuzzy set design we use manual procedure based in reduction set presented in [2]. In this case, every implication was developed into graphical tool to indicate all operations to build every specific relation and linguistic representation.

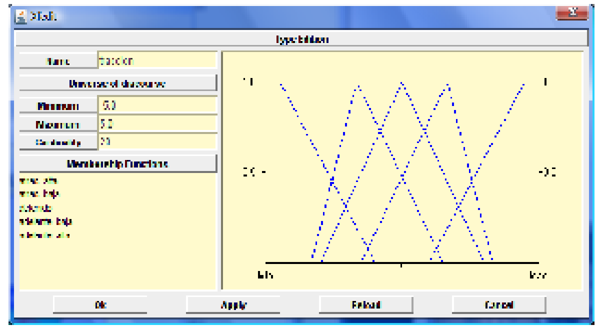

Fig. 5 Example of input fuzzy set using triangular.

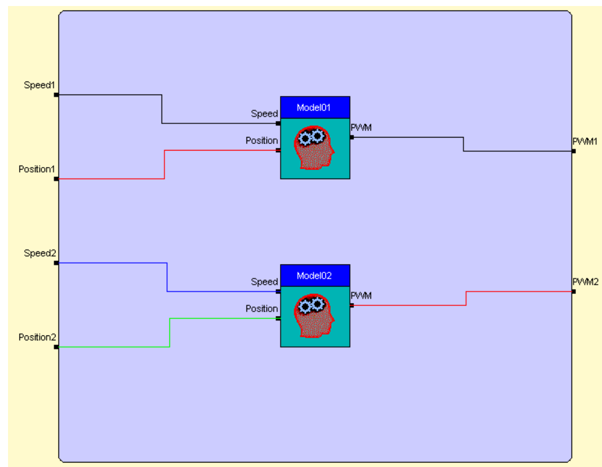

Fig. 6 Fuzzy model of controller implemented in Xfuzzy, this module is composed by two similar controllers, only adjusted by specific characteristics of every DC motor.

```
#ifndef
_AO51_Controller_INFERENCE_ENGINE_
#define
_AO51_Controller_INFERENCE_ENGINE_

#include <stdio.h>
#include <math.h>
#include "xfuzzy.hpp"
#include "AO51_Controller.hpp"

//++++++++++++++++++++++++++++++++++++
++//
//   MembershipFunction
MF_AO51_Controller_xfl_trapezoid  //
//++++++++++++++++++++++++++++++++++++
++//

MF_AO51_Controller_xfl_trapezoid::MF_
AO51_Controller_xfl_trapezoid(double
```

```
min,double max,double step,double
*param, int length) :
ParamMembershipFunction(min,max,step)
{
 this->name =
"MF_AO51_Controller_xfl_trapezoid";
 this->a = param[0];
 this->b = param[1];
 this->c = param[2];
 this->d = param[3];
}

MF_AO51_Controller_xfl_trapezoid *
MF_AO51_Controller_xfl_trapezoid::dup
() {
 double param[4] = {a,b,c,d};
 return new
MF_AO51_Controller_xfl_trapezoid(min,
max,step,param,4);
}

double
MF_AO51_Controller_xfl_trapezoid::par
am(int _i) {
 switch(_i) {
  case 0: return a;
  case 1: return b;
  case 2: return c;
  case 3: return d;
  default: return 0;
 }
}
```

Fig. 7 Part of software generated for Xfuzzy suite, observe membership function description and their fuzzy relationship.

In fuzzyfication we use two techniques to interpret every output, Center of Gravity (CoG) and MeanFuzzy (MF); all models are test over specification tool Xfuzzy, obtained preliminary results that are implemented over embedded structure linking our trajectory database with distance and speed for every block detected over arena.

For software implementation we use Puppy Linux 4 for embedded platform with C++ compiler to evaluate our programs and database driver is operated by MySQL server, in this case we propose a simple program to link our database algorithm with fuzzy code generated.

Protocol is based only into 5 bytes, starting and finishing byte control with 7FH value, internal bytes include address of every microcontroller, one byte of speed and one for distance. Another sequence is implemented to output PWM control for every motor.

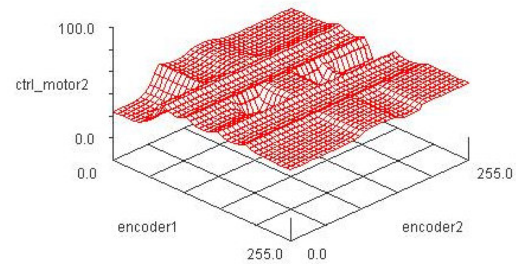

Fig. 8 Output response graph with encoder position relation with left motor, depending of position, motor fits their rotary movement. These values are obtained using CoG method.

6. Results and future work

As preliminary results, we obtain satisfactory responses of PWM controller, all with a fitness around 4 percent error over ideal respective test with this architecture, we need refine our hardware structure to obtain better results to improve our response, an frequency test will be necessary to evaluate all behavioral system.

7. Conclusion

This project gives us a different focus over embedded application strategies to evaluate simple controllers using artificial intelligence techniques.

8. Acknowledged

We appreciate all support of Nuevo Leon Institute of Technology, particularly Robotic Lab CuerBot Team.

9. References

[1] H. N. Pishkenari, S. H. Mahboobi, and A. Meghdari, “On the Optimum Design of Fuzzy Logic Controller for Trajectory Tracking Using Evolutionary Algorithms”, Proceedings of the 2004 lEEE Conference on Cybernetics and Intelligent Systems Singapore, 1-3 December, 2004, 660-665.

[2] I. Baturone, F. J. Moreno-Velo, S. Sánchez-Solano, V. Blanco, J. Ferruz., “Embedded Fuzzy Controllers on Standard DSPs”, Proc. IEEE International Symposium on Industrial Electronics (ISIE 2005), Croatia, June 2005.

[3] T. A. Henzinger, J. Sifakis, “The Discipline of Embedded Systems Design”, *IEEE Computer Society, USA, October 2007, pp. 32-40.*

[4] I. Baturone, F. J. Moreno-Velo, S. Sánchez-Solano, V. Blanco, J. Ferruz., "Embedded Fuzzy Controllers on Standard DSPs", Proc. IEEE International Symposium on Industrial Electronics (ISIE 2005), Croatia, June 2005.

[5] D. L. Hung, "Dedicated Digital Fuzzy Hardware "Proceeding of the IEEE Micro, IEEE, August 1995, USA, pp. 31–39.

[6] Kontron, web site September 2008, http://www.kontron.com

[7] BusyBox, web site July 2008, http://www.busybox.net

[8] Gersnoviez A., Baturone I., Moreno-Velo F.J., *Extracción de Bases de Reglas Simples y Lingüísticamente Interpretables*, Proc. XIII Congreso Español de Tecnologías y Lógica Fuzzy ESTYLF 2006, Spain, September 20-22, PP 111-116.

[9] Puppy, web site September 2008, http://www.puppylinux.org/

APRS Operations and the APRS Space Network

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Abstract: *Too many hams seem to have completely misunderstood APRS as just a vehicle tracking system that transmits GPS coordinates. When in fact, APRS is exactly the opposite. APRS is a communications text-messaging and information receive system for the distribution and display of relevant immediate information of use to the mobile or portable operator. Via the APRS Amateur Satellites, this capability is extended world-wide and fits in the palm of your hand.!*

My response to those people who think of APRS as a tracking system is that the tracking-only application is a relatively dead-end way of thinking about ham radio, and no wonder they are not interested, because in most cases, no one really cares where they are. But flip it around, focus on the receipt and display of relevant ham radio information and text-messaging and Email from the palm of your hand and APRS represents the epitome of ham radio. And on our congested and shared AMSAT uplinks, the ability to get all of your relevant QSO information through the satellite in about 1 second is very valuable to the use by large numbers of operators. Most cubesats and other university satellites are capable of serving as APRS transponders, even while they are performing their primary mission. We need to encourage such operations, all on the one 145.825 channel for synergy with other satellites there and the global network of ground stations.

Key Words: APRS, ham radio text messaging, Satellite Objects

NEW INITIATIVES: No matter where you are on the planet, if you have your APRS radio with you, there is a communications opportunity on the order of every hour or so via the APRS satellites (ISS, PCSAT, GO-32, ECHO and some cubesats and other satellites in work). You can uplink to these satellites with as little as a 5 Watt HT and whip antenna or via your mobile with omni antenna. There is no reason why we cannot support many more APRS transponders on the many cubesats and other small student and university satellites.

Most hams even in 2008 do not realize that APRS operators have been able to use their radios for local/global text messaging and Emails for the last 10 years? This was long before the present teen-ager craze of text messaging on cell phones.

Figure 1. W4HFZ's typical mobile setup includes VHF, UHF, HF, a GPS and APRS.

In a time when overall chatter on the VHF FM radio channels is declining, this paper should shed some light on how we can find each other in the RF wilderness and communicate so much easier. Finding each other is also important when there is a local situation, emergency, disaster, or simply when something exciting is happening that you want to share with others.   We equip our cars with amateur radio technology, but are we really using it effectively?   Before we get into the satellite aspects of APRS reporting and messaging, it is important that AMSAT operators of APRS radios realize the value of their APRS radio terrestrially as well and become proficient in its use…

National Calling Channels and Voice Alert: The frequency 146.52 MHz is a good channel for the traveler, but when you are only in range of a passing mobile for about 3 to 5 miles and are passing at a combined rate of over a mile every 30 seconds, running into others on 52, would require everyone to be calling CQ every 2 to 3 minutes for their entire trip. This doesn't happen. But for APRS operators, there is a better national calling channel on 2 meters that is far more active… 144.39 MHz.

APRS mobile operators get dual-use from their APRS radios (see figure 2) by not turning the packet-receiver volume down, but instead turning the volume up and muting the packet noise by simply setting CTCSS 100. This mutes the packet noise, but makes their speaker fully ready to receive a nearby simplex voice call. We call this Voice Alert [R1]. It means at any time, anywhere, you can make simplex voice contact with an APRS operator by just calling between packets by voice with CTCSS 100. This makes it possible to *always* be able to get in contact with the APRS operator in simplex range. Of course, as soon as contact is made, you must QSY to a packet free voice channel for the QSO.

Figure 2. For over 10 years, there have been a variety of fully integrated APRS radios as shown here. Shown left to right, first, in 1998 was the Kenwood D7 and then the D700. Then the DR-135 with add-on HamHUD to give it an APRS display capability, and then in 2007 the fully capable D710 and recently Yeasu announced the VX8R.

Voice Alert Radar: But Voice Alert with CTCSS 100 for mobiles has even better features. Since the APRS mobile has set CTCSS 100, this also means that his APRS radio is transmitting his local position packets marked with a TONE 100 tag on them. These TONE 100 packets are unique to all the other wall-to-wall digipeated packets on the APRS channel, because they are the only ones that are heard SIMPLEX DIRECT. This means that any other Voice Alert APRS station within simplex range (usually about 3 to 5 miles) may occasionally hear the once every minute or so packet from another nearby mobile. This is like *a proximity radar alert* for another APRS operator nearby. This is better than "52" because these Voice Alert stations are automatically transmitting their "Voice Alert" radar ping CQ every minute or so. This guarantees you can't pass each other unannounced like "ships in the night"…

Voice Alert is not just for APRS operators. Anyone can use it, with any CTCSS equipped mobile radio. Just monitor 144.39 in North America with CTCSS 100 when on the open road and you will occasionally hear a few pings from any passing APRS mobiles looking for a QSO. When you hear one, just call QRZ by voice and ask him to QSY to 52 for a nice contact.

Operating Frequency Identification:
The most significant new initiative in APRS is the addition of the frequency field. This allows all APRS operators to announce the voice frequency they are monitoring. The disadvantage of Voice Alert is that it only works simplex direct. But adding repeater frequencies in everyone's position packets that show up on the front panel of APRS radios or heads-up displays (HAMHUD) as shown in figure 3 extends our voice communications reachability out 50 to 100 miles via repeaters.

Figure 3. This D710 display list was sorted by callsign (W's) and station WB4APR-3 is a fixed station reporting that he is monitoring 147.51 MHz. Clicking on this list will reveal 3 more pages of info on that station, or you can just press TUNE button and talk to him if his repeater or frequency is in range.

Figure 4. The new D710 mobile radio adds a column for frequency info and also has a TUNE button for instant QSY to contact one of those stations. The first three objects are nearby voice repeaters, and AB9FX has two stations nearby, Another D710 monitoring 52 and his D7 HT monitoring 446.000.

Automatic Frequency Transmit: In 2007, the new TM-D710 radio allows the operator to configure his status text to automatically insert the frequency of the voice band of the radio into the real-time position packets on the data band automatically. If the operator changes frequency, then his position report will have the new frequency! This means that if you see another D710 operator on your APRS radio or see him on your GPS map, then his actual operating frequency is shown and you can QSY there to give him a call. As shown in figure 4, the wider screen of the new D710 has an added column to display the frequencies of other stations on the front panel.

Recommended Voice Repeaters Everywhere: In addition to the frequency of other operators, the APRS network now transmits locally recommended voice repeater calling frequencys for travelers in the area [R2]. You can see three of these in figure 4 and 5. These local repeater APRS objects include the Frequency right on the front panel list and when selected, even include the Tone, Net times, and meeting dates as well. Since these repeater objects contain a frequency, when you drive into a new area, you can just push the TUNE button to tune to the locally recommended voice channel. The new D710 has this TUNE button for one-step QSY to someone else's frequency. An additional feature is the new SORT button which can SORT the list alphabetically or by range making it easy to find others. The display above is after an alphabetic sort so that all the Frequency objects show up at the top of the list.

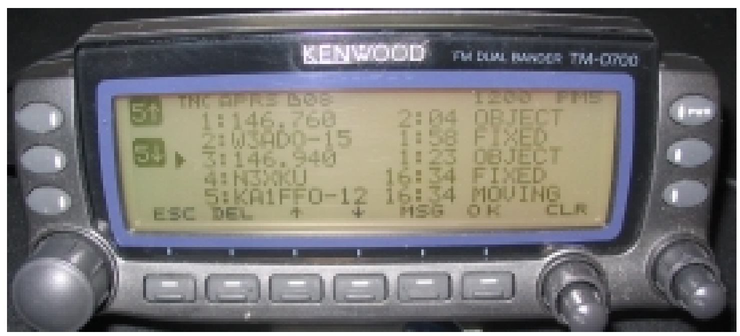


Figure 5. By using the recommended local voice repeater frequency as an APRS object name, these recommendations show up for the mobile traveler whenever he enters a new area. This D700 shows the most recently received 146.76 is in direct range. The older 146.94 has moved down the list since it was heard 35 minutes earlier.

Echolink and IRLP Node Frequency Objects: Other frequencies of immediate local interest to the mobile traveler are the EchoLink nodes, IRLP nodes and Winlink Telpac stations. Echolink and IRLP nodes are displayed on the APRS radio's list as node numbers instead of callsigns to facilitate ease of use by mobiles as shown in figure 6 and include their Frequency, Tone, Range and Status (Rdy, Bsy, Lnk). With these VOIP systems and APRS, the infrastructure is already in place to make mobile-to-mobile real-time global communications possible. The APRS operator just sends a message requesting a call to station XXXX. An engine somewhere monitoring the APRS global data feed grabs this message, looks up the nearest VOIP node to the two mobiles, then sends a message to each telling them the frequencies. The operators tune to their local VOIP frequency and QSO. All we need is someone to write this AVRS engine software (Automatic Voice Relay System) [R3]

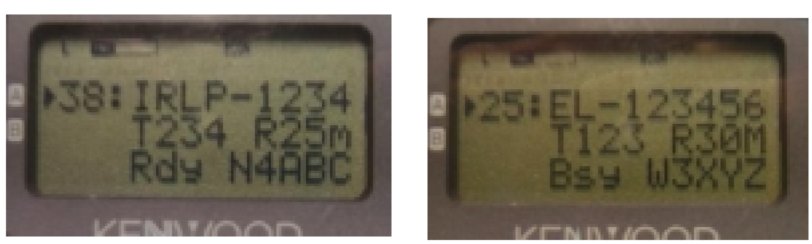


Figure 6. Nearby Echolink and IRLP nodes can also beacon their Position, Frequency, Tone and their node numbers. This makes mobile-to-mobile dial-up global communications possible. These displays show the node number and tone., but the second line should actually be the frequency.

APRS is *not* just a vehicle tracking system!

APRS was originally conceived as a local real-time information distribution and display system with operator-to-operator messaging back in the 1980's even before GPS tracking was added [R4]. That is, APRS is a digital information channel monitored by everyone for distribution of short beacons or messages or announcements about anything going on ***now*** in ham radio in the area. Just knowing who was on the air was valuable information. APRS stood for Automatic -Packet- Reporting System. A universal channel network for local packet information (not Position reporting).

When GPS became inexpensive in the 90's, this led to lots of APRS mobiles and in many cases the appearance to the casual observer that APRS was just a vehicle tracking system. Unfortunately, this is the ***wrong*** impression. APRS is about hams communicating with hams and being situationally informed about all ham radio activities around them or in the case of the amateur satellites, keeping informed about the objects above them and operators using them. For example:

What other mobiles are nearby?... Are there any traffic problems, or slowdowns? Where?
What is the current weather, N, S, E and W of town?... Are there any NWS warnings or watches? Where?
What repeater frequency are the others using for voice?... What IRLP, or EchoLink nodes are nearby?
Are there any SkyCommand basestations available?
Is there access to winlink or APRSlink? What frequency and where?
Is there any ATV on the air right now?... Are there any nets, meetings or gatherings in progress right now.
Are there any announcements or bulletins about coming events?
Are there any AMSATS currently in view?... What frequency? What direction? What Doppler?
Is there any special DX coming in right now?
Is anyone sending me messages?
What repeater frequency is Joe on right now (a DTMF only user)?... Hey Joe, call me on 52!

Transmitting AND Receiving Local and Satellite Info:

Not only are many people not aware of what they could be receiving in their mobile or via satellite, but many that are using GPS trackers do not even receive APRS at all. There are very few ham radio applications that are based on transmit-only systems and APRS is ***not*** supposed to be one of them. APRS is a network for the two-way exchange of relevant information. The purpose of this paper is to remind the general ham population how useful this digital information network can be to the mobile operator as a resource in not only maintaining situational awareness of all of ham radio around him or above him, but also being a rapid keyboard messaging channel (think text messaging), a national Voice Alert calling channel and a satellite data display system.

Figure 7. This HAMHUD display shows that station KE4NYV is 141 miles north and is doing 63 MPH on a heading of 123 degrees. His device is identified as an OpenTracker2 (APOT2A). His position report includes his voice operating frequency as 146.52 with a tone of 107 Hz for voice contact. His position is translated to a waypoint and displayed on the map of the attached GPS.

Heads-Up Display: APRS can be added to any mobile radio using the HAMHUD [R5] kit which can be connected to any radio to not only transmit APRS, but also receive and display the local APRS packets as shown in figure 7. Early versions of the HAMHUD connected to a TNC which was then connected to the radio. But newer versions have the TNC built in for an easy one-plug solution. This is an inexpensive way to receive and display APRS local information while mobile.

DSTAR or any Radios and APRS:

One area we are particularly interested in is how to display APRS information to the mobile DSTAR Digital Voice user or any other conventional FM radio. Of course the easy way, is to simply connect the RC-D710 stand-alone APRS Display Head to the audio DIN jack on the back of the DSTAR radio as shown in figure 8 and set up the left band of the radio to the APRS 144.39 channel.

The display to the right has the D710 display showing the Packet Monitor display just to show that it is receiving APRS packets on the left side of the radio. This solution is plug-n-play since most radios these days have the mini-din audio plug for external access to TX and RX audio.

Figure 8. The D710 display on a 2820 DSTAR radio!

GPS Map Displays:

Not only do the APRS radio and hamhud displays give you textual information, any attached GPS with a map display can be used as your APRS map! It shows all surrounding APRS stations, mobiles, weather stations, and objects, right there on the GPS even those you receive via satellite. With a good GPS with built-in maps, no laptop is needed in most APRS mobiles. Recently, the AVMAP G5 even includes the full APRS symbol set so these other stations appear on the GPS map with full color symbols as shown in figure 9.

Figure 9. GPS units attached to APRS displays convert all stations heard to waypoints for display. The new AVMAP-G5 when connected to the D710 even supports the full APRS symbol set so that the mobile operator does not need his PC to see the full APRS tactical display.

Instant Information Display

While monitoring the satellite downlink or national APRS terrestrial channel, Each new incoming packet with new information flashes on the radio or HamHud screen for 10 seconds or so as shown in figure 10. In this way you are instantly alerted to anything new in range without your hands ever leaving the steering wheel. This display is useful for conveying to travelers the location and frequency/tone of the local calling frequency as well as all other assets or satellites in view. A new feature of the D710 is that the Display Head can be used as a stand-alone APRS display when hooked to the audio connections of any radio. This is useful when removed from the mobile and maybe carried inside to the club or EOC and operated with any HT.

Figure 10. Typical flashed display on receipt of a new nearby packet. This D700 display shows how the left side of the radio flashes each new packet momentarily. It shows why we like to concentrate information into the first 20 or 28 bytes of a packet so that it displays well on the 10x10 display of the D7 and the 10x10x8 display of the D700 shown here. Here we see the local repeater, its tone, its typical range, and its weekly net times.

RADIO SETUP FOR SATELLITE OPERATION:

The D700 series radio has 5 independent system configurations so that you can easily switch between terrestrial and satellite operation with the press of a button. Typically the mobile operator will have on configuration for local commuting, another for the open road, another for mode J Satellites and another for Mode B satellites. These modes automatically configure the proper uplink and downlink band as well as configure the internal TNC to 1200 or 9600 baud and also for cross band operation.

Common APRS Settings: The common convention is to set your terrestrial callsign with an SSID of –7 if you are using a handheld, and to use –9 for your mobile. For your satellite operations use the SSID of - 6. The reason to change the SSID is so that as your APRS data is received into the global APRS internet system (APRS-IS) those packets that went via the satellite will be separately logged compared to those via the terrestrial network.

Most of the APRS menu items are self explanatory, but the most important setting not found in the APRS menu is under the RADIO-DISPLAY menu where you should set the DISPLAY-MODE to 3. This puts the APRS softkeys on the front panel for rapid access to the APRS LIST and BEACON buttons which are the most useful to the APRS traveler and satellite operator. Without this setting, APRS functions are hidden from the front panel and are not as convenient as they should be. The D710 has a hot key to toggle between soft key menus without the press-and-hold function on the D700. There are numerous web pages with suggestions on setting up the various APRS radios for optimum APRS [R6].

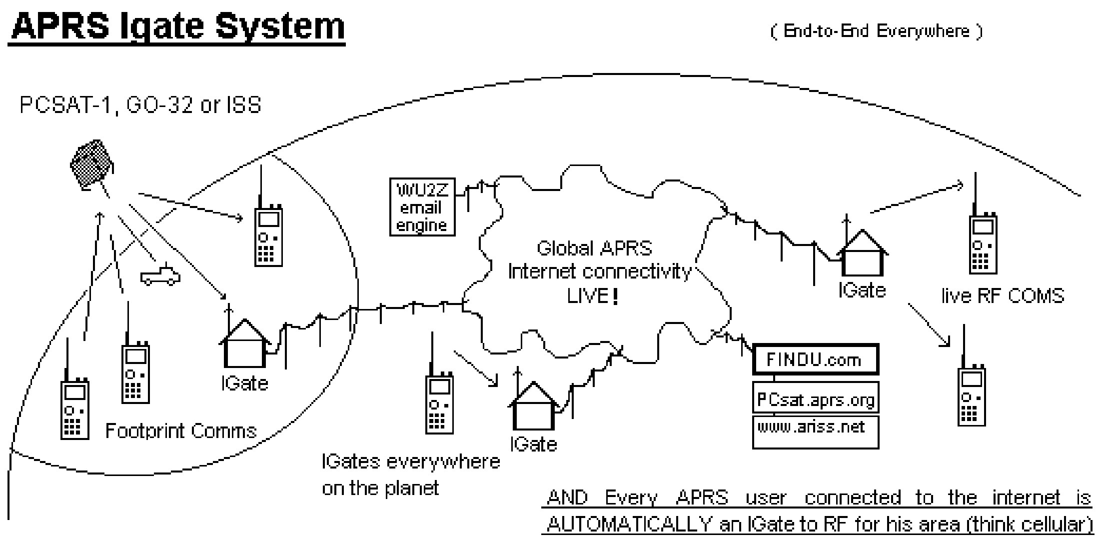


Figure 11. Although APRS is a local information resource, it has global connectivity via the free bandwidth of the internet as shown in the above figure. The primary function of the Internet backbone is to allow for end-to-end messaging between any two users by simply knowing callsigns. All APRS packets go into the global channel, but only end-to-end messages come back out to the intended recipient.

GLOBAL REAL-TIME AND SATELLITE MESSAGING: Although APRS on RF is only a local or single satellite footprint system, it is globally connected for station-to-station messages as shown in figure 11. APRS has had local and global text messaging for 10 years. This is because all APRS messages transmitted anywhere all get captured into the APRS-Internet system (APRS-IS) by home stations or satgates linked to the internet. If any such Igate anywhere sees the recipient of your message in its local RF area, it will automatically pull that live message packet from the APRS-IS and send it in real time to RF to the targeted user. His system will generate an ACK and the ack will travel the reverse route to the sender in real time. This is not Email. These messages are live. If the recipient is not on the air, the message dies. No routing information is needed, just the sender and receiver callsign. If both stations are on the air anywhere in the Global APRS system, their packets get to each other without any prior routing or address knowledge required. Messages up to 45 characters show up nicely on the D7 display as shown in figure 12.

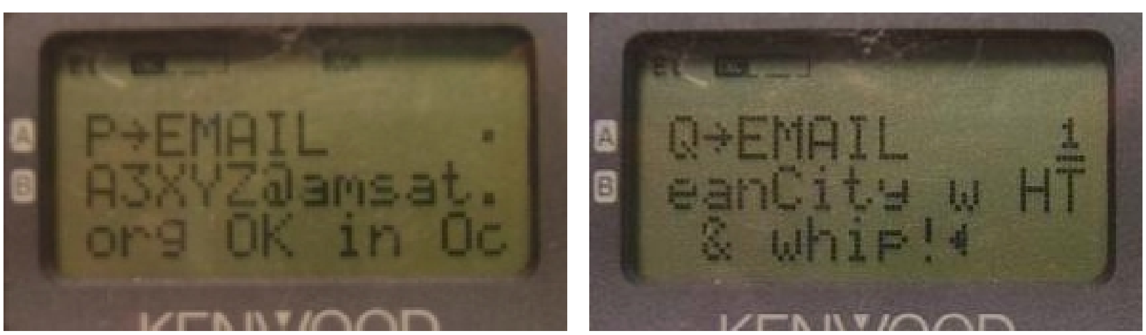
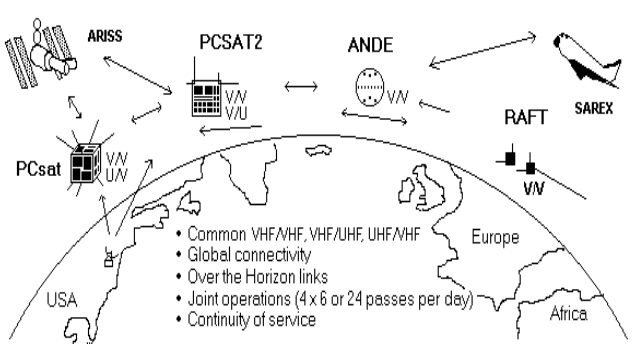


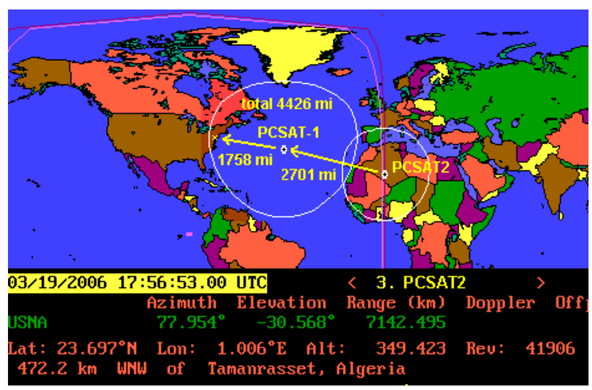
Figure 12. APRS messages are global and real time, as long as both stations are on the air. This message is not to another callsign, but to the pseudo-callsign of Email. This special call will be captured by the APRS-IS and turned into a standard Email for delivery to the indicated recipient.

EMAIL: In addition to live real-time global messaging, you can also use APRS to send one-line email to anyone from your mobile, complements of the APRS email Engine maintained by the Sproul Brothers, WU2Z and KB2ICI. Simply address your normal APRS message to “EMAIL” and enter the email address as the first word of the message line. Their WU2Z Email Engine at Rutgers University (see figure 11) will capture the message and wrap it up as normal email and send it to the internet. The Email engine will also send back a confirmation that the Email was sent.

This Email capability is the basis for APRS emergency messaging in disaster areas or for first responders. This capability (including via the APRS satellites) make it possible to send an email from almost anywhere in the world at least a few times a day. Recognizing the great potential for this system, all ham radio operators are encouraged to transmit a simulated emergency tesst message via any of the APRS satellites at least once a month to validate their abilities. See http://www.ew.usna.edu/~bruninga/sset.html.[R7]

GLOBAL APRS SATELLITE CONSTELLATION: All of the Naval Academy Satellites operated on the 145.825 packet radio satellite channel. This channel was pioneered by the DOVE satellite back in the Early 90’s and has had a number of packet satellites since. As shown in figure 13, with all satellites operating on the same frequency (just like the terrestrial APRS system with all digipeaters operating generically on the same channel) the sum of all such satellites provide a continuum of support to mobile satellite operators.





During the March 2006 joint PC1<=>PC2 operations period, numerous dual hop elemetry and user packets were observed. This telemetry packet from PCSAT2 is just about as far as we can get with satellite-to-satellite-to USNA. Notice how few European or USA users were in the footprint making it more probable that PCSAT-1 could hear PCSAT2's signal. WB4APR

Figure 13. All of the spacecraft operating on 145.825 provide a generic packet relay system and a continuation of coverage and availability. Not only does this provide better access, but it also permits dual hop contacts as shown on the right. A packet from PCSAT-2 relayed by PCSAT-1 to our ground station in Maryland over a path of 4426 miles.

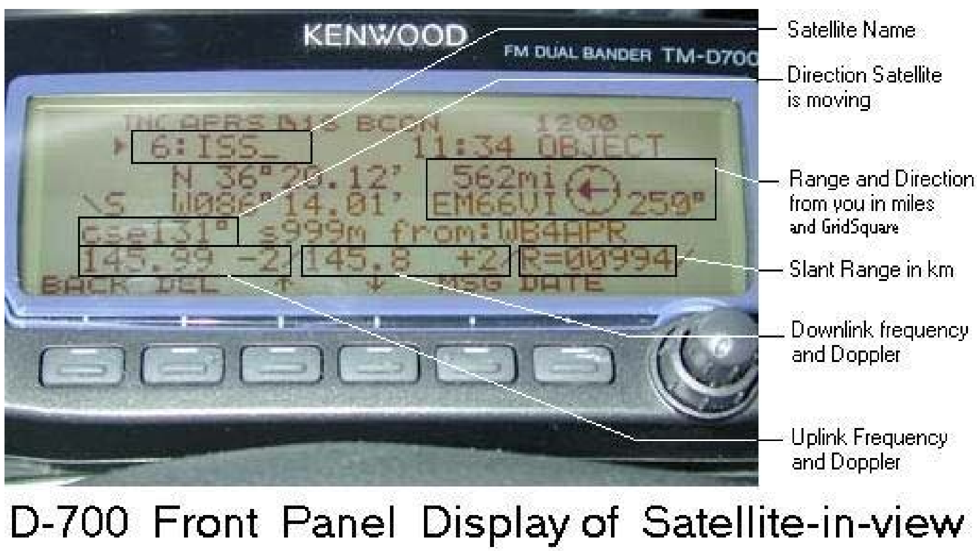
Most digital satellites and most of the Cubesats could support this APRS relay capability in their communications system designs. Even while performing their primary and scientific missions, these satellites could also relay occasional packets from users in view. With only 1 second per user, the power load on the satellite in this mode is miniscule. Even a cubesat power budget could handle a few additional 1 second packets per minute.

SATELLITE ALERTS: Not only are there several APRS satellite digipeaters in space, but there are numerous satellites that you can operate FM voice too while mobile with your FM rig [R9]. The problem is that most of us are simply not attuned to the dozen or so passes per day when we could be operating the satellites if we just knew they were in view. It turns out, your APRS radio or HAMhud can instantly alert you and everyone else in your region any time an FM or APRS satellite comes into view. All it requires is someone in the area to set up a satellite-object server.

The satellite will appear like any other APRS object on the front panel of your radio showing you not only the callsign, name, location, distance and direction from you, but also it will show the frequency and even the current Doppler as shown in figure 14. In other words, everything you need to know on the front panel of your radio. In addition, once every 10 minutes a satellite schedule is transmitted to your mobile of any satellites that may come into view in the next 80 minutes.

Over the years, dozens of AMSAT satellites could be worked from the mobile FM rig including SAREX, ARISS, SUNSAT, ECHO, UO-22, UO-23, PCSAT1, PCSAT2, SO-41, SO-50, ANDE, RAFT and GO-32. Unfortunately, at this writing, only ECHO, GO32 and sometimes ARISS and PCSAT-1 can be used reliably for packet and AO-50, and AO-51 (ECHO) for voice.

Figure 14. The D700 display showing the info displayed on an ISS satellite object. This info is updated once a minute if someone is running the APRSdata.exe program in the area. The bearing and distance are shown and also the uplink and downlink frequencies plus range.



Settings: Satellite Alerts are only visible if someone in your region is running an APRS data resource server such as the old DOS program called APRSdata.EXE. This program runs automomously at someone's shack keeping track of all the Amateur Satellites of use to mobiles. If anyone of them comes above the horizon in your area, the software begins generating 1 minute updates to an APRS object and transmitting this object out to the region. These objects will appear on the front panel of everyone's APRS radio or HamHUD display in the area as shown in Figure 14. On the D7 walkie-talkie display, the information is easier to see at a glance as shown in figure 15 and 16.

Figure 15. In-View Satellite data on the D7 screen shows the operating frequencies and present Doppler. Other displays on the D7 show the direction and distance.

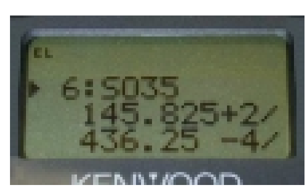
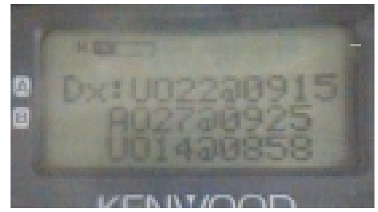


Figure 16. A special satellite schedule packet is transmitted every 10 minutes to update this display in the D7's and D700's DX list. It can show up to four of the upcoming satellite passes expected in the local area. This one showed the times of the next UO22, AO27 and UO14 satellites.



WAYPOINTS, MAP MARKS, TRAFFIC ALERTS: Mobile Operators can even use their APRS radios to place APRS Objects on the maps of all APRS users in the area. This is useful if you want to report a traffic jam, an accident, a speed trap or anything else you want other APRS users to see on their maps. You do this by simply temporarily changing your APRS mobile radio callsign to the NAME of the object you want to uplink. Include in your status text the nature of the object for all to read, and then transmit it a few times. This position report with the new NAME will appear on the map at your current location. Then be sure to change your callsign back to your call and keep moving. The NAMED object will remain on everyone's screen at its original position, even though you keep moving. This is simplified by setting something like ALERT-X as a permanent callsign in one of your program memories. The reason to randomly choose an SSID is because all ALERT objects from other mobiles will usurp each other unless they are unique. So choosing an SSID will reduce your chance of being usurped by a factor of 16 to 1. Or you can use other names such as MARK-N or SPECL-N, or LOOK-N or HERE-N. Because in the status text is where you will tell people what it is about.

Typically you might be mobile and mark an accident. Then you can tell other APRS operators by voice or by an APRS MESSAGE BULLETIN saying something like "Accident at my MARK-N". They can then see the MARK on their GPS map.

Remember, the APRS radios have several pre-programmed STATUS texts to choose from in each of the program memories (PM). If one of them is pre-loaded with "Accident @ my MARK-N" then you can post this object with only a few button pushes. One to select the PM with the MARK-N callsign and another to select the pre-programmed status text. Done.

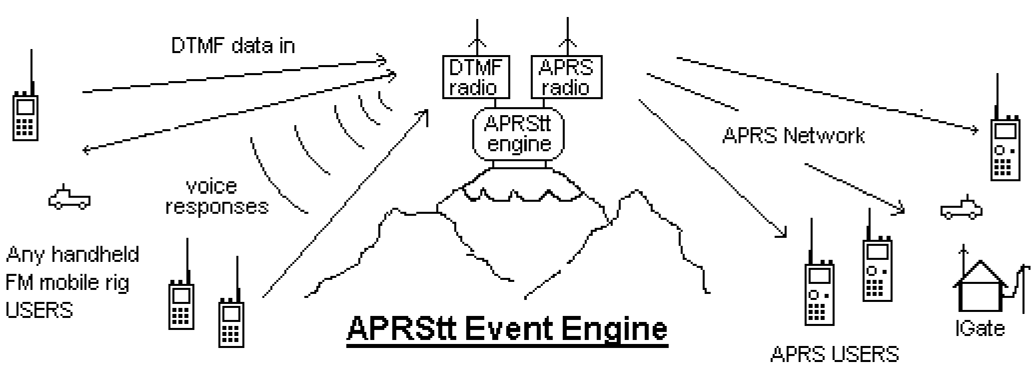


Figure 18. With APRS-touchtone conversion software at voice repeaters or special events, anyone with a DTMF HT can check-in to the global APRS system by just pressing a DTMF memory button.

APRS Check-ins Using Any DTMF Radio.

At the 2001 RAC convention and Dayton in 2002, we introduced the capability to convert DTMF tones from any handheld or mobile radio to APRS information as shown in figure 18. This capability called APRS-Touchtone or APRStt™ [R10] has the potential to revolutionize Ham radio by letting anyone with a DTMF radio check-in to the APRS system, not just those with an APRS radio. By just keying in one's callsign into a DTMF memory only once, then one can check-in to APRS at any time with just a single key press. Just a callsign on DTMF on a repeater conveys almost 90% of what is important in APRS. Hearing that DTMF, the APRStt repeater can forward the following information into the global APRS system:

- Callsign, Date and Time of checkin
- Position (shown within the 1 mile vicinity of that APRStt repeater)
- Frequency, Tone, or DCS
- Reverse patch, Echolink or IRLP node number
- A few bytes of DTMF message if needed

Not only is all that information now in the APRS system, and nearby local APRS operators on the front panel of their radios, but anyone in the world can see that station now on the global APRS system using any of the number of APRS-Internet resources such as FINDU.COM. Just a simple check of http://map.findu.com/callsign* will reveal all that information on any APRS station or object.

CONCLUSION: Many of us only have time to really enjoy ham radio while we are mobile. The purpose of this article is to make sure everyone is aware of the vast potential of information out there that should be made available to the mobile operator on his front panel screen. Due to limited space, only a few of the dozens of display screens and data formats could be shown in this article. Think of these APRS mobile displays as Tiny Web Pages of Local Live information [R11] everywhere you go. Compared to cell phones, the big advantage of ham radio is it's one-to-many access to information. But just like a dead-band, there is only information to receive if someone else is transmitting it.

So think outside the box. APRS has been available as this local information resource for over 15 years, but many operators are still not taking advantage of this valuable local and global resource. Think about what info you can put out in your own immediate simplex range neighborhood that would be useful to the traveler or visitor. But be considerate. One area's local information, if received somewhere else, is SPAM!

References:

[R1] Voice Alert : http://aprs.org/VoiceAlert3.html
[R2] Local Repeater info: http://aprs.org/localinfo.html
[R3] Echolink / IRLP / APRS: http://aprs.org/avrs.html
[R4] The main APRS page: http://aprs.org/aprs.html
[R5] HAMHUD web page: http://www.hamhud.net/
[R6] D700 setup: http://aprs.org/txt/D700-faq.txt
[R7] APRS Emergency Tests: http://aprs.org/sset.html
[R9] APRS Satellites: http://www.ew.usna.edu/~bruninga/astars.html
[R10] APRS Touchtone: http://aprs.org/aprstt
[R11] APRS Tiny Web Pages, 19th ARRL/TAPR Digital Conference Proceedings, September 2000, Orlando Florida. Pp13-20.

The Meteor Shower Nobody Saw—Revisited

By: Joe Lynch, N6CL[1]

Abstract

The placement of seismometers on the Moon's surface by the Apollo astronauts yielded evidence of a huge event during the dates of June 20-30, 1975. Previous research has assumed that this event was a lunar meteor storm. In 1992 this author presented a paper at the Central States VHF Society Conference on the supposed lunar meteor storm in which text from the “The World Above 50 MHz” column in the September 1975 issue of *QST* was used to determine whether or not there was support for the theory of a lunar meteor storm. Results of that examination were inconclusive.

Recent research into the Earth's magnetotail has caused this author to reexamine the original premise, that the seismometer activity of June 20-30, 1975 was a lunar meteor storm. This reexamination has caused this author to form the hypothesis that this activity was not a lunar meteor storm after all, but rather a series of events that were caused by the influence of the Earth's magnetotail on the Moon's surface. This author has further hypothesized that certain events occurring at the same time were what exacerbated the effects of the magnetotail on the lunar surface, thereby contributing to the overall intensity of the sandstorm. Finally, this author has hypothesized that these same events will occur at the same time during a similar period in June 2016. Should the resultant intense sandstorm occur as it did during June 20-30, 1975, it could be very problematic for any astronauts that might be on the lunar surface during this time frame.

Introduction

Recent publications concerning the Earth’s magnetotail’s effect on the Moon have caused me to revisit a paper that I presented at the 1992 Central States VHF Society Conference entitled: “Historical Meteor Storms,” which was published in the conference’s *Proceedings*. Subsequently, I reprinted the essence of that paper in my VHF Plus column in the August 1992 edition of *CQ* magazine.

In that paper I discussed the historical October 9, 1946 Giacobinid-Zinner Comet and the November 17, 1966 *Leonids* meteor showers, along with a supposed meteor shower that affected the Moon during June 20-30, 1975. I titled that section of my paper “The Meteor Shower Nobody Saw.” The following—with updated inclusions in brackets—is from my paper:

> While the Giacobinid-Zinner Comet meteor shower was spectacular in its effect on the 6 meter ham band and the *Leonids* storm displayed its wonder on the 2 meter ham band, they also were very visible showers. There was, however, a [supposed meteor] shower that apparently far surpassed these two, but that no one is known to have seen.
>
> Evidence of this shower that nobody saw came by way of the Moon. The Apollo astronauts left seismometers on the moon during their missions in the late 1960s [and early 1970s (please see photo 1 and sidebar “Bell Ringing Moonquakes or Sandstorms?”)].

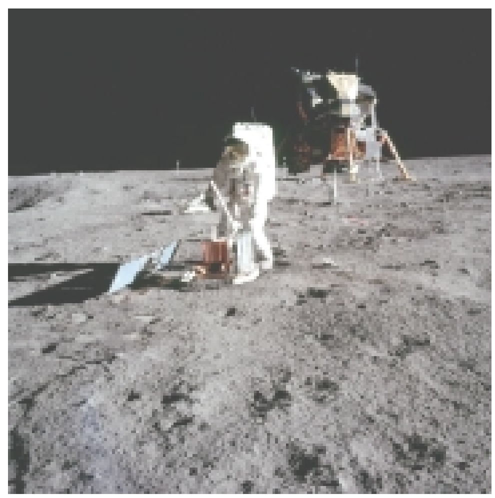


Photo 1: Astronaut Buzz Aldrin deploys a seismometer in the Sea of Tranquility. Photo courtesy NASA.

> During June 1975 these seismometers detected [what seemed to be at the time] a very intense meteoroid onslaught that lasted for around ten days. A group of Brazilian astronomers, headed by Pierre Kaufmann, became aware of these reports and decided to examine VLF data for the same period. They published the results of their studies in an article entitled “Effects of the Large June 1975 Meteoroid Storm on Earth’s Ionosphere,” which appeared in the

November 10, 1989 issue of *Science* magazine (pages 787-790).

They decided to use the VLF data because of the known effects of meteor ionization to the D- and E-layers of the atmosphere. The D-layer forms a waveguide effect on signals within the VLF frequency range, transporting them for long distances across the earth's surface. Meteoroid vaporization is known to cause phase shifts in the D- and E-layers of the atmosphere and, thus, phase shifts in the reception of the VLF signals. Therefore, examination of VLF reception records could reveal any meteor-caused detectable effects on these layers of the atmosphere.

First, by examining data from several different VLF transmitters, they concluded that [there was evidence of a radiant that] was low in the sky during the affected days, in the same general location of the Sun. [They also concluded that] because of the sunlight, the [so called] shower was not visible. However, their examination of the [seismometer data caused them to conclude] that the shower was as much as three to nine times as intense as the Giacobinid-Zinner Comet caused shower.

Was this shower otherwise detected? While it occurred during normal sporadic-E season, could there be any unusual events on VHF during that time frame or, did what was perceived to be normal sporadic-E events mask the effects of the shower?

Kaufmann[2] et al.'s research indicated that the [Earth] days of [lunar] activity were between June 20 and June 30, with the prime days being June 22-23 and June 26-27. An examination of Bill Tynan, W3XO's "The World Above 50 MHz" column in the September 1975 issue of *QST* (pages 78, 136, 138, and 140) showed that sporadic-E type propagation occurred during these days, with especially intense reports of events occurring on June 22 and June 30.

One of the most interesting reports (to this editor), was of a three way QSO on June 22 that Bill (then located in Maryland) had with K3AAY, and K8CAY, the latter being only 280 miles away, in West Virginia. He convincing concluded that the mode of propagation had to be sporadic-E. He goes on to refer to other reports of very short skip contacts during the same day. Oddly, this short distance propagation was also cited as typical during the Giacobinid-Zinner Comet caused shower.

Bill also reported on receptions made by Pat, WA5IYX, (near San Antonio, Texas) of numerous signals during the days indicated. Most notably were the receptions, on June 30, of many sporadic-E type signals throughout the FM broadcast band and the low band VHF television band. These signals were being copied as early as 7:10 AM, Pat's local time. Pat also reported reception of several high band VHF television stations east of him in Florida. These receptions lasted for as long as 3 minutes at a time. Additionally, on the same day, Glenn Hauser, of Enid, Oklahoma, also reported reception of a high band VHF television station from Florida. Glenn also reported reception of YVVK, a Caracas, Venezuela, channel 3 television station. Although there was an increase in activity on June 30, there were not correlating data in the Kaufmann studies. It is possible that the data they examined were not complete on this day (a point they allude to in their article).

Bill also quoted a report from W7NFC, in Athens, Oregon, that indicated contacts will all states in the W1, W4, and W5 call areas during the day of June 22. He goes on to include other reports that specified that day and others during latter June and early July. Bill concluded these reports by observing that "the day-of-days was June 22, with QSOs all over the country [being reported]."

However, these days are during the sporadic-E time frame and any activity could have been (and was) easily interpreted as sporadic-E caused propagation. As stated, June 22 seemed to be a key day for both data. However, Bill does not report any correlating data on June 26. Could it be that many hams were on the air on Sunday, June 22, and that few hams were on the air on Thursday, June 26? Could it also be that most of the activity was overnight on June 26-27, whereby many [North American] hams were in bed, not expecting or suspecting anything out of the ordinary?

For as much meteor shower activity, there seems to be little other correlating amateur radio VHF data (absence of 2 meter reports, for example). Again the question is asked, "Could the amateur radio observations be incomplete because 'nobody was on the air?'" In conducting unrelated research, your editor looked back into his 6 meter log for the last three years and found that each Memorial Day weekend the band had been open. No matter that the dates of the weekend have floated. Without exception, the band was open during some time of the weekend. Was the band open because people were home and on the air or was the band being open and people being home coincidental?

Perhaps more study of pertinent log entries should be performed in order to see what effect this unknown June 1975 sporadic meteor storm had on VHF communications during the key days in late June.

Now, 16 years after I published my paper and presented it at the CSVHF Society conference, I have come to believe that the supposed lunar meteor storm of June 20-30, 1975 was probably not a meteor storm after all, but rather successive sandstorms on the lunar surface caused by the earth's magnetotail. Why have I come to believe this new hypothesis? What follows are what I identify as pieces of the puzzle that have led me to my hypothesis.

The first piece of the puzzle to my new hypothesis appears on page 790 of the Kaufmann, et al. paper: “However, the lack of strict day to day correlations between data from Earth and moon suggest that the meteoroid stream was not homogeneous in space.” Their concluding remark tells of their inability to tie what appeared to them to be a tremendous meteor storm on the Moon’s surface to anything that occurred on Earth during the same timeframe.

I came to my next puzzle piece to my new hypothesis via my reading a NASA report entitled “The Moon and the Magnetotail,” which was published on the web on April 17, 2008[3]. In that article author Dr. Tony Phillips discussed the work of Dr. Tim Stubbs, a University of Maryland scientist working at the Goddard Space Flight Center. Phillips quotes Stubbs: “Earth’s magnetotail extends well beyond the orbit of the Moon and, once a month, the Moon orbits through it (please see Figures 1-3). This can have consequences ranging from lunar ‘dust storms’ to electrostatic discharges.” Phillips adds: “There is compelling evidence that fine particles of moon dust, when sufficiently charged-up, actually float above the lunar surface.”

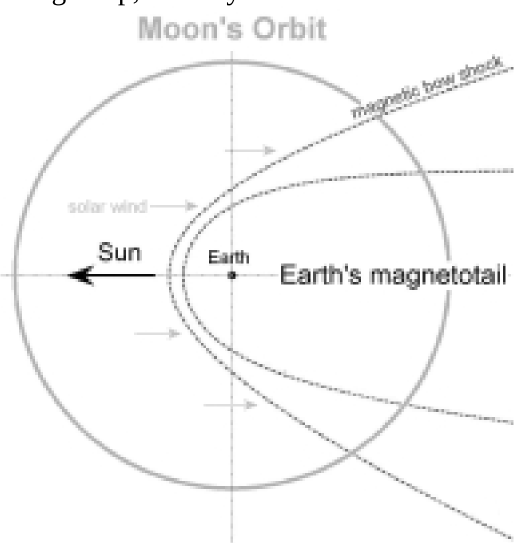


Figure 1: The Moon’s orbit crosses Earth’s magnetotail. Figure courtesy NASA.

When I read Stubbs’ and Phillips’ comments, my mind flashed back to my 1992 CSVHFS paper and I wondered if what Kaufmann, et al. observed was not a meteor shower but rather a magnetotail-caused series of sandstorms. Phillips’ next quote of Stubbs really got my attention: “If the Moon is full, it is inside the magnetotail. The Moon enters the magnetotail three days before it is full and takes about six days to cross and exit on the other side.”

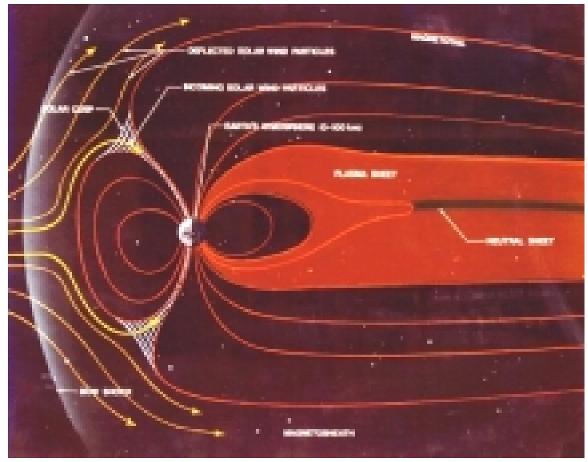


Figure 2: Detailed view of the Earth’s magnetotail. Figure courtesy NASA.

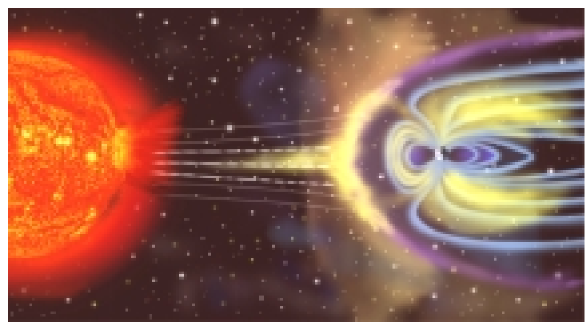


Figure 3: The Sun’s influence on the Earth’s magnetotail. Figure courtesy NASA.

From that quote, I asked this question: “Was the phase of the Moon at full during June 20-30, 1975?” Indeed it was. Full moon for 1975 was on June 23 at 1654 UTC. Going back to Kaufmann, et al., I noted that their evidence of the data from those seismometers indicated intense activity on the dates of June 22-23 and 26-27, 1975, which pretty much coincides with Stubbs’ comments concerning the transition of the magnetotail across the Moon’s surface.

A reservation that I had about my hypothesis was this: “What was special about those dates that the magnetotail would have a more intense influence over and against other dates?” To answer my reservation, I first checked with solar records concerning Sun-caused events that might trigger a more elongated or more intense magnetotail. I found evidence of a minor solar flare on June 30, 1975 (which might explain the more intense sporadic-E amateur radio propagation reports on that date). However, absence of any other events, I concluded that the magnetotail was probably not abnormally influenced by the Sun during those critical days.

While it seemed that I had reached a dead end, my research did surface another paper, this one authored by Mike Hapgood[4] of the Rutherford Appleton Laboratory of Chilton, Didcot, Oxfordshire, UK. His paper, "Modeling long-term trends in lunar exposure to the Earth's plasmasheet."

In Hapgood's paper he discusses how the magnetotail affects the Moon during its crossing the magnetotail at solstices—in particular the peaks and valleys associated with the Moon's approximate 18.6 year nodal period precessional orbit. At the vernal equinox of the precessional orbit, the lunar declination can reach 28° north or south each month. Around 9.3 years later (the next time being 2015) the declination reaches only 18° north or south each month.

Concerning the June 20-30, 1975 events, the summer solstice for 1975 was on June 22, at 0027 UTC. As it turns out, this particular crossing was during that time of the Moon's precessional orbit was at the peak of the narrower (18°) declination (see Figures 4 and 5).

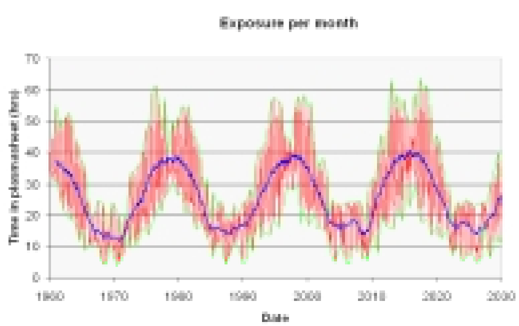


Figure 4: Predicted lunar exposure to the plasmasheet as a function of time over the period 1960 to 2030. The red curve shows the total exposure to the plasmasheet during each monthly crossing of the magnetotail. The blue curve shows the effect of smoothing the red curve with a 25-month running mean. The green curves show the maximum and minimum monthly exposures in half-yearly bins centred on the solstices. Figure used by permission from Mike Hapgood.

For me, this third factor of the Moon's nodal period precessional orbit seems to be enough to support my new hypothesis that what happened on the Moon during June 20-30, 1975 was likely a series of sandstorms probably caused by the swath of the Earth's magnetotail across the Moon's surface.

Another piece of the puzzle can be found in the December 7, 2005 Science@NASA story entitled "Moon Storms.[5]" In that article authors Trudy E. Bell and Dr. Tony Phillips write about the Lunar Ejecta and Meteorites (LEAM) experiment that was installed by the Apollo 17 astronauts in 1972. The purpose of the experiment was to look for dust kicked up by small meteoroids that would hit the Moon's surface. According to Hunt and Phillips:

> Apollo-era scientists wanted to know, how much dust is ejected by daily impacts? And what are the properties of that dust? LEAM was to answer these questions using three sensors that could record the speed, energy, and direction of tiny particles: one each pointing up, east, and west.
>
> LEAM's three-decade-old data are so intriguing, they're now being reexamined by several independent groups of NASA and university scientists. Gary Olhoeft, professor of geophysics at the Colorado School of Mines in Golden, is one of them:
>
> "To everyone's surprise," says Olhoeft, "LEAM saw a large number of particles every morning, mostly coming from the east or west—rather than above or below—and mostly slower than speeds expected for lunar ejecta."
>
> What could cause this? Stubbs has an idea: "The dayside of the moon is positively charged; the nightside is negatively charged." At the interface between night and day, he explains, "electrostatically charged dust would be pushed across the terminator sideways," by horizontal electric fields.

Concerning the so-called lunar meteor storm hypotheses, while Kaufmann, et al. dealt with some aspects of them, it is necessary to mention two other theories concerning those hypotheses. First, in an article entitled "The Dark Ages: Were They Darker Than We Imagined?[6]" author Greg Bryant makes the following point concerning the annual *Beta Taurids* meteor shower and the June 20-30, 1975 lunar meteor storm:

When the astronauts went to the Moon, they placed seismometers on the Moon's surface. At the end of June, 1975, they registered their major series of lunar impacts. The impacts were detected only when the nearside of the Moon (where the astronauts landed) was facing the Beta Taurid radiant. At the same time, there was a lot of activity detected in Earth's ionosphere, which has been linked with meteor activity.

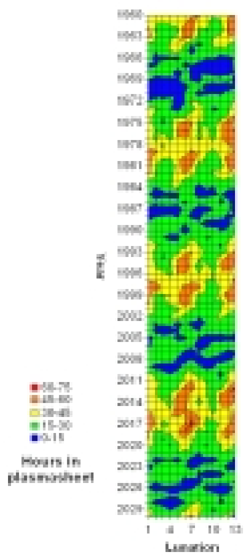


Figure 5: The short-term modulation in predicted lunar exposure to the plasmasheet. The red curve shows the difference between the half-yearly maxima and minima in monthly lunar exposure (as derived from Figure 4). For reference the blue curve shows the long-term modulation in the form of the 25-month running mean exposure. Figure used by permission of Mike Hapgood.

Bryant is not unique in his suspecting the *Beta Taurids* meteor shower involvement. Kaufmann, et al. cite K. Brecher ("The Canterbury swarm: Ancient and modern observations of a new feature of the solar system," American Astronomical Society Bulletin 16, 476, 1984) and J. Dorman, S. Evans, Y. Nakamura, and G. V. Latham ("On the time-varying properties fo the lunar seismic meteoroid population," Proceedings of the Lunar Planetary Science Conference 9, 3615-3626, 1978) as supporters of the *Beta Taurids* meteor shower theory.

Second, in an article entitled "Possible relationship between the Farmington meteorite and a seismically detected swarm of meteoroids impacting the Moon"[7] author Jürgen Oberst suggests a link between the Farmington meteorite[8] and the lunar meteor storm, while at the same time discounting the *Beta Taurids* meteor shower connection because that meteor shower does not show "swarming," which, according to Oberst was necessary to explain the "observed large seismic signals." He further points out that "for objects in orbits of Taurid meteors, the longitude of the ascending node, Ω, shifts by about 35° on average during such a period (Jones, 1986)." Hence, the suggested association is quite unlikely although it cannot be ruled out. It is also important to note concerning the *Beta Taurids* that their active dates are usually between June 5 and July 17, with a peak of June 28, which may or may not preclude their effect on the Moon during the peak days of June 22-23, and 25-26, 1975.

Finally, regarding the *Beta Taurids*, from their first discovery by Jodrell Bank observers during June 20-27, 1947, they have been consistently defined as a weak stream meteor shower with no clear peak—particularly because it is a daytime shower that relies on radio observation reports for its definition. Additionally, the International Meteor Organization points out in their 2008 calendar of meteor showers that because of its proximity to other radiants, it is difficult to clearly define it from the other radiants[9]. Therefore, it is my opinion that to attribute such a massive lunar storm that, as Kaufmann, et al. noted was not homogenous to Earth, to the *Beta Taurids* is at least problematic. Furthermore, efforts to support the theory that the *Beta Taurids* shower could produce massive amounts of large boulders by way of linking it to the theory that the June 30, 1908 Tunguska explosion is also problematic because the Comet Encke hypothesis is one of many hypotheses that attempt to explain the Tunguska event[10].

Recent observations[11] of explosions on the Moon's surface have tried to make a correlation between meteorites and such explosions. Commenting on the observations thus far, researchers have concluded that not all impacts are meteorites. Some may be sporadic meteorites; some may be space junk. In fact, the ratio of sporadic hits and other debris to known meteor showers is 2:1 in favor of the sporadic hits. Commenting on the researcher, Dr. Rob Suggs, KB5EZ, of the Marshall Space Flight Center stated: "That's an important finding [because] it means there's no time of year when the Moon is impact-free."[12]

What does not seem to be explored in their research is whether or not such sporadic impacts may in fact be Moondust that has been excited by solar wind and thus caused to crash to the surface after such excitation.

Finally, I would like to add one more piece to the puzzle that might be significant to my hypothesis. That piece of the puzzle is the combined effect of the Moon's and Sun's gravitational pull on the Earth's magnetotail. While it has already been shown that the Moon gets a lashing from the Earth's magnetotail[13], because of this lashing it is also possible that during certain timeframes, such as during the days of June 20-30, 1975, with the Moon phase at full and the Earth being at summer solstice on nearly the same date, that this lashing is exacerbated by the influence of the Moon's gravity, combine with the Sun's gravity. Such combined gravity was exceptionally strong, thereby exerting an exceptional pull on the Earth's magnetotail onto the Moon's surface, which in turn resulted in an exceptionally strong sandstorm, the likes of which have not previously been recorded.

It is for this same reason that I am hypothesizing that another potential problematic timeframe could be the days immediately before and after June 20-21, 2016. Such sandstorms could be catastrophic for astronauts who are colonizing the Moon without the appropriate preparedness.

In summary, it is my hypothesis that what Kaufmann et al. investigated as a meteor storm was more likely sandstorms caused by the Earth's magnetotail. The evidence I have found to support my hypothesis seems to indicate that Moon appears to have crossed through the Earth's magnetotail at the right timeframe (peak of the Moon's nodal period precessional orbit, during the summer solstice, and when the Moon was at full phase) for a series of sandstorms to have occurred that were detected by the seismometers left by the Apollo astronauts. While, as mentioned above, several have tried to tie the lunar events of June 20-30, 1975 to a meteor storm or storms or remnants of the Farmington meteorite (none more thoroughly than Kaufmann, et al.), it is my position that the evidence supports my hypothesis over and against these other hypotheses.

Concerning the significance to the amateur radio weak signal community, in particular the significance to EMEers, it is that there might be a possible influence on EME communication during these sandstorms. Knowing when they might occur might be important to predicting possible degradation in EME communication during such events.

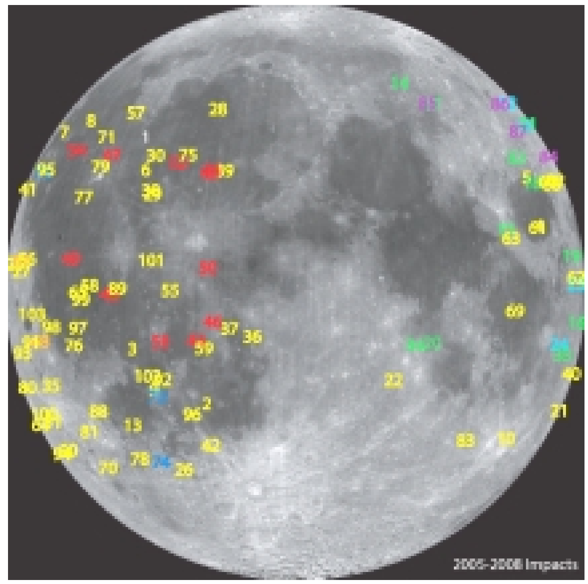


Figure 6: A map of the 100 explosions observed since late 2005. Figure courtesy NASA.

Much more importantly, however, is the significance to NASA and their new lunar exploration program. The significance for NASA is that these sandstorms could be very problematic for the astronauts while on the Moon's surface, or even in orbit around the Moon. In particular, the experience of the Apollo astronauts with Moondust provided some indication of the problems the dust posed to their exploration.

For example NASA researcher Mian Abbas[14] commenting on the nuisances of Moondust stated: "Moondust was a real nuisance for Apollo astronauts. It stuck to everything – spacesuits, equipment, instruments."

The sharp-edged grains of the Moondust scratched faceplates, clogged joints, blackened surfaces, and made dials nearly unreadable. Abbas adds, "The troublesome clinginess had a lot to do with moondust's electrostatic charge."

Regarding the possibility of a repeat of the possible magnetotail-caused sandstorms, during the dates June 20-21, 2016, as well as the dates of June 20-21, 2035, the Moon's phase will be full the day before the summer solstice during the peak of the Moon's nodal period precessional orbit—such as was a very similar alignment of the Moon's phase, summer solstice, and the Moon's nodal period precessional orbit for the dates of June 20-30, 1975.

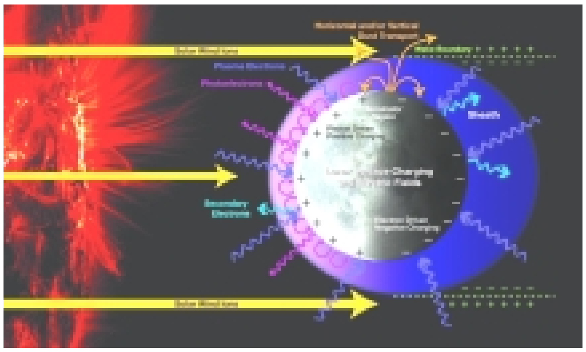


Figure 7: Lunar surface charging and electric fields caused by sunlight and solar wind. Credit: Jasper Halekas and Greg Delory of U.C. Berkeley, and Bill Farrell and Tim Stubbs of the Goddard Space Flight Center. Figure courtesy NASA.

Sidebar: Bell Ringing Moonquakes or Sandstorms?

Between 1969 and 1972, Apollo astronauts placed seismometers at their landing sites at various locations around the Moon. For a number of years the Apollo 12, 14, 15, 16, and 17 instruments radioed data back to Earth until they were switched off in 1977.

In the March 15, 2006 Science@NASA article entitled "Moonquakes[15]" author Trudy E. Bell wrote about Clive R. Neal, associate professor of civil engineering and geological sciences at the University of Notre Dame, who, along with his 15 member team, spend considerable time identifying and categorizing the four types of Moon quakes. Of importance to me was the identifying of Moonquakes that were caused by meteors striking the Moon's surface. From Bell's article is the following excerpt:

> There are at least four different kinds of moonquakes: (1) deep moonquakes about 700 km below the surface, probably caused by tides; (2) vibrations from the impact of meteorites; (3) thermal quakes caused by the expansion of the frigid crust when first illuminated by the morning sun after two weeks of deep-freeze lunar night; and (4) shallow moonquakes only 20 or 30 kilometers below the surface.
>
> The first three were generally mild and harmless. Shallow moonquakes on the other hand were doozies. Between 1972 and 1977, the Apollo seismic network saw twenty-eight of them; a few "registered up to 5.5 on the Richter scale," says Neal…
>
> Furthermore, shallow moonquakes lasted a remarkably long time. Once they got going, all continued more than 10 minutes. "The moon was ringing like a bell," Neal says.

In light of my hypothesis concerning the seismometers' recorded lunar activities of June 20-30, 1975, it is my suggestion that maybe some of the relative long-lasting shallow Moonquakes were in reality the readings of the ongoing Magnetotail-caused sandstorms rather than "bell ringing" Moonquakes.

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[1] VHF editor, *CQ* magazine and Editor, *CQ VHF* magazine, 5851 E. 21st Place, Tulsa, OK 74114, phone: 918-835-9794, cell: 918-809-6392; email: n6cl@sbcglobal.net.
[2] Kaufmann, Peter, V. L. R. Kuntz, N. M. Paes Leme, L. R. Piazza, J. W. S. Vilas Boas, K. Brecher, & J. Crouchley, "Effects of the Large June 1975 Meteoroid Storm on Earth's Ionosphere," Science, November 10, 1989, vol. 246, pages 787-790.
[3] Please see: http://science.nasa.gov/headlines/y2008/17apr_magnetotail.htm.
[4] This paper was published in the October 2, 2007 issue of *Annales Geophysicae* (vol. 25, pages 2037-2044), the journal of the European Geosciences Union.
[5] Please see: http://science.nasa.gov/headlines/y2005/07dec_moonstorms.htm.
[6] This article was originally published in the September 1999 *Universe* magazine and is now posted on the Internet at: http://gchbryant.tripod.com/Articles/darkages0999.htm.
[7] Please see *Meteoritics* 24, 23-28, 1989.
[8] On June 25, 1890, at 1 p.m. local time a brilliant fireball was seen over the Midwest part of the United States. The resulting meteorite landed in Farmington, Kansas. The metal of the meteorite was later determined to be chondrite.
[9] Please see: http://www.imo.net/calendar/2008#spring.
[10] Please see: Ľubor Kresák, "The Tunguska object – A fragment of Comet Encke?" *Astronomical Institutes of Czechoslovakia, Bulletin*, vol. 29, no. 3, 1978, p. 129-134. An abstract is available online at: http://adsabs.harvard.edu/abs/1978BAICz..29..129K. A copy of the full text can also be accessed from this URL.
[11] Please see: http://science.nasa.gov/headlines/y2008/21may_100explosions.htm?list209719.
[12] Ibid.
[13] Please see: http://www.sciencedaily.com/releases/2008/04/080420123319.htm.
[14] Please see: http://science.nasa.gov/headlines/y2008/10apr_moondustinthewind.htm.
[15] Please see: http://science.nasa.gov/headlines/y2006/15mar_moonquakes.htm.

Drake Middle School science lessons

Poster Session

Mark T. Jones, Seth Clark
Drake Middle School
655 Spencer Ave
Auburn, Alabama 36830

Mark Jones and Seth Clark are 6^{th} and 7^{th} grade science teachers at Drake Middle School respectively. In our poster presentation we highlight our lessons in 6^{th} -grade Earth science on constructing a moon-base and the vertically aligned 7^{th}-grade life science lesson by Dr. Jones on comparing and contrasting biome parameters with the environment on the Moon, Mars and space.

Mr. Clark's lesson includes students comparing and contrasting the colonization of Jamestown Virginia with the future colonization of Mars. Students will recreate the infrastructure of Jamestown and then have to speculate, research and decide in teams on what the infrastructure of a Moon base will require. As exploration of the concept, students will have to set up long term support for the moon base as supply chains Earth and what resources the moon has to offer. Students will finally research what scientific studies can be conducted from a Moon base to include an overview of satellite technology and the possibility of beginning a Mars mission from the Moon.

In Dr. Jones' class, students in 7^{th}-grade life science will research missions to Mars under the guiding theme of space probes. Some failures of probe missions include the loss of contact once the probes reach space. Students will compare and contrast the harshest conditions on Earth to the Moon, Mars and Space. Students will then decide on their own research mission and design a sequence of events to get the probes to their destinations. Students will also use the programming tutorial software called ALICE to design their own probe in space with appropriate hardware to survive the parameters of space. Students will then see this type of thinking in practice by exploring the Academy of Aerospace Quality website.

These lessons are being piloted this year at Drake Middle School with the intent of refining the lessons for student engagement and career education in engineering.