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AMSAT
RADIO AMATEUR SATELLITE
CORPORATION

PROCEEDINGS OF THE AMSAT-NA

18th Space Symposium and AMSAT-NA Annual Meeting

October 27-29
2000
Portland, Maine

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AMSAT-NA

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and **AMSAT-NA**
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Table of Contents

Table of Contents (continued)

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ANGUS S. KING, JR.
GOVERNOR

October 27, 2000

Dear Friends,

On behalf of the citizens of Maine, it is a pleasure to welcome you to our state for the 18th AMSAT Space Symposium and Annual Meeting.

Maine, like other states, features a number of amateur radio operators who use this technology to communicate with individuals across the country and the world. With the innovations that satellite communication now offers, the advances possible in this field are dramatic. As we have seen with other advancing technologies such as e-mail and the Internet, the world can become smaller and more cohesive. The thought of someone in Portland or Presque Isle, Maine communicating with a citizen in Singapore or Australia through the use of satellite-connected radios is astounding. I look forward to seeing the progress that your group will make in these ventures.

Again, welcome to Maine.

Sincerely,

Angus King

Angus S. King, Jr.
Governor

Welcome – and have a great meeting!

PHONE: (207) 287-3531(Voice)
FAX: (207) 287-1034
(207) 287-6548 (TTY)

Welcome

It is with great pleasure that I personally welcome each of you to the 2000 AMSAT-NA Annual Meeting and Space Symposium. This meeting continues a proud tradition that AMSAT started in the early 1980s to provide an annual forum for amateur satellite enthusiasts to gather and share their ideas among like-minded friends and colleagues. What's more, as you will soon see (if you haven't already) my own native Northern New England is a beautiful setting for meetings this time of year. Make sure you plan some time away from the official proceedings to enjoy your unique surroundings.

This year marked yet another major milestone in our Phase 3-D project. In January, P3-D arrived safely at the launch site in Kourou, French Guyana to await a ride to orbit on an Arianespace Ariane 5 launch vehicle. What's more, if all is going as planned (and that is a BIG 'if' as I write these words!) many of our Phase 3-D experimenters will have been working very hard at the launch site to prepare the satellite for launch. However, as I have been saying for many months, a satellite sitting at the launch site in Kourou is still a far cry from one that is up and running in orbit. Unfortunately, what this means for the Phase 3-D project is that the *most* uncertain time for us may still lie ahead.

That is, anyone who has not been directly involved in the design, construction and launch of one of our complex spacecraft simply cannot have the same deep awareness of the EXTREME level of uncertainty that faces any group contemplating such endeavors. Besides the obvious uncertainties of never having enough skilled hands and brains (or time) available to build them, there is the added uncertainty of low (often non-existent!) leftover cash for parts, integration, as well as test and transport of the satellite. This is *in addition to* trying to design and implement innovative ways to account for the myriad of uncertainties associated with thermal, radiation and vacuum extremes that the spacecraft will encounter in orbit. Then there is the minor (?) concern of placing your brainchild on top of a big bomb (a.k.a. "rocket") specifically designed to hurtle it into the cosmos at several times the normal force of gravity.

By any measure, AMSAT as a whole has come a long, long way, since our beginnings. The future, with a number of new satellites slated for launch in the near future, and a number of others on the drawing board, is very, very bright. However, we need to continue to remember that what we do is fraught with uncertainty. I also ask for your continued support in giving our experimenters, many of whom will be present at our meetings here, all the respect and encouragement we can collectively muster.

As many of you also know by now, this will be my last AMSAT Annual Meeting at which I will be presiding as your President. I have always believed that in volunteer organizations, each of us should endeavor to rise from the ranks to serve in positions of leadership, but then, after serving honorably in those positions, we should strive with equal vigor to return to the ranks from whence we came. This approach keeps the organization fresh and alive with new ideas and new ways of approaching the many challenges we face. I believe that serving four years as your Executive Vice President and then for two years as your President are quite enough. It is time to bring a fresh face to the President's chair. As I step aside, my only hope is that in just one small way, my leadership has left the organization just a little bit better off than when I arrived.

Thanks again for joining us in Portland and have a *great* weekend!

73,

Keith Baker, KB1SF
President, AMSAT-NA

So You Want to Build a Satellite!

By: Dick Jansson, WD4FAB

Abstract

Recent conversations among the Amateur Satellite community have shown an interest in a low-cost replacement for an OSCAR 13 type of mission. AO-13 was a popular satellite, indeed, and having a low cost follow-on replacement is an attractive idea. It is not that there is anything wrong with the P3D mission, but it has taken over ten years and many dollars (and Deutsch Marks) to bring to fruition. Is such a new mission possible? The answer to that lies in getting a properly sized spaceframe, holding a limited amount of equipment, to a GTO orbit. Low-cost also implies a mission without propulsion. Other papers will deal with some of these aspects of such a mission. It is the intent of this paper to show how a practical spaceframe can be designed for existing launchers and launch environments.

The Challenge

A significant number of us, from fourteen different countries, have worked a rather long time to bring the P3D spacecraft to the point of being ready for launch - too long of a time, more than ten years. We have poured our hearts into this project and it is a masterpiece, including the proverbial "kitchen sink". Since the loss of OSCAR 13 (AO-13), the amateur satellite community has also been at a loss for a high-altitude, "world-wide" communications satellite platform. Many of us feel that a ten year gestation time for bringing a satellite to fruition is much too long, especially at a time when we do not have a fully useable global communications platform. (The ailing AO-10 does not fill that bill.)

When we combine these factors into a cohesive set of brain waves we can conclude that we need to think of new, high-altitude satellites that truly fit the concept of AMSAT's famous KISS principle of design. Such a design *must* be low cost, easy to build and easy to launch. Now, the list of what constitutes a simple satellite design certainly can be debated, depending upon one's interests in satellite communications. There is some consensus on the following list of key points of such a design, however:

- High altitude orbit for wide area coverage and long-distance DX operations
- Transmitting and receiving equipment for wide-band, multi-user SSB operations
- No propulsion
- No more than three years from start to launch
- Cost less than $500,000
- Re-use as much prior design technology as possible
- Weight less than 50 kg

Such a list of "requirements" may seem oppressive, but let us see how these play into making something simple that we can collectively afford, construct and operate.

All of the AMSAT Phase 3, high-altitude elliptical orbit spacecraft have had their orbital start by being launched into an orbit called Geosynchronous Transfer Orbit, or just GTO for short. This is the intermediate orbit achieved by a launcher placing a synchronous orbit satellite into space. This is an elliptical orbit with an apogee of about 36,000 km and a low perigee. Such high altitudes have proved popular with Amateur satellite users for really wide area communications coverage, giving pleasurable, un-pressured intercontinental communications for many hours at a time, unlike low-earth-orbit (LEO) satellites. As the coverage of the earth is large, such orbits are popular with the DX operator in many of us.

Similarly popular have been the bandwidths of the transmitting and receiving equipment (transponders) of satellites such as AO-10 and AO-13, as they provided lots of "elbow room" for many simultaneous SSB QSOs. Phase 3D will also have these features, which allow many operators to use the satellite at the same time, in deference to the single-channel FM LEO satellites.

GTO operations typically have an orbit with an apogee of about 36,000 km and a low perigee of only hundreds of kilometers. The Ariane 4 launches, that placed AO-10 and AO-13 into orbit, had characteristic perigee values of 200-300 km and thus required quick action by the spacecraft controllers, using on-board propulsion systems, to raise this low perigee to avoid orbital decay. The Ariane 5 launcher is a different story, as it leaves satellites in a GTO with perigee values in the range of 600 km, and the orbital drag of that perigee is insignificant, eliminating the need for any perigee-raising propulsion. On-board satellite propulsion systems are expensive and lend a very large element of complexity to a design. A satellite without propulsion really becomes light and fulfills our KISS goals.

Another target for this prospective satellite design is that it can be completed within a three year period. This time is sufficiently short enough to be attractive to constructors to maintain their interests and application. Maintaining a cadre of volunteer constructors is a significant challenge; a short gestation period should enhance their retention to the program. We also need to maintain and retain the user and support communities. This becomes difficult with a lengthy program. This time concept also affects the funding efforts, as long programs cost more. While a target of $500,000 is seen as a maximum, such a sum should be viewed as an absolute top limit and funding budgets should really be set to considerably lower values.

To construct this conceptual satellite we must think in terms of reusing as much of the broad technology base that we have created over the last 25 years. There are many good ideas. There are some ideas that are too expensive, or otherwise inapplicable. So those of us doing the scheming on this design have lots to choose from, and this will be explored with you in this paper. One clear goal of any such design deals with design concepts previously used, and "if it isn't broken, don't fix it". One of the goals that benefits from our prior experience is that the completed satellite design must not be so heavy that it causes launching problems, and a 50 kg goal seems reasonable.

Spaceframe Design

With the preamble complete, let me explore with you what kind of spaceframe can be constructed to meet these goals. The first concept is that the satellite must be able to fit in an existing launcher that will provide us the desired GTO positioning.

Clearly I will not consider another P3D spaceframe as that is much too large and costly, although it fits the Ariane 5 launcher. Arianespace does have a mini-satellite launching platform with the Ariane 5, called ASAP5. In fact, the AMSAT Microsat satellites were launched in 1990 on the very first ASAP implementation on an Ariane 4 launcher. For Ariane 5 the ASAP5 platform has gotten larger and more capable. The ASAP5 is not so large, however, that we could mount another Phase 3C (OSCAR 13 or AO-13) spaceframe. These limits rule out using one of the more recent existing spaceframe designs. We need to explore what kind of spaceframe can be placed on an ASAP5 platform that will provide us with the satellite features that are desired.

Without consulting Arianespace on their ASAP5 payload limits, I can at least identify a geometry that is useful. Getting this design accepted for launch would be another matter and will not be explored in this paper.

Implicitly, the goals of this spaceframe are for a spin-stabilized operation that uses magnetorquer techniques for attitude and spin control, much as for AO-13 and for the early operations of P3D. This then means that the mechanical design must insure that the design is spin stable about the desired axis.

Another key driver is that of power generation. AO-13 had an initial peak power generation of about 70 Watts, and used six solar panels of 400x540 mm. This power level is expressed as a beginning-of-life (BOL) and at a sun angle of $\beta=0°$ (Beta angle), fairly standard rating methods. Actual power use should not exceed 60-70% of the peak value, as solar cell age-decay and sun-angle conditions will not support higher power consumptions. This power level can be considered barely comfortable for the kinds of communication equipment that we would like to orbit. It is clear that the size limits of satellites that can be mounted on an ASAP5 platform also significantly restrict the power generating capability and thus maximum transmitter power output.

We would like to be able to reuse as much of the electronic equipment designs from P3D as possible, and this drives some of the internal spaceframe design. Some modules can be directly used from P3D, while only the modular housing can be used for others. This will be explored later.

We cannot place a P3C spaceframe on an ASAP5 platform, as it is too large, and P3D is too large and expensive. What is wrong with the geometric concepts of P3D? This is exactly what went through my mind! I did not need to "invent" a new geometry, just a new set of dimensions. Let me explore this one with you. Fig.1 is the result of this head-bone exercise, a design shape that you should recognize. Like most AMSAT satellites, this is really a flying antenna platform and the spaceframe shape helps supply that larger platform. I do not pretend to have completed antenna designs posted on top of this spacecraft, merely some useful representations and concepts borrowed from P3D.

This design of spaceframe, which I will call P3E for this moment, is 900 mm across the flats of the hexagonal cylinder, and it is 400 mm high. This gives six solar panels that are 400x520 mm, very near the size of those for OSCAR 13, and a power production of 82 W using GaAs (η=18%) solar cells or 69 W using more conventional silicon BSFR (η=15%) solar cells.

Well, now, how does this fit onto the ASAP5 platform? Actually I cheated and studied the fit before the shape that I have shown you. Fig.2 shows a sectional view of the Ariane 5 payload mounting to the upper propulsion stage. You can see that this is a large cavity as the ϕ5400 mm is 17.7 feet across the outside! The internal dynamic clearance inside of the shroud is still large at ϕ4570 mm. And the ASAP5 platform is ϕ3860 mm. While this P3E spaceframe can fit on the ASAP5 platform at this point, there is no guarantee that it would be allowed. It turns out that the V clamp-band separation section used for P3C would provide a very nice mounting for the P3E.

Figs.3 & 4 show the line drawings of the assembled spaceframe and its structural skeleton. While I can guarantee that there will be changes in this design before any flight, the spaceframe design shown is plausible and is based on our P3D experiences. I have liberally employed the use of NC machining for this design, coupled with good sheet metal practices. Hopefully some of these NC parts can be reduced to sheet metal. The calculated all-up mass of this spaceframe is 10.6 kg and approximately 2 kg of fasteners will need to be added, totaling 12.6 kg, which places us well on the way toward a 50 kg spacecraft.

Payload Modules

This is probably the most controversial aspect of any such project, especially since most of our contributors to this are electronically inclined. I feel, however, that we cannot afford to load up on modules and experiments willy-nilly. We must stick to basics to hold down weight, cost, and development time. We must reuse as many of the basic modular designs provided early on for P3D. The concept has proven flexible and adaptable to a wide range of variants.

Another concept is that any module with significant power dissipation must be carefully scrutinized as we cannot afford a highly specialized spacecraft thermal system, as we have in P3D. All of the higher power dissipation elements must be adaptable to conduction cooling, especially in transmitters. From P3D we do have some useful modular adaptations that can be used on P3E.

Now for the suggested module list:

- U Band transmitter, HELAPS
- S Band transmitter, HELAPS
- U, L & S Band receivers and preamplifiers
- IHU2 computer, adapted from P3D, with CAN-LAN bus
- Sensor Electronic Unit (SEU), GPS and preamps
- Battery Charge Regulator (BCR)

The design shows that there are six equipment bays, and each can only hold a single stack of P3D-type modules on the equipment panel that is 254x400 mm. The above list does not include a RUDAK as is on P3D, even though I know that the digital experimenters will want one. Any such RUDAK unit must be able to operate on just 2-3 W, which is quite a change from P3D as that module consumes 19 W running bare, and up to 32 W with everything cooking. This mission cannot afford such power-hog modules. The principal consumer of power on this P3E mission must be the prime payload, the RF communications equipment.

One experiment on the P3D mission will bear careful watching for its applicability to P3E. This is the spacecraft-wide buss system called CAN-LAN. When we first evolved the designs for P3D, in the early 1990's, a common bus system was desired to reduce the wiring complexity and penalty. At that time, however, such buss systems had not evolved to the level of certainty that was needed to base the spacecraft electrical design upon. Nevertheless, work did proceed on flying a buss system as an experiment. The CAN buss system was determined to be applicable as integrated circuit chip-sets were becoming available. In P3D this buss system is widely used to interconnect experiments that are not mission critical. With success on the P3D mission, it may be worthwhile to use such a buss system as the principal interconnect method on P3E.

An area of potential controversy is that there is no V Band equipment (2 meters). Principally this is a three-fold situation, being a lack of module and antenna spaces, and that there are more reliable Amateur communications that can be obtained using U, L and S bands.

Antennas

That we are all ham radio operators automatically makes all of us antenna experts! That comes with the territory. Now down to real antenna conditions. Show in Figs.1 & 3 is one possible configuration. The large circular patch antenna is straight from the P3D spacecraft and is for U Band operations on 435-437 MHz. The P3E top surface is large enough to be able to hold three of these patch antennas for the desired gain, but then there would not be room enough for any other antennas. Thus only a single patch is shown for U Band.

Taking from our experience with the U Band patch antennas, an array of three patch antennas is shown for L Band operation on 1267-1270 MHz. This should provide useful gain of 10-12 dBic, less than for P3D but about correct for a spin stabilized satellite in a 36,000 km elliptical orbit.

For S Band operations, in the range of 2400-2402 MHz, a small Helix antenna is shown. P3D uses such a Helix for one of the S Band antennas. There may be a problem here in that such an antenna protrudes prominently from the spacecraft, and this may make for more difficult interfacing to the Ariane 5 launcher. A more desirable antenna for S Band would be a patch array. That array may need to be of an etched circuit board design as opposed to the "air design" arrays used on U and L Bands.

Not shown are any provisions for omni-directional antennas needed at times on such a mission. This could possibly consist of single patch antennas or some kind of $\lambda/4$ wire antenna. Stiff wire antennas sticking out of the spacecraft would again address the issue of "things sticking out" and possible launcher interface issues. However, a U Band $\lambda/4$ antenna would only protrude some 172 mm and a L Band $\lambda/4$ antenna would only protrude some 59 mm.

All of these discussions not withstanding, this proposed P3E spaceframe does afford a pretty nice piece of territory that can be used for the needed communications antennas. We need to wisely use this resource. Once the module complement of the mission is settled, the next large area of "discussion" would be that of antennas.

Power Generation & Storage

Shown in Figs.1 & 3 are solar panels populated with solar cells of the same size used on P3D (25x62 mm). They nicely fill the 400x520 mm panels with six strings of 19 cells. It would be planned to wire these cells into three strings of 38 cells, close to the arrangement in P3D of 41 cells per series string. This provides a solar power supply of about 19 VDC that can be boosted to about the 28 VDC needed to charge the 20 NiCd, or preferably NiMH storage cells. It is also clear that we must strive to obtain the highest output

(GaAs) solar cells that we can. This will be an expensive item.

The P3D auxiliary battery configuration is in mind for service in this P3E spacecraft as it has a high power density and a capacity of about 20 Ahr. This is seen as a pretty robust energy storage method for P3E. A battery configuration of 20 cells was determined to be desired on P3D as it precluded any power buss voltages that would exceed 30 VDC under any conditions. This voltage boundary is needed to avoid any possible semiconductor damage due to device common rating limits starting at 30 VDC on many semiconductors. In P3E, it is planned that the battery cells would be grouped into assemblies of five cells per unit and mounted in the central cylinder of the spaceframe. Such a mounting will provide some useful latitude in achieving a proper spin-balance of the assembled spacecraft. This battery with its mounts (P3D) will weigh about 11 kg.

All of this power operation will be controlled by an adaptation of the P3D battery charge regulator (BCR). The principles of the BCR go back many years to the earliest Phase 3 spacecraft, P3A, in the 1978-80 time frame. By keeping the same power buss voltage used on P3D, we can avoid the need for any major BCR design change.

The solar panels themselves will involve a lot of the technology employed for P3D, with some from AO-13. These panels are planned to be a honeycomb design of 400x520 mm with a core thickness of 6.4 mm (0.250 in.) and using 0.2 mm thick carbon fiber facesheets. The P3D panels were 675x1102 mm and 12.7 mm thick using 0.4 mm thick facesheets. This facesheet thickness was found to be much greater than needed, and the smaller panel reduces the facesheet thickness requirement even more. AMSAT experimenters are conversant with all of the technologies needed to produce such panels.

Conclusion

It seems obvious to me that creating the design of a P3E spacecraft is mostly a task of marrying much of what is already known and bringing that to a new spaceframe configuration. Approaching such a project in this manner can insure that it can be done in a reasonable amount of time and for a reasonable amount of funds. Probably the largest uncertainty is that of finding workable conditions for an interface with the Ariane 5 ASAP5 platform.

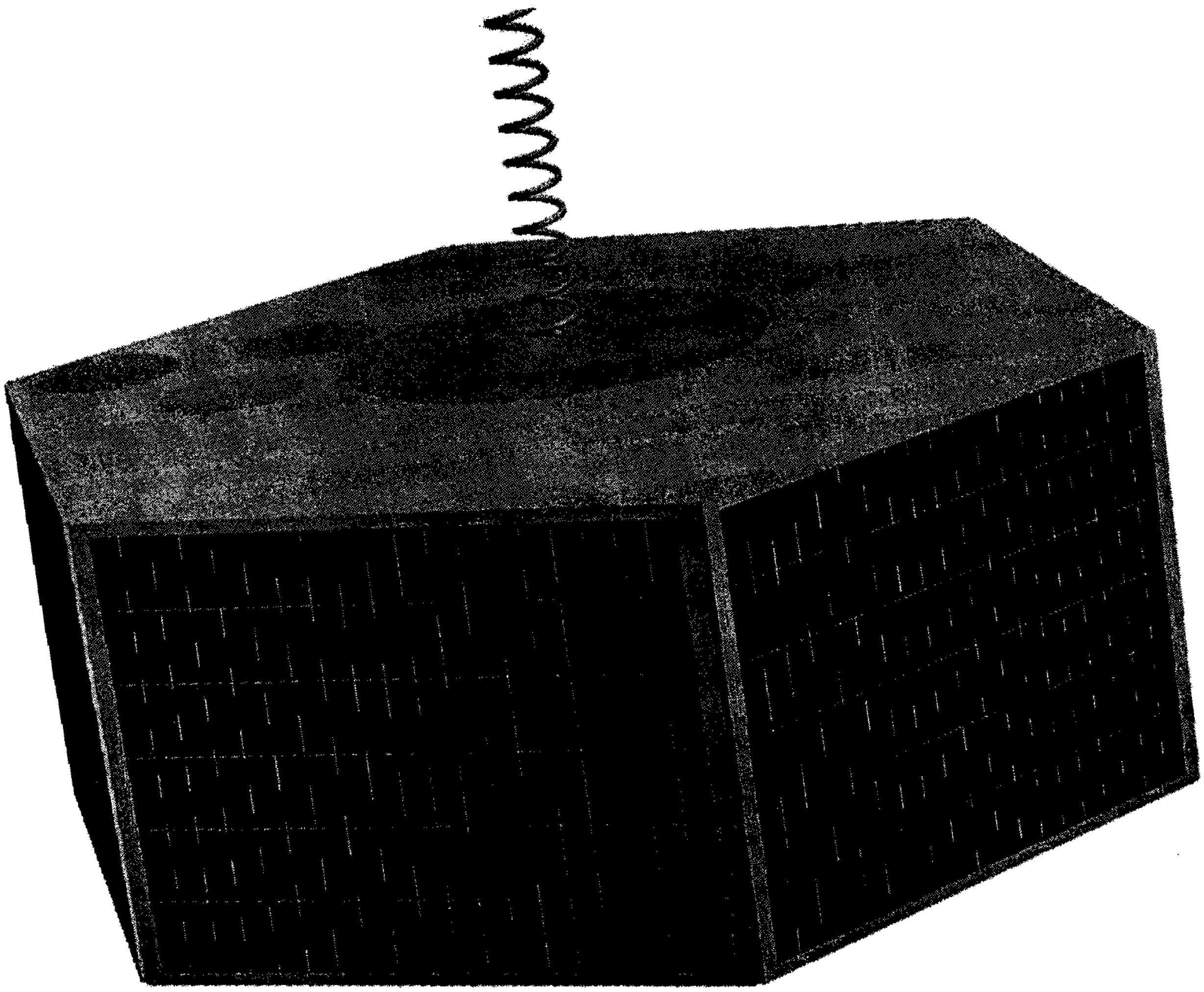


Fig.1, P3E Rendered Overview

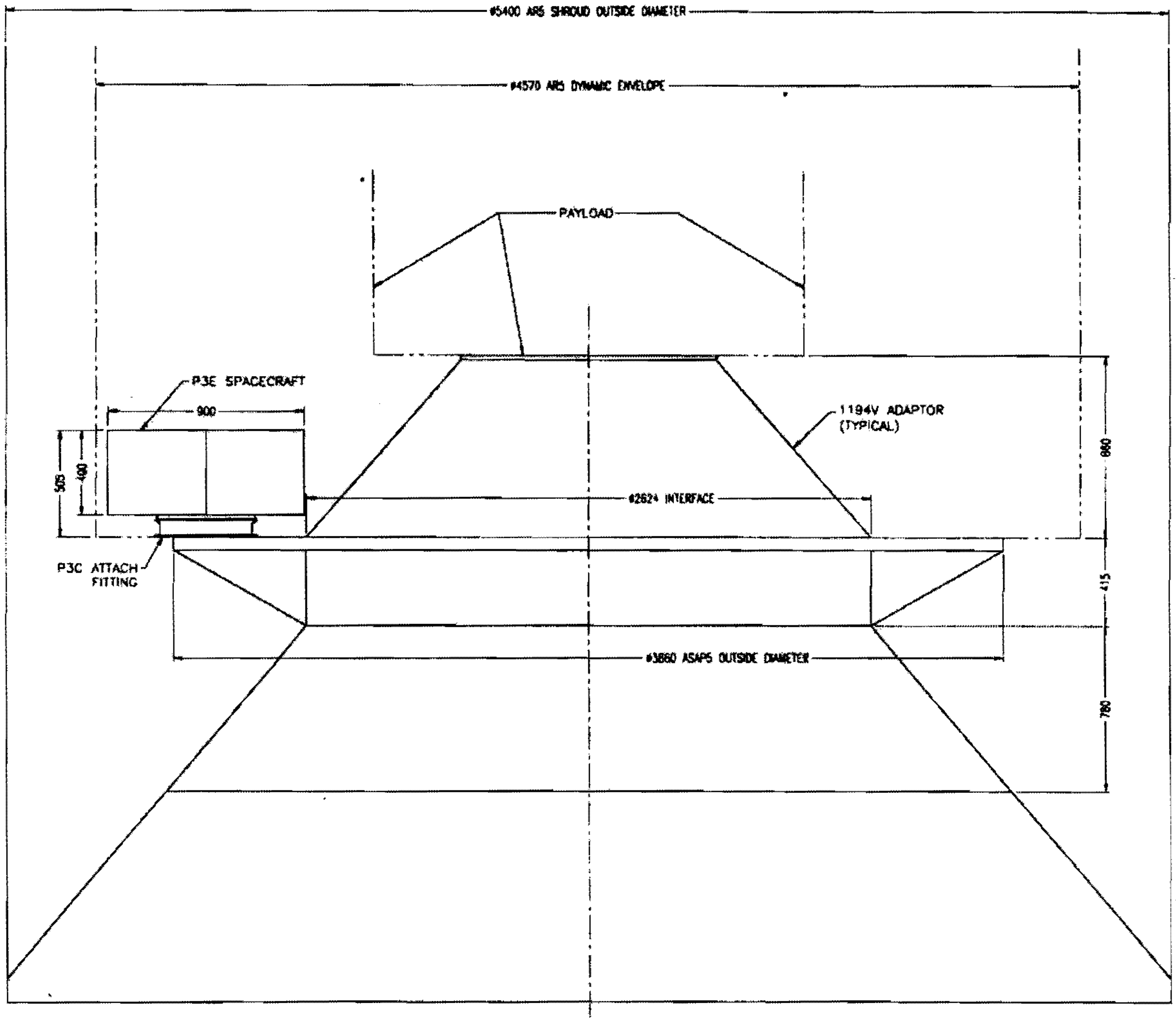


Fig.2, Ariane 5 Space Available

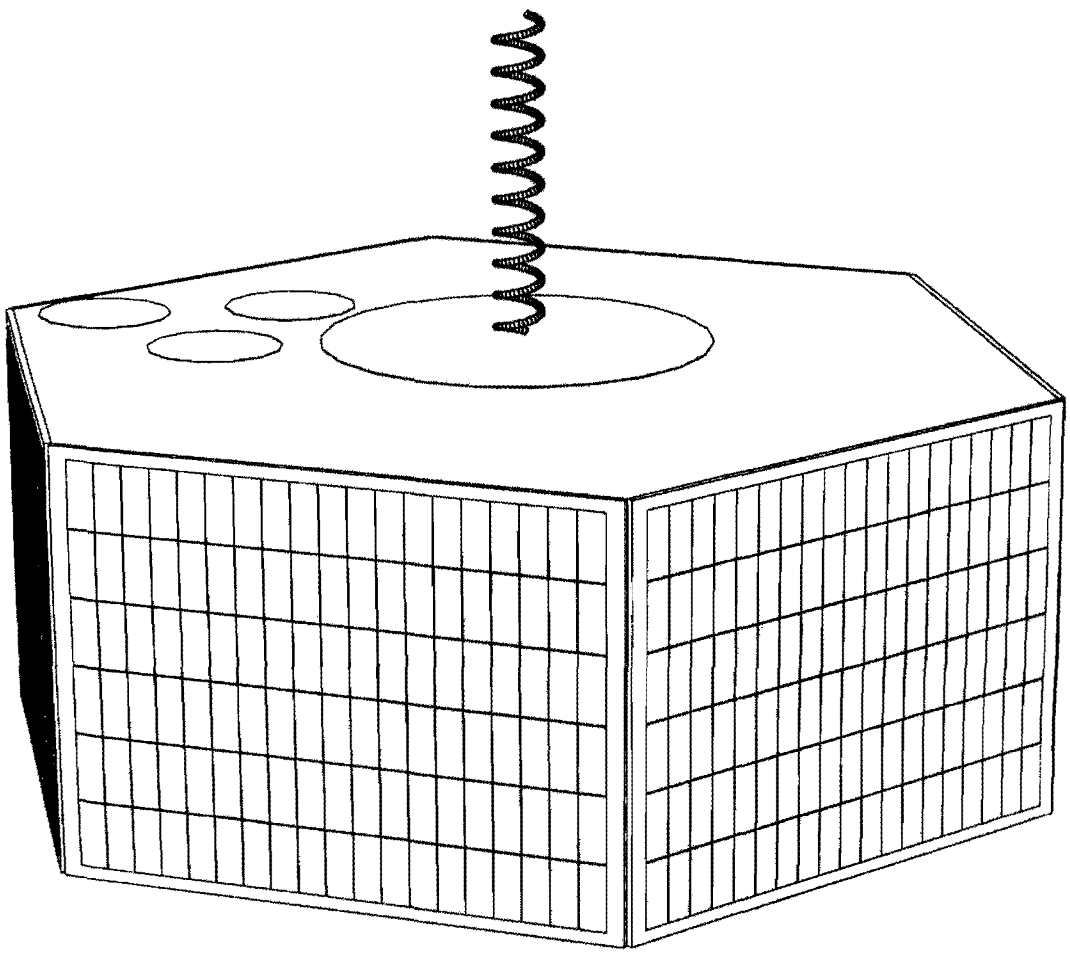


Fig.3, P3E Line Overview

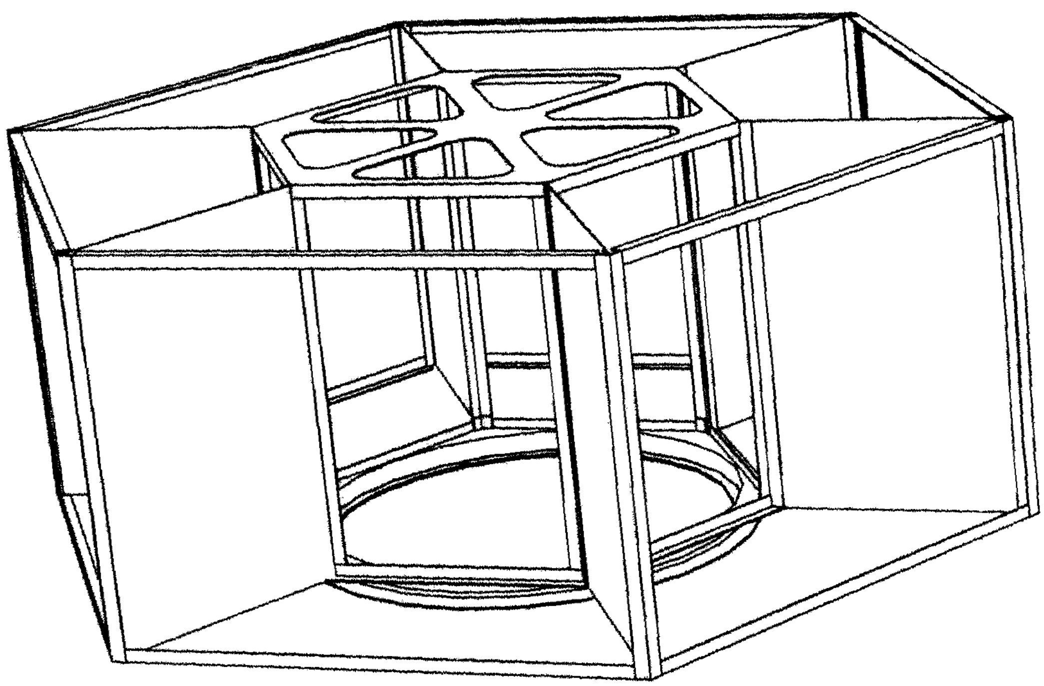


Fig.4, P3E Spaceframe Skeleton

Amateur Radio On-board the International Space Station

Frank Bauer, KA3HDO
and
Will Marchant, KC6ROL

Abstract

Amateur radio has had a substantial presence in human space flight since the mid-1980s. For over 16 years, amateur radio space enthusiasts in the U.S., Russia, and Germany have worked diligently to develop, deploy and coordinate operations of on-orbit amateur radio stations on the U.S. Space Shuttle and the Russian space station Mir. Human space flight is expected to change in the near future as the aerospace community rapidly evolves its focus towards operations on the International Space Station (ISS). The international amateur radio community is working with the aerospace community to make amateur radio a permanent fixture on ISS. This update of last years paper will summarize the status of the ISS program, the development of an initial station for use on-board ISS, and the opportunities and plans for implementing a permanent amateur radio station on-board the ISS.

Ham Radio and the Human Space Flight Connection

Amateur radio has had a significant human presence in space starting with a flight on board the space shuttle orbiter Columbia on the STS-9 mission late in 1983. At that time, astronaut Owen Garriott, W5LFL, provided an unprecedented level of excitement to the amateur community by talking to hams on the ground using a 2-meter FM transceiver. These modest beginnings 17 years ago have led to a significant, nearly continuous presence of ham radio in human-tended space vehicles today.

With twenty-five flights, the Space Amateur Radio Experiment (SAREX) has become the most flown payload on board the Space Shuttle. The primary goal of SAREX is to pique student's interest in science, technology and communications by allowing schools around the world to talk with the astronauts during Shuttle missions. The crew also uses the equipment for a limited number of personal chats with close friends or family members and to talk to hams on the ground during their break times. SAREX has accomplished a number of firsts in human space flight. SAREX was the first to demonstrate crew-tended 2 meter voice, packet radio from space, crew tended amateur television uplinks and Slow Scan TV uplinks and downlinks.

In 1988 a permanent amateur radio facility was placed on board the Russian space station Mir. Technical capabilities have steadily increased on Mir over time. Currently Mir provides capabilities for 2m voice, a packet bulletin board system, slow scan television, a 70cm repeater, and a digi-talker. This station, developed primarily by our German (SAFEX) and Russian colleagues, provides an important spontaneous link for the astronauts and cosmonauts. While it isn't officially a backup communications source for Mir, ham radio has served as a secondary psychological ice-breaker; for the Mir crew, particularly after events such as the political and economic reorganizations in Russia and the 1997 Mir/Progress accident.

The Mir space station amateur radio facilities have provided a critical capability for the crew. As stays in space get longer and longer the psychological impacts of isolation become more severe. Amateur radio allows the crew to interact with friends and loved ones as well as serving educational needs with school contacts. The ability to perform random QSOs provides a vital psychological break for a crewmember that may have been stuck "in a tin can" with their crewmates for months at a time.

The world's space flight community is now concentrating a significant amount of their resources on the development and implementation of an International Space Station (ISS.) The ISS has gone through a number of name and configuration changes since its first inception in 1985. The current design calls for modular components from a number of countries to be lofted on board Russian expendable rockets and the United States Space Shuttle. Construction began in 1998 with permanent human residence to start in 2000.

With ISS hardware design and development underway, preliminary planning for ISS on-orbit operations took place through joint experiments and U.S. astronaut visits on board the Russian space station Mir. This joint U.S.-Russian activity was called ISS "Phase 1." U.S. astronauts learned valuable lessons on Mir during their 4-6 month stays. Astronauts were primarily transported up to Mir using NASA's Space Shuttle. Supporting experiments, hardware and materials were carried on the shuttle or on the Russian Progress resupply ships. This effort had refocused nearly all the Space Shuttle missions to become Mir/Shuttle docking flights. Since these missions were typically fairly short and exceedingly busy, the SAREX team had curtailed its activity on those Shuttle missions. During the construction of ISS, the U.S. space shuttle has become a primary carrier of ISS hardware, materials, and crew. Thus, these flights will also be too busy for SAREX activities. During this time of transition, the SAREX team reduced its activity on the shuttle and concentrated on astronaut amateur radio operations on Mir. In parallel, the SAREX team in the USA worked with its international partners to make the ISS a permanent base for amateur radio operations. The amateur radio facility on ISS is expected to be used by the visiting shuttle crews, if they have time, and will serve as an educational outreach and recreation tool for the crews stationed on the ISS.

In November of 1996 a meeting was held at Johnson Space Center in Houston, Texas with representatives from national amateur radio organizations of eight countries. This meeting served to initiate the dialog on the development of a permanent amateur radio station on ISS. The outcome of the meeting was a Memorandum Of Understanding (MOU) that states that the groups would work together to coordinate the development of one amateur radio plan for the ISS. This coordinated international station would be called ARISS for Amateur Radio on the International Space Station.

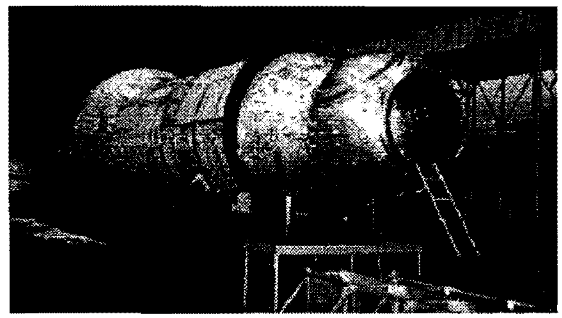
In July of 1998 a follow up meeting was held in Surrey, England to better define the hardware complement to be flown for ARISS. An international "hardware committee" has been established which will define the permanent ham station for ISS, given the space and power resources obtained from the ISS project. An administrative committee was also established to work on matters such as the station call sign, third party traffic and general operations scheduling. On-board space for the permanent ISS facility is expected to become available late in the ISS construction project (around 2004). In the interim, the international hardware committee has been charged with implementing a series of "transportable stations" which can be launched as early as December 1999.

A joint meeting between NASA and Energia was held in Houston on January 22-27, 1999. This meeting finalized the design of the initial set of amateur radio hardware for the ISS and was to "develop a more effective understanding and advocacy of the ARISS program within NASA and Energia." The hardware proposed includes equipment housed in the pressurized "Zvezda" service module as well as antenna systems located around the periphery of Zvezda. A total of four amateur radio antenna systems were baselined and hardware delivery schedules were established. A detailed set of minutes from this meeting, including details of the hardware concept, have been published in the AMSAT Journal (reference #3.)

A meeting was held amongst the ARISS partners in early 2000 at the ESA/ESTEC facility in The Netherlands. Meeting minutes are available on the ARISS web pages. Briefings from all the working groups were presented. A significant outcome of the meeting was the reorganization of the European ARISS members into one group with four votes in ARISS matters. This leaves the voting ARISS members as: Canada, Europe, Japan, Russia, and the USA. The other partners have two votes each.

ISS Development Status

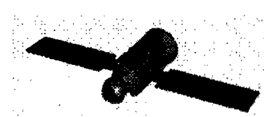
Deployment of the ISS is progressing fairly well. The first component of the ISS is the Russian Functional Cargo Block (FGB) named "Zarya." See figure 1. This first ISS element was launched November 20th, 1998 on board a Russian Proton rocket. The Russian built Functional Cargo Block provides initial propulsive capability through the early life of ISS. The first USA built "node," named "Unity," was launched on space shuttle flight STS-88 a month later on December 4th. The nodes provide six connection ports that will allow different modules to be docked, providing a way to build the ISS out of separate modules. The Russian built "Zvezda" Service Module launched on July 12th, 2000. It provides propulsive, attitude control, and life support



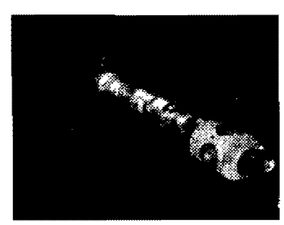
systems for the ISS.

Functional Cargo Block (Zarya)
readied for Flight
Figure 1

In September of 2000 the STS-106 Space Shuttle flight to ISS, called the "2A.2b Logistics flight," will carry supplies to ISS. The ARISS team in the US has arranged for the launch of an initial ham station, with



Functional Cargo Block "Zarya" November 1998



STS-106 2A.2b Logistics Flight September 2000

voice and packet capabilities on 2 meters and 70 cm, on this flight. This initial station, called "ISS Ham," will provide a temporary ham radio capability on board the ISS.

UF-3 September 2004
Figure 2

The initial station will be temporarily located in the Functional Cargo Block, and will only support 2m operations through the FGB "Sirius" antennas. External antennas for the Service Module will be delivered later and are scheduled to be installed on a spacewalk during mission 5A.

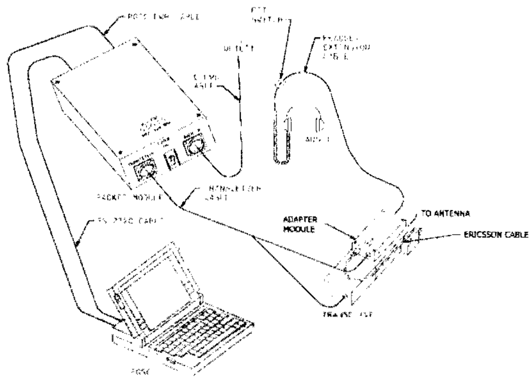
Several years later on flight UF-3, (figure 2) currently scheduled for September 2004, the ARISS US team has arranged for space on board an "EXPRESS Pallet." EXPRESS Pallets are mounted external to the station, and it is expected that there will be room for a fairly sophisticated "OSCAR like" payload.

A request is in progress for permanent rack space in the "habitation module" which is to be launched on flight 16A in late 2005. The request includes access to external antennas and access to the ISS computer systems for status information.

Initial Station Development Status

A block diagram representation of the initial ISS Ham radio station is shown in figure 3. The initial ham radio station on ISS will use intrinsically safe commercial 2m and 70cm hand held radios from Ericsson. See figure 4. These radios are extremely rugged and will not pose a hazard on the Space Shuttle or ISS.

The radios are very simple to operate, with text displays for frequency configurations. If needed, they can be easily reprogrammed to support future configurations.

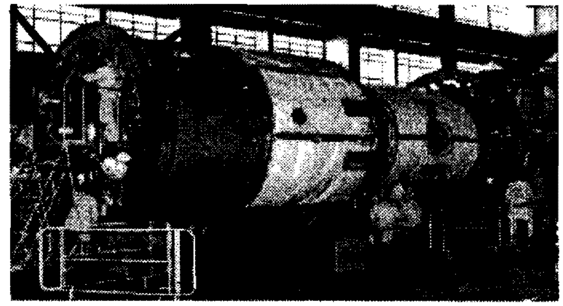


Initial ISS Ham Configuration
Figure 3

Ericsson Radio, Power Converter, Adapter Module, & Headset
Figure 4

The packet bulletin board system on Mir has proven to be incredibly valuable for educational and recreational activities. The primary problems observed with the Mir packet system is the limited memory space for messages and the fact that only a single connection can be made at a time. Hams unfamiliar with Mir packet operating practices have been known to lock up the system over an entire pass because the single connection does not time out for approximately 5 minutes. The Terminal Node Controller (TNC) that is being qualified for the ISS transportable station is the PicoPacket TNC from PacComm corporation. PacComm TNCs are also used on board Mir so the user interface for the Mir and ISS systems will be close if not identical. The PicoPacket will also support multiple connections so this should ease some of the problems that have been seen when connecting to Mir.

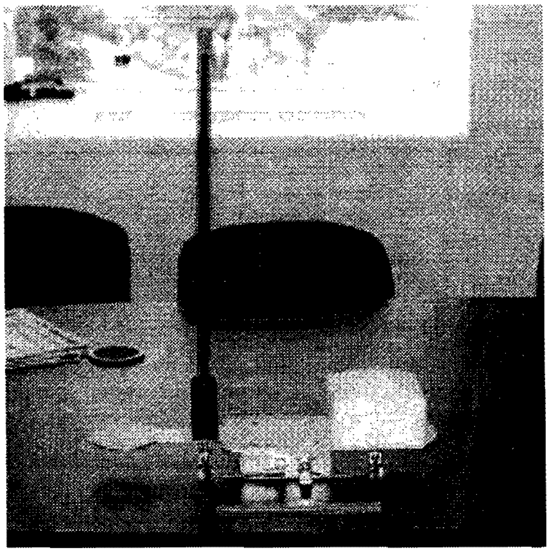
The ISS Ham initial station will initially be installed in the FGB and then move to the Russian Service Module. The service module has no rack space for an amateur radio station, so the station will be attached to the wall using Velcro. A power receptacle has been reserved for the radio station and a Russian power cable has been produced to attach to the service module power receptacle. Our Russian colleagues have installed a total of 4 antenna feedthroughs on the Service Module to support ISS Ham operations. Four antenna systems will be mounted around the periphery of one end of the service module. See Figure 5. These externally mounted antennas (see Figure 6) are being supplied by our Italian colleagues to provide a 4-6 watt voice and packet communication capability.



Approximate Antenna Locations
Figure 5

All these components are to be delivered to the ISS on the 2A.2b logistics flight (STS-106) that is tentatively scheduled for launch in September of 2000. The ISS Ham hardware that will be installed inside the Service Module (radios, packet TNC, etc.) has completed qualification and flight verification testing and has been delivered to the Spacehab team at the Kennedy Space Center. The Spacehab team has loaded the "pressurized module" hardware into the Spacehab module that serves as the hardware stowage facility for the 2A.2b STS-106 mission. The antenna systems and their special adapters and cables are currently under final integration and testing. They will be transported in Spacehab and then mounted on handrails outside of the Service Module during a spacewalk on ISS mission 5A.

The antenna systems being developed for ISS include a dual band VHF/UHF antenna, a multi-band microwave antenna and a diplexer mounted on a plate that attaches to an Extra Vehicular Activity (EVA) handrail-clamping device. See figures 6-10. A total of four flight antenna systems are being developed. These four antenna systems will attach to the four bulkhead feedthroughs on the Service Module that were made available to the ARISS international team through substantial efforts by Sergej Samburov, RV3DR in Russia.



Antenna System Mockup
Figure 6

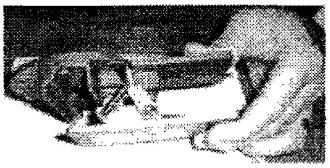
Antenna System Components
Figure 7

Top view of the EVA handrail clamp adapter
Figure 8

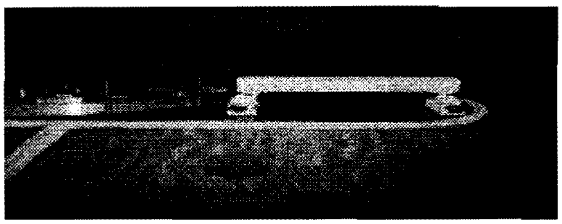
A high fidelity EVA mockup was developed by the AMSAT-NA/Goddard Amateur Radio Club team in Washington DC. This mockup (see figure 6) and four additional mockups were delivered to Matt Bordelon, KC5BTL, in Houston for EVA training. On one of the four antenna systems, the VHF/UHF dual band antenna will be swapped out with a 2.5 meter HF antenna. In all, the four antenna systems will support amateur radio operations on 20 meters, 15 meters, 10 meters, 2 meters, 70 cm, L-band and S-band.

The VHF/UHF and HF antennas were developed by the ARISS team members in the U.S. They use a flexible measuring tape covered with yellow Kapton as the driven element. A large circular piece of Delrin provides a solid mounting interface and houses the connector and attachment hardware. A tuning stub is mounted below the VHF/UHF antenna to provide maximum efficiency of the antenna system. The design is very robust and has no sharp edges.

The microwave antenna system, developed by the ARISS members in Italy, will support L-band and S-band operation. Alberto Zagni, I2KBD, and Paolo Pitacco, IW3QBN, are leading the antenna system development in Italy with past coordination by Fabrizio Bernadini. The microwave antenna design chosen by the ARISS team consists of a flat spiral antenna mounted on a printed circuit board that is mounted on an aluminum box that serves as the antenna cavity. A white Delrin radome covers the antenna to protect the antenna from damage and the crew members from sharp edges during EVAs. See figures 7 and 11. This antenna is dual use in that it is intended for ham operations and NASA/Energia use. It has been specially designed to serve as the antenna system which enables the ISS crew to transmit and receive local video during their EVAs using a Glisser television system.

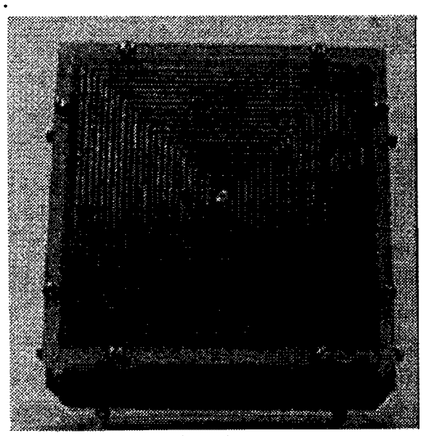


Side view of the EVA handrail adapter
Figure 9



Side view of EVA handrail
Figure 10

The diplexer, designed and developed by the Italians, provides an efficient split in radio signals between the lower frequency (HF/VHF/UHF) antenna and the microwave antenna. The antennas, diplexer, EVA "Clothespin-type" handrail clamp, and the various coax connections will be integrated in the U.S. on an antenna system plate developed by the U.S. team as shown in figure 7.



Microwave (L/S) Antenna
Figure 11

The flight antenna systems are currently being integrated and run through a battery of antenna measurements at the NASA Goddard Space Flight Center, in Greenbelt, Maryland. AMSAT-NA member Ron Parise, WA4SIR is leading a team of hams from Goddard's Microwave Branch in the test activity. Once antenna testing is completed, the four antenna systems will be shipped to the Kennedy Space Center for launch on in 2001.

Initial Station Upgrades

Several upgrades to the ham radio station on ISS are planned. These include upgrades to the initial station, development of a larger, transportable station, installation of the Express Pallet system and the development and installation of the Permanent, Rack mounted system.

Upgrades of the initial station will include a SAFEX supplied digitalker module, a cable for dual band (2-meter/70 cm) operations, a SSTV capability and an RF filter to prevent interference with the Russian communications system using 143.625 MHz. The digitalker speaker-microphone functions as a digital voice memory beacon and was developed by the German SAFEX team members. With this device, the crew members can record short messages in the digitalker's memory, and the unit then sends the message as a beacon at specific intervals. The ARISS team expects to launch this hardware on a Shuttle/ISS flight in the year 2001.

In late 2001 there exists an opportunity to place an upgraded transportable station on ISS. This will likely consist of a SAFEX supplied dual band transceiver, digitalker, and packet unit which will provide a more robust dual band capability to support operations until the permanent station can be implemented.

A Permanent Amateur Radio Station on the ISS

Plans for the development of a permanent amateur radio station located in the habitation module have also begun. A set of derived requirements were generated for the permanent station. These are shown below.

Permanent station derived requirements:

- Eight minute contact with well equipped ground station
- Computer to computer radio links
- Thirty second contact with a minimal ground station
- Autonomous beaconing of status in digital form
- Still picture transmit & receive
- Video transmit & receive
- Support continuous contacts (for at least thirty minutes)
- Support multiple concurrent operations
- Space-to-space as well as space-to-ground operations

Based on these requirements, the NASA ISS management were briefed on specific interfaces for the ham station. The briefing suggested 30 kg of hardware in a standard 19 inch wide rack. The rack-mounted system would be 24 inches high and would draw 200 Watts of power. The station includes external antennas, and connections to the ISS audio, video, and computer networks. ISS management thought these requests were quite reasonable. A summary of the hardware described included:

- Multi-band radio support: 10m, 2m, 70cm, & up
- External Omni antennas for voice and low rate data: nadir and zenith
- 5-25 Watts transmit power; 100 Watt for ATV
- Flexible TNCs (probably DSP based)
- Multiple transceiver systems to support concurrent operations
- PC interface to the ISS flight computer systems
- Video processing capability (to support SSTV and ATV)
- Gained antennas for high data rates
- Active station control through the ground
- Pass planning and scheduling software
- Expandability for experimentation

The briefing also suggested external allocations for four "microsat class" payloads that could be changed out. This would allow schools and universities to develop stand alone payloads and not have to worry about attitude control, or power concerns. This allocation has been made on an EXPRESS Pallet scheduled for a flight in 2004. It will be incumbent upon the hardware committee to rapidly formulate plans to effectively utilize this space before it gets reallocated to another project.

Plans for utilizing the externally mounted payload opportunities of the EXPRESS Pallet still need to be generated. The initial EXPRESS Pallet is on the bottom of the ISS so it provides an ideal Earth view for amateur radio operations. Each Pallet can hold six experiment adapters, and ARISS had been allocated half of one of those, to be shared with a Jet Propulsion Laboratory optical communications experiment. The JPL experiment has been cancelled, and the status of the ARISS EXPRESS Pallet allocation is being investigated. Each adapter has a cubic meter of usable volume and a kilowatt of power is available on each EXPRESS Pallet.

Plans for utilizing these resources will come in the form of proposals to the international hardware committee. It will be the responsibility of the international hardware committee to evaluate the technical merit and feasibility of the proposals and generate a final integrated plan for the ISS. Those

wishing to review the status of the various ISS hardware proposals are welcome to peruse the world-wide-web site:
http://ariss.gsfc.nasa.gov

Launch windows and configurations of the final permanent station are still being evaluated. Designs will be modular to allow easy replacement of failed components and to allow for upgrades and experimentation. Command station operations will be supported from the ground so that crews will not have to spend valuable time reconfiguring the station.

Conclusions

The historic use of amateur radio on the Space Shuttle and Mir to support educational outreach, crew personal contacts and interaction with terrestrial-based hams will become even more important when the international aerospace community migrates to the International Space Station. The ARISS international partners are working hard to transform the dream of a permanent amateur radio station on the international space station into a reality. The first ARISS hardware, the "Initial Station" has been developed by an international team and is expected to be on-board ISS late this year or very early next year.

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CubeSat: The Next Generation of Educational Picosatellites

Prof. Jordi Puig-Suari, jpuigsua@calpoly.edu
California Polytechnic State University
San Luis Obispo, CA
Prof. Robert Twiggs KE6QMD, Bob.Twiggs@Stanford.edu
Stanford University
Stanford, CA

ABSTRACT

A picosatellite called CubeSat is now under development by more than 20 groups of amateur radio enthusiasts and universities. This picosatellite that is a 4" cube and will weigh about 1kg presents a real advantage for interested space enthusiasts in that it is significantly less expensive to build than micro or nano satellites and due to the small size and weight will be relatively inexpensive to launch into space. There is a technical challenge of building a useful satellite this small, but also political challenge of providing the frequency spectrum that would be required if hundreds of these CubeSats were launched using the amateur frequency bands. This paper will describe the international program of developers, the launch opportunities available for CubeSats, some of the issues with global operation of these satellites, some experiments planned for them and some proposals for sharing amateur frequency bands for educational purposes.

TABLE OF CONTENTS

1. INTRODUCTION

The current trend in satellites to do more for less cost has led to the "Smaller, Cheaper, Faster, Better" space missions. It is generally resulting in many cases of doing things the same way as before in a somewhat smaller format for less cost, but this has been cited as the basis for some of NASA's recent deep space mission failures.

To support some science missions and in proposing new missions, the trend is now to see what can be done by decreasing the spacecraft sizes by orders of magnitude. This is becoming more practical with the rapid advances in decreasing electronics size, in greatly increased capability and very low power consumption. This decrease in size also directly benefits the mission cost in lower launch costs.

There are several programs now exploring micro, nano and pico satellite sizes. These sizes ranging from <100kg to <1kg are being developed and tested by combined programs such as the ones discussed in this paper with Stanford University, The Aerospace Corporation, Santa Clara University, University of Tokyo, Dartmouth College, California Polytechnic State University and groups of private amateur satellite enthusiasts.

This paper will describe a program for a picosatellite called CubeSat as a collaborative effort to continue developing the picosatellite, provide a convenient low cost launch interface and coordinate launch activities.

2. CUBESAT DEVELOPMENT PROGRAM

After the experience gained with OPAL and the launch of the picosatellites, it was determined that picosatellites could be used for many useful space missions as well as a practical space education program.

The nominal OPAL picosatellite was 4x3x1 inch. To get sufficient power from body mounted solar cells, it was determined that a better size would be a cube that had enough surface area to be able to generate at least two watts with the present state-of-the-art solar cells. This was found to be practical with the new 25% efficient triple-junction GaAs cells on a surface of 3.5x3.5 inches.

It was found that the OPAL tube launcher provided practical means of launching picosats since it did not require a direct interface for each picosatellite. The picosatellite was held by four corners with two per launch tube. From this experience, it was decided to design a cube that was 4 inches per side. A metric system unit was chosen as the standard considering a recent NASA Mars failure. The CubeSat dimensions of 10cm were selected being very close to the 4 inches originally used. This allowed room for the solar panels and room to contain the cube on some rails in a launcher tube. With each cube being 10cm long, it was decided to do an initial design for a launch tube that would hold 3 cubes. Thus the new picosatellite called CubeSat and launcher tube was conceived.

Since the students at Stanford University were all occupied building microsatellites, it was decided to form a collaborative relationship between Stanford and California Polytechnic State University (Cal Poly) at San Luis Obispo, CA. Cal Poly also had a reputation as a very hands-on undergraduate engineering university. This collaborative effort was established in the fall of 1999 where Cal Poly would complete the launcher design, build a prototype and evaluate it for improvements.

The CubeSat program was announced to many of the organizations, educational and amateur groups that were interested in building low cost picosatellites. This paper has descriptions of the launcher from Cal Poly and CubeSat developments from an amateur radio group in Washington D.C. called The Stensat Group, University of Tokyo, and Dartmouth College. There are now more than 20 organizations world wide that are beginning development of the CubeSat picosatellite.

2.1 CubeSat Launcher Development

2.1.1 Launcher Requirements

One of the main objectives of the CubeSat program is the development of a new class of standardized picosatellites. The CubeSats' size and mass standards, 10 cm cube and 1 kg respectively, is developed as an extension of the picosatellites deployed by Stanford's OPAL spacecraft. The CubeSats' dimensions are large enough to provide significant power through the use of body mounted solar cells. Moreover, the CubeSats' mass is large enough to carry a significant payload given current developments in small and efficient sensors, processors and communications equipment.

Beyond the initial form factor and mass of the CubeSats, additional standard features are determined by the need to interface the spacecraft with a standard deployment system. The CubeSat deployer must satisfy a number of requirements:

- The deployer must protect the launch vehicle and primary payload from any mechanical, electrical or electromagnetic interference from the CubeSats even in the event of a catastrophic CubeSat failure.

- The CubeSats must be released from the deployer with minimum spin and a low probability of collision with the launch vehicle or other CubeSats.

- The deployer must have the ability to interface with a variety of launch vehicles with minimum modifications and with no changes to the CubeSat standard.

- The mass of the deployer should be kept to a minimum.

- The deployer should incorporate a modular design that allows different numbers of CubeSats to be launched on any given mission.

- The resulting CubeSat standard should be easily manufactured without using exotic materials and expensive construction techniques

The Poly Picosatellite Orbital Deployer (P-POD) shown in Figure 2.1 is the result of a lengthy development process by Cal Poly students to satisfy the requirements above.

The tube design produces a reliable linear course for the CubeSats without significant spin. This deployment method was successfully demonstrated in the Opal mission. The tube provides an enclosure strong enough to handle the structural failure of one of the CubeSats while providing a Faraday cage to protect the primary payload. During the deployment sequence the CubeSats ride on rails built into the corners of the tube and a simple spring provides the force to push the CubeSats out of the deployer with a linear velocity of approximately 0.3m/s.

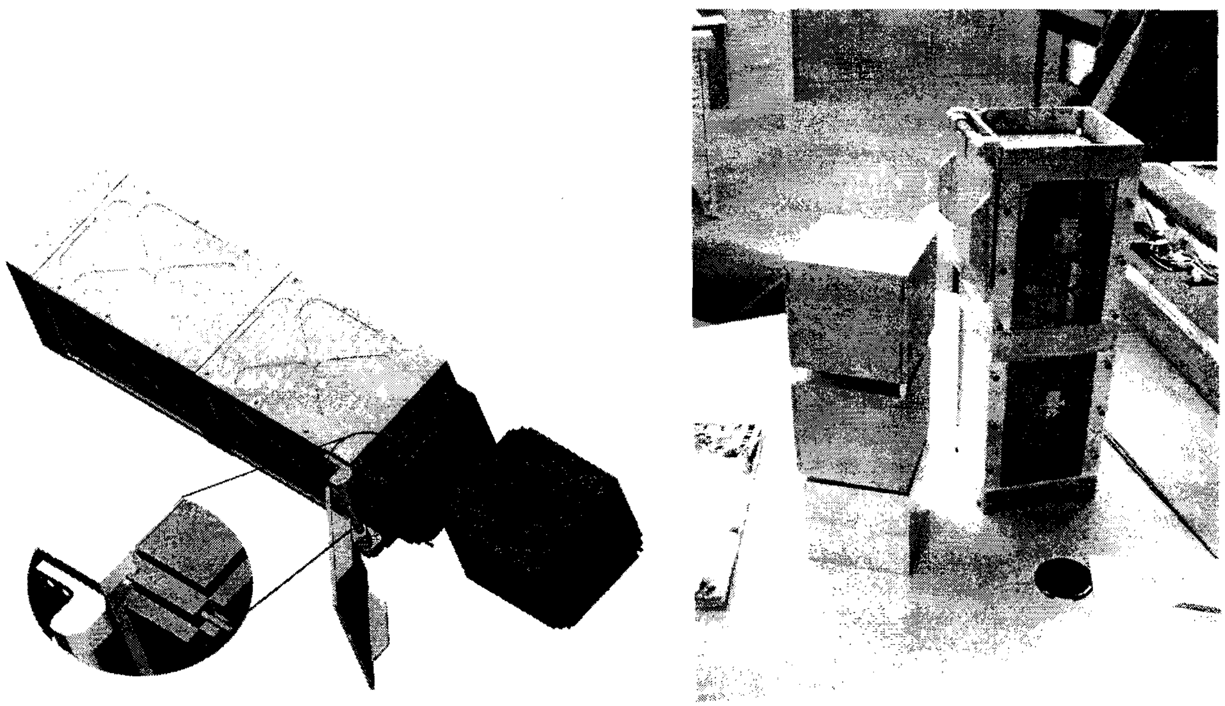

Figure 2.1: P-POD releasing CubeSats with rail detail and Prototype Model

Deployment is initiated by the release of the P-POD's spring-loaded door using a G & H Technologies cable release actuator. The standard P-POD deployer contains 3 CubeSats although the design could be lengthened to fit a larger number of CubeSats. In addition, the P-POD's design allows a number of deployers to be mounted together on a launch vehicle as shown in Figure 2.2.

The P-POD is constructed using 7075-T6 Aluminum due to this material's high strength, ease of manufacture and relative low cost. The deployer is designed to sustain 15g loads resulting in a total P-POD mass of approximately 1.5 kg.

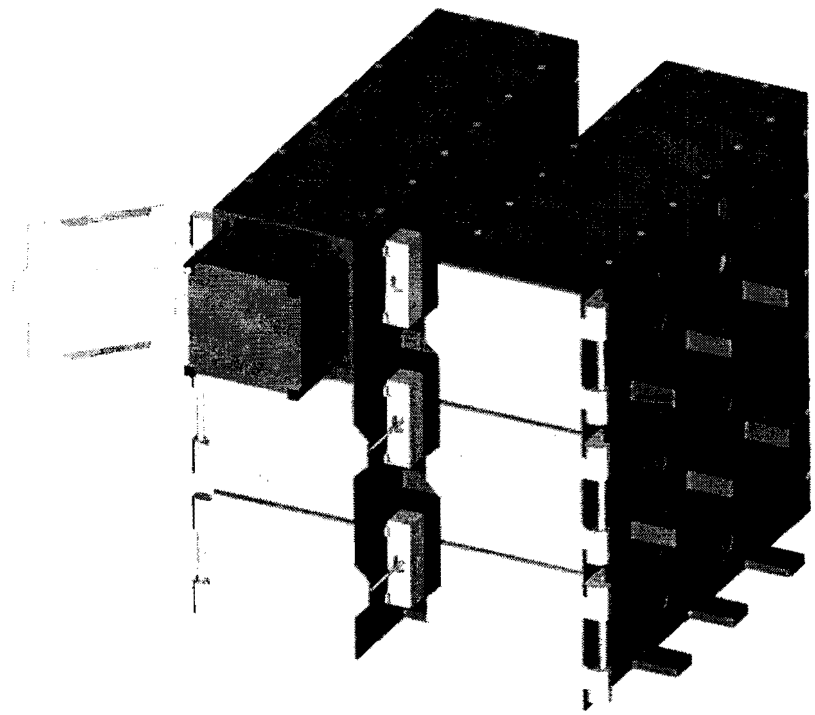

Figure 2.2 A 2 X 3 Launcher Set for 18 CubeSats

Given the P-POD's design, a final set of standards for the CubeSats can be developed. A CubeSat specification drawing is shown in Figure 2.5. In addition to the basic size and mass requirements some standard requirements are introduced by the deployer.

- The CubeSat needs 8.5 mm clearance on the four side edges, which will be used to slide along the internal rails of the deployer.
- Eight 7 mm standoffs on the top and bottom faces of the CubeSat are required to provide separation between CubeSats.
- On top of each side, excluding space for the rails and standoffs, an additional 6.5 mm space is available to accommodate solar panels, antennas, or other components extending beyond the 100mm limit.
- A minimum of one kill switch is required in the standoffs on the top plate (Figure 2.5) to insure that none of the CubeSats are active during launch. Along with the kill switches there is also a requirement for a "remove before flight" pin, to deactivate the CubeSat during shipping and loading.
- An optional data port can be included in the design in order to complete last minute check or to charge internal batteries after the CubeSat is loaded into the deployer.

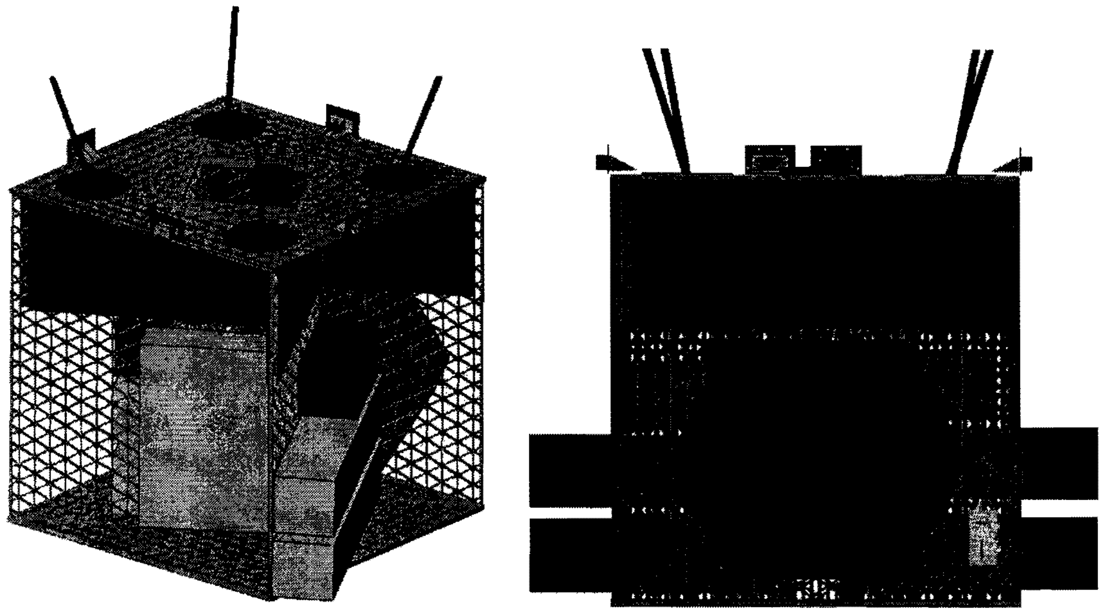

Figure 2.3 Launcher Tubes Shown on MPA Used for OPAL

Figure 2.3 shows four launcher tubes mounted in the MPA used for OPAL. Figure 2.4 shows a single length tube used by developers for fit check of the CubeSat dimensions. It can also be used for vibration, thermal cycle and vacuum testing. This tube also is used as a shipping container to ship the CubeSat to Cal Poly for final integration into the P-POD.

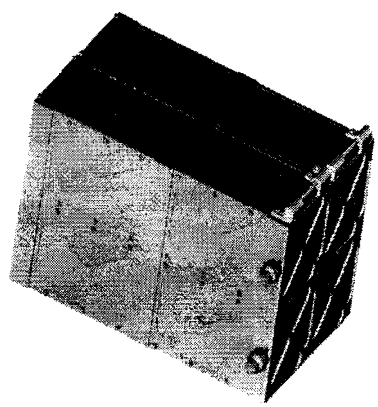

Figure 2.4 Single Length Launcher Used by CubeSat Developer

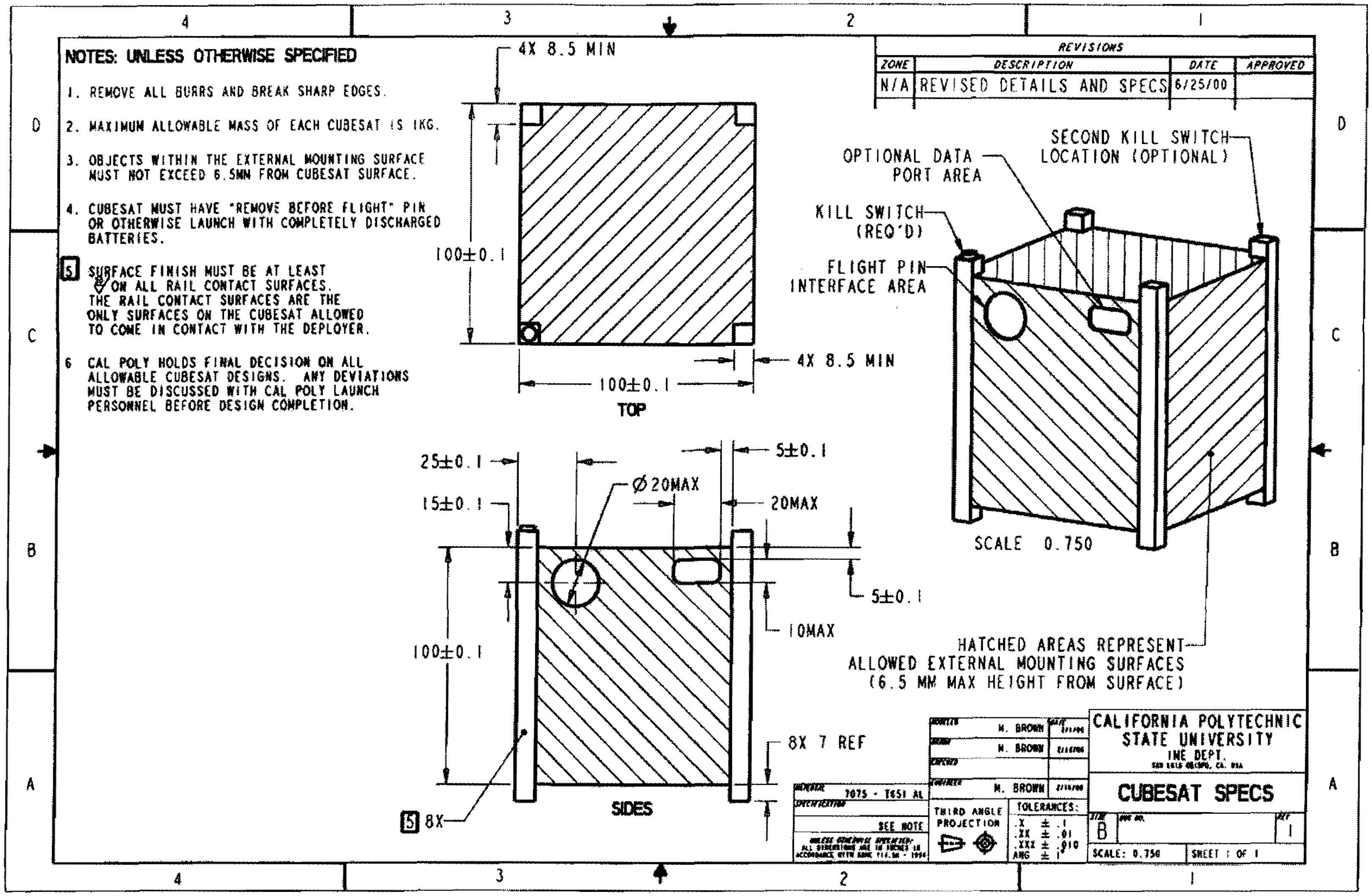

Figure 2.5 CubeSat Physical Dimensions

Participants in CubeSat Program

3.1 The Stensat Group

3.1.1 Introduction

The Stensat Team is a group of engineers including amateur radio operators who came together to design a satellite because we are engineers and have nothing better to do. We wanted an unusual hobby and figured this can't be too strange without the risk of being put in a mental institute. Kevin Doherty, Hank Heidt, Jim Bobbus, and Dave Nemai made up the original group for the first Stensat amateur satellite. Joining the CubeSat program is Ivan Galysh and Gil Dutchover from the Naval Research Laboratory. Each member brings a unique skill to the group and has the great desire to design and launch a successful satellite.

We were asked to develop a standardized generic vehicle. The purpose is to design a bus once and allow users to concentrate on the payload and not the spacecraft design. The CubeSat design will provide a standard bus to allow simple and easy control of the payload while allowing flexibility in the design of the payload.

3.1.2 CubeSat Design

The basic design of the satellite is comprised of a cube structure with a stack of circuit boards inside. Each face of the satellite will be covered with solar cells. The center of the satellite will have two rechargeable batteries. The batteries split the functions of the satellite into two parts. One half of the satellite contains the satellite computer, communications electronics, and attitude control system. The other half is available for a payload.

The CubeSat design is influenced by target characteristics defined by the group and constraints placed by the CubeSat Program. The CubeSat program constraints are the dimensions and mass. The group defines all other design characteristics.

The CubeSat program put a couple of constraints on the design of the satellite. The first constraint was the dimensions to be a ten-centimeter cube. The cube also requires having rub rails for deployment out of the CubeSat launcher. The other requirement is the mass of the satellite. The current constraint is one kilogram. This constraint imposes significant limitations and challenges in designing the structure of the satellite. A 10-centimeter cube of water has a mass of one kilogram. Materials used in the satellite structure have a significantly higher specific density than water. This limitation requires a creative approach to designing the structure. A 10-centimeter cube will have a large empty volume inside. The current CubeSat design has a mass of about 800 grams leaving 200 grams for the payload.

There are several group defined target characteristics influencing the design of the CubeSat. The reproduction of the CubeSat is to be less than one thousand dollars. The design is to be simple and use standard commercial components. The critical components selected should have some radiation data associated with it. For example, Motorola using the MOSAIC process manufactures the transmitter and receiver integrated circuits. This process is known to produce radiation tolerant devices.

Another characteristic includes low power consumption. Available power is to be 1 watt. Bus mean power is specified to be about 250 milliwatts. Redundancy is designed into portions of the power system. Most of the redundancy lies in the solar cell circuitry and power distribution. Each face of the satellite contains eight solar cells. Four solar cells are connected in series. The two series of solar cells on each face are connected in parallel. If a solar cell fails on a face, only four solar cells are lost. The other four still contribute to the satellite power bus. Each face is connected in parallel. The batteries are also redundant. Circuitry isolates the batteries from each other while allowing them to contribute to the bus power.

To minimize components and structural mass, some components have multiple purposes. The solar cells will provide power and also be used as sun sensors. The printed circuit boards with the solar cells also have a coil pattern on the opposite side for use as the magnetorquer coils. The circuit board stack containing the satellite processor, communications, and payload will also be structural members.

Payload services are designed to provide flexibility in operating the payload. Communications and control from the satellite processor include an IIC bus and digital control signals. The IIC bus was developed by Philips Semiconductor and provides a simple serial interface to the payload. Four digital bidirectional lines are available to the payload. Two analog to digital converter inputs are made available to the payload. A power control signal is provided to allow the satellite processor to power down the payload. A payload reset signal is also provided. The receiver audio signal is provided to the payload. This allows the payload to monitor received signals. The user can communicate directly with the payload through the receiver. The payload also has access to the transmitter modulation signal. When allowed, the payload can generate its own modulation for transmission.

3.1.3 Current Design

The current CubeSat design uses some of the design from the original Stensat picosatellite. The CubeSat will use the same uplink and downlink frequencies and modulations. The receiver uses a Motorola MC13136 single chip receiver. It is designed to receive on the 2-meter amateur radio band. The gain of the receiver is about 100 dBm. It can support FSK modulation bit rates up to 9600 baud. The receiver operates at a voltage range from 3 volts to 5 volts. It consumes a mere 15 milliamperes.

The transmitter uses the Motorola MC13176 single chip transmitter. It operates in the 70-centimeter amateur radio band. It can support up to 9600-baud FSK modulation bit rates. The transmitter operates at 3 volts. It is connected to an RF Microdevices RF2104 single chop amplifier. At 3 volts, it can output up to .5 watts consuming 300 milliamperes.

The integrated circuits used in the receiver and transmitter are radiation tolerant. Based on data and testing from other satellite programs, the Motorola devices are manufactured using the MOSAIC process. This process happens to be very radiation tolerant. The RF Microdevices RF2104 amplifier uses bipolar-junction technology and is also fairly radiation tolerant. These devices have been used in previous commercial and military satellites.

The antennas are deployable antennas mounted on the surface of the satellite. It uses the rub rails in the launcher for deployment. The antennas are constructed on a piece of printed circuit board as a copper trace. There are four such circuit boards, two for the uplink and two for the downlink.

A typical amateur radio satellite ground station can be used to communicate with the CubeSat. All modulation techniques and frequencies are typical.

The power system consists of the solar cells, batteries, and the power distribution and control circuitry. Each face of the satellite contains eight solar cells. The solar cells are grouped into two sets of four solar cells. Each set of solar cells is connected in series. The two sets on each face are connected together in parallel. They are isolated with schotky diodes. If one series fails, the other series can still be used. Each face is connected in parallel. This configuration maximizes redundancy and maximizes power efficiency for the circuitry.

The batteries selected are lithium-ion rechargeable cells. The cells need special handling. They operate normally between 3.1 volts and 4.2 volts. If the cells are discharged too much or overcharged, the cells may explode. The power circuitry contains circuitry to maintain safe operation of the cells. The power converters are charge pump circuits. The power bus is unregulated. The voltage can range from 3 volts to 4 volts.

The satellite controller contains a single chip computer. The processor selected is a PIC controller from Microchip. It is a PIC16C77. The PIC contains an eight channel eight-bit analog to digital converter. It also contains several digital ports. The controller accepts commands from a DTMF decoder using a dual tone sequence. The controller also generates AX.25 telemetry packets that are APRS compatible. An MX614 FSK transceiver is used to generate the AFSK tones. The telemetry packet contains environmental sensor data, payload sensor data, and operation status. The controller monitors its environment with the analog to digital converter. The inputs of the analog to digital converter are connected to a temperature sensor, bus voltage sensor, bus current sensor, and two payload analog signals. The four payload digital signals are connected directly to the controller. Each digital signal can be commanded to operate as an input or an output. The state and direction of each signal is included in the telemetry packet.

The satellite controller board contains a latchup detection circuit. Being in orbit, the processor is exposed to high energy particles. Eventually, the processor will be hit by a high energy particle and have one or more transistors latched in an improper state. This can cause the processor to draw a large amount of current. The latchup detection circuit is designed to detect a sudden increase in current and cycle the power to the processor. Cycling power clears up the latchup. Not all high energy particles cause a latchup. Some will cause a bit flip called a single event upset (SEU). An SEU can cause data to be corrupted or program execution error. The circuit designed uses a MAX890L high-side current switch. The MAX890L allows the current limit to be set with an external resistor. When the current exceeds the limit, the device will cycle the power. The MAX890L is used to detect current increases greater than 200 milliamperes. Even though the PIC processor consumes less than 40 milliamperes during normal operations, the total dose radiation effects need to be considered. As the processor is exposed to radiation, the total dose accumulation will cause the processor to increase its power consumption over time. Total dose radiation testing showed that the processor consumed 180 milliamperes at its end of life. In the case that a small latchup occurs where the current increase is less than the limit, the voltage from the MAX471 current sensor is monitored for changes. It is possible for a latchup to occur in the processor and the processor to still operate. Software would be used to detect the smaller current changes. If the current change is determined to be a latchup, the processor can stop pinging the external watchdog timer. The watchdog timer is a MAX824. If it is not pinged within 1.6 seconds, it will cycle the power with a MOSFET transistor. If an SEU causes data or program execution to be corrupted, the processor will stop pinging the watchdog timer. All of these devices are connected in series. The MAX890L is connected to the power bus. Next, the MAX471 current sensor is connected to the output of the MAX890L. The MOSFET transistor is connected to the output of the MAX471. The two Maxim parts can support of to 1 ampere of current. The power through each Maxim part is through a very low impedance resistor. The voltage drop is insignificant. The combination of hardware and software provide a robust latchup and SEU detection system.

The PIC controller underwent radiation testing at the Naval Research Laboratory. Exposing the die to a laser performed Latchup and SEU testing. The laser is used to approximate high energy particles. Latchup was determined to occur at about 17 MeV. When exposing certain parts of the die, the processor continued to operate during a latchup event. The maximum current measured during a latchup was 600 milliamperes. The PIC controller was never damaged by a latchup. The SEUs occurred at about 2 to 3 MeV. It took little energy to flip bits. Exposing the EEPROM to the laser actually induced program execution errors. None of the EEPROM bits could be flipped by laser exposure. The maximum energy level exposed was about 300 MeV. Even at this high energy level, no damage was induced. When the watchdog timer was exposed to the laser, it stopped working. It was not able to reboot the processor. An external watchdog timer is needed. For total dose testing, the PIC controller was exposed to an x-ray source. The x-ray source was calibrated so that it could be correlated to a cobalt-60 radiation source. The PIC controller failed after being exposed to 20 Krads. The failure was due to the EEPROM being set to all zeros. The PIC controller could be reprogrammed. For a second exposure, the PIC controller was exposed to and additional 15 Krads before complete failure. The PIC controller couldn't be reprogrammed after the second exposure.

The first payload will be a picosat attitude control experiment. The payload will control the spacecraft magentorquers. It will have magnetic field sensors for each axis. The processor architecture will allow for software uploads. The processor will need to be fast enough to calculate orbital position from time and uploaded keplarian elements. At this time, one of the newer faster versions of the 80C52 eight bit processors has been selected. It can access external memory and peripherals. If the experiment is successful, then a more compact version of the 80C52 can be used. Radiation hardened versions of the 80C52 do exist for those who need longer duration missions. Subsequent satellite designs will incorporate the attitude control on the satellite controller.

3.1.4 Satellite Structure Evolution

When the group started designing the CubeSat, the group went through a few design evolutions. The initial design specification early in the program was for a 3.5 inch cube. The design was highly modular. There are only two different types of panels. All of the side panels are identical. Each panel is made of 1/8-inch aluminum. The center area is machined out to allow for mounting of a solar panel and magnetorquer coil. The inner sides of the panels have rails machined to allow mounting of the circuit boards. The top and bottom panels are designed to deploy antennas. The antennas are constructed of piano wire and wrap around a racetrack machined in to the top and bottom panel. A solar panel can be mounted on the panels. The panels also provide shielding for the RF electronics. The RF circuit board mounts to the panel. The components are oriented into the panel cavity. The circuit boards are stacked and can slide into a partially assembled structure using the rails on the side panels.

Assembly is simple. The RF circuit board has connectors for each face. The connectors are used to connect the solar cells, magentorquers, and sensors to the bus. The side panels contain the mating connectors. The side panels are attached to the top and bottom. The connectors help in alignment and provide the snap together assembly. Assembling three sides to the top and bottom panels allows the circuit board stack with battery compartment to be slid into the structure. The last side panel is then snapped in and all screws can be inserted.

3.2 Dartmouth College

3.2.1 Introduction

DARTSat is a CubeSat being designed and built by students and faculty at the Thayer School of Engineering at Dartmouth College. This program is to take a modular approach to educational and research microsatellite design. Professor August S. Moore directs this program.

An initial structure design was based on the 3.5-inch cube. The main difference is increasing the size to a 10-centimeter cube and adding rub rails. The 10 cm cube meets the CubeSat structure requirements. The panels were designed for solid panels 1/8 inch thick. Then the problem with the design was that the mass exceeded the limit. The structure had a mass greater than 1.5 kilograms.

The latest design uses minimal aluminum. Four slotted posts are connected together with thin sheets of aluminum. The assembly requires epoxy. No screws are used. The circuit boards contribute to the structural strength. The battery is not mounted in an enclosure. It is epoxied between two circuit boards.

3.2.2 Standardized Design

The Stanford / Cal Poly CubeSat program has presented a unique opportunity to develop a modular architecture for extremely small educational and research spacecraft. The vision is to develop a standardized satellite bus that provides basic power, control, and communications functionality to one or two miniaturized payloads. These payloads are constructed as stand-alone components with standardized interfacing that will allow them to be "snap-in" additions to the DARTSat bus. Service modules are manufactured and subsequently paired with unique payloads as specific launch opportunities are realized.

The first generation DARTSat is a testbed for this concept and will begin an ongoing program of satellite development and space-based research at Dartmouth College's Thayer School of Engineering.

3.2.3 CubeSat Design

The approximately 4-inch cube specified by the CubeSat program defines the overall configuration of DARTSat. Of the 61 cubic inches available in the configuration, 75% are dedicated to the satellite bus and structure. A payload bay, designed to accept either several PCBs or a component box measuring 3 by 3 by 1.5 inches, is situated on one side of the cube. Photovoltaic cells are installed on five of the six sides of DARTSat. The side not covered is optimized as a radiator to regulate the satellite's internal thermal environment and act as the deployment point for the satellite's four antennas. DARTSat is passively oriented to the earth's magnetic field to provide consistent pointing of communications antennas, experiment sensors, and photovoltaic panels.

DARTSat's highly integrated Microprocessor Control Unit (MCU) is extremely compact and occupies a single PCB that is only 2.75 inches square. It is designed around the Intel 8051 family of microcontrollers. The microcontroller's firmware operating system performs all of the satellites major functions, including burst transmission of experimental data, power management, and mode switching for the satellite's transmitter. Ground control of microprocessor functions is accomplished through simple strings of "touch-tones" interpreted by a Dial-Tone MultiFunction (DTMF) decoder. A 9800 bps packet modem is installed to transfer both research and satellite system data via ground stations equipped with standard HAM radio packet data receiving capability. And a simple Power Allocation and Monitoring (PAM) subsystem, commanded by the MCU, will provide real-time control of the power consumption of individual components and subsystems. Electrical power is distributed on a 3.6V bus. Two, 3.6V Li-Ion battery packs are used to provide redundancy and buffer the power generated by the external GaAs photovoltaic panels.

Satellite communications is accomplished through FM Amateur Radio Frequencies. Use of two frequencies, the 144 MHz band for transmitting and 440 MHz band for receiving, maintains flexibility, decreases transceiver complexity, and allows the satellite to be used as a HAM radio repeater. Deployable dipole antennas, one for each band, provide fairly efficient transmission strength and the passive pointing provided by the earth's magnetic field insures good ground reception as the satellite passes over North America.

3.2.4 Conclusion

The DARTSat team has focused its efforts on the development of the satellite service bus. Payloads for DARTSat are under development here at Dartmouth and at other institutions. These include plasma and auroral mapping experiments and unique GPS applications. Because the extremely modular nature of DARTSat allows for payloads to be conceived and produced independently from the satellite services, a wide variety of payloads from a large number of sources are possible.

3.3 University of Tokyo

3.3.1 Introduction

Intelligent Space Systems Laboratory (ISSL), a laboratory directed by Prof. Nakasuka in the Department of Aeronautics and Astronautics, University of Tokyo, has been studying a large membrane space structure for several years with an intention to apply it to huge solar cells, communication antenna, debris catcher or other missions[7-9]. One way to deploy such large membrane in space is to use centrifugal force. The mission of ISSL's CUBESAT is to experiment the deployment of large thin film solar cells using centrifugal force generated by spinning the satellite main body. Figure 3.3.1 shows the image of the satellite with its membrane deployed. The results of the experiments will be useful for studying the way of deploying a huge membrane as well as finding out a simple way to provide large power to small satellites without much complicated systems.

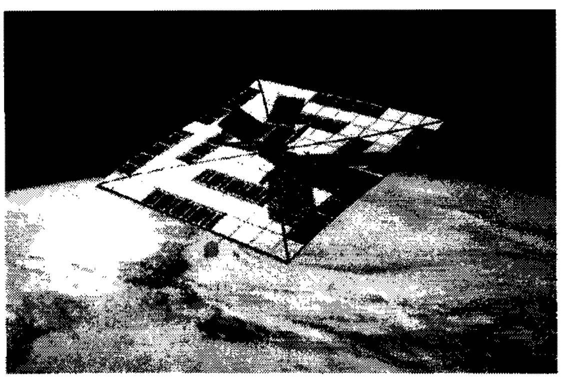

Figure.3.3.1 Image of Univ. of Tokyo CUBESAT on orbit with Membrane Deployed

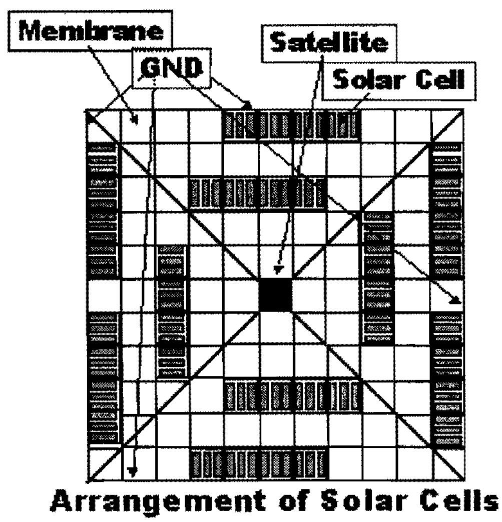

Figure 3.3.2 Configuration of Membrane (after deployment)

In the CUBESAT mission, we specified the following four success levels, which also show the mission scenario.
Level 1) Educational objectives to experience satellite design, fabrication, testing, launch, operation and analysis of results.

Level 2) To receive some beacons from the satellite. This success means that the satellite could endure the environment of launch, and that the subsystems needed for downlink communication work properly in space.
Level 3) Successful experiment of deployment of membrane and receive of the experiment data by using uplink command. All the operation until this level is performed using the power loaded on the battery before launch.
Level 4) The solar cell on the membrane supplies power to the battery and the satellite will survive for some period.

3.3.2 Brief Description of the Satellite and Subsystems

3.3.2.1 Weight and Power Budget

The design is under way and so some parts are subject to change.

3.3.2.2 Membrane

Figure 3.3.2 shows the configuration of the membrane. Total 120 solar cells are glued to some part of the Kapton membrane, which will produce 27.9 W when the solar angle is maximum. The size of the membrane after deployment is 880 mm by 880 mm, and it is before deployment folded around the cubic body of the satellite.

Several experiments to find out the required rotational speed to deploy the membrane successfully have been performed, which indicated that the rotational speed of 20 rpm is required to deploy the membrane from the folded position, and that 5 rpm is required to keep the shape of the membrane after deployment.

3.3.3 Schedule

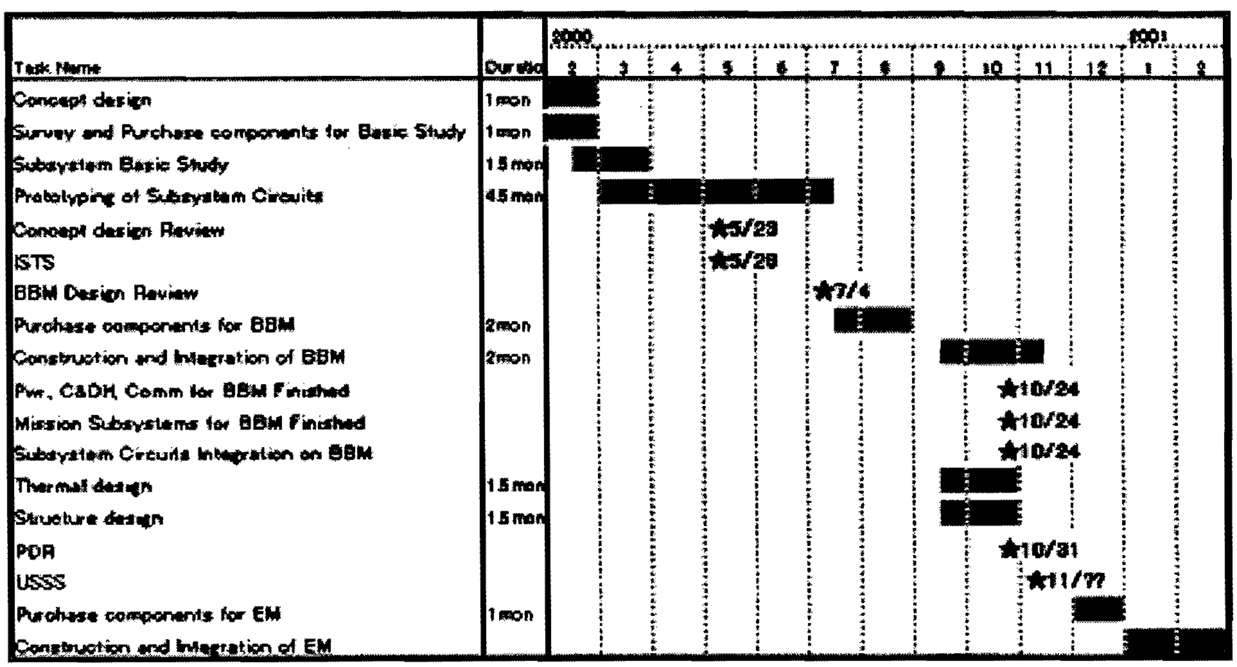

Figure 3.3.3 Schedule of University of Tokyo CubeSat

3.4 California Polytechnic Institute

3.4.2 PolySat: Cal Ploy's Prototype CubeSat

The Cal Poly prototype CubeSat, PolySat, meets the deployer's constraints for size, mass, shape, and interface. The purpose of our prototype is twofold: first, to validate the deployer standard design and second, to demonstrate that CubeSats provide a viable platform for basic experiments in a space environment. PolySat is a minimum configuration satellite, consisting of a simple set of components required to demonstrate low-Earth orbit operation.

PolySat's structure is consistent with the deployer's standard. A 100 mm cube has been designed with the required guide rails and interface for the deployer. The structure is composed of six individual panels of aluminum 7075-T6, totaling a mass of 0.2 kg and strong enough to survive launch loads. Mount points for antennas on the exterior and various internal components are provided.

The communications system consists of a downlink transmitter, an uplink receiver, and independent antennas for each. Downlink is provided by a modified on-board Alinco DJ-C4T 440 MHz amateur radio transmitter. This is commercially available for $70 retail, and offers 300 mW output, at a cost of 1.11 W when transmitting. It is very robust and compact. Further, it generates very little heat in operation and has low idling power requirements. Both our own requirements and FCC amateur regulations demand an independent uplink receiver capable of providing a minimum of an "off" command for the downlink transmitter. Requirements analysis revealed that commonly available amateur radio receiving equipment would likely suffer from overload and serious intermodulation distortion (IMD) from strong earth generated signals on nearby frequencies was solved by using a MICRF004.

This data receiver on a chip (commonly used for garage door opener receivers) is from Micrel, Inc. This solution is quite cheap to implement at about $30. It is easily modified to receive in the 144 MHz amateur radio band with extremely low power requirements and low sensitivity. Low sensitivity, usually a disadvantage, affords the CubeSat uplink receiver relative immunity to spurious signals. Compensation is easily provided on earth by increased amplification and antenna gain with commonly available amateur radio components. This receiver choice enables future enhancements for the uplink channel such as reset command or even simple reprogramming of the onboard processor.

Independent dipole antennas mounted on one face of the box provide the downlink and uplink capability. The antenna design mirrors the technique used on OPAL, namely metal "measuring tape" available at any hardware store. It is flexible, holds its shape well and has served as adequate material on previous missions. The antennas are folded down against the satellite body with monofilament held down by a short length of nichrome wire. Upon deployment, a current is passed through the nichrome wire, which will heat the monofilament and release the antennas.

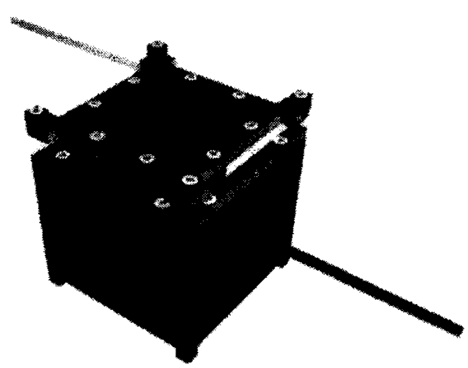

Figure 3.4.1. The PolySat with Deployed Dipole Antennas

Amateur radio frequencies (and licenses) are used for low cost and a readily accessed base of experience. In addition to inexpensive, commonly available equipment, there exists a large network of amateur radio operators with well-equipped ground stations available to assist in our mission. This is a tremendous advantage for a small startup group of undergraduate students.

Command is provided by an Atmel BasicX PIC microcontroller running custom software, written for the project. This chip provides 8 digital and 8 analog lines for I/O. The processor activates the transmitter at required intervals for downlink tasks. The FCC required identification of the transmitter is given in Morse code using tone modulated FM under the call sign "N6CP" (Cal Poly's Amateur Radio Club) followed by mission specific data. The data is encoded using dual tone multi frequency (DTMF) tones by the processor. The transmitter is keyed by the processor at specified intervals while the encoded data is passed to the audio input for transmission. The use of DTMF encoding involves a relatively slow rate of data transfer but increases the simplicity and reliability of our link. This can be important if we unexpectedly lose gain or experience increased noise on the frequency. Currently, sensors being considered for PolySat include thermistors to measure the temperature of the structure and key components as well as a voltage sensor for the batteries.

Power is provided by two on-board battery packs consisting of two lithium-ion batteries each. Step-down converters are used to provide 5V to the computer and receiver and 3.7V for the transmitter. This battery pack provides 209 watt-hours using four cells of 116g each. This represents approximately 150 hours of transmitting time.

PolySat uses passive thermal control, using coatings and paints to control heat radiation and absorption. Operating range is expected to be -40ß C to 70ß C.

As described, the PolySat spacecraft is well under the 1kg mass constraint. Since the transmitter operates only for small periods of time at specified intervals, it is expected to maintain operation over a lifespan of several weeks.

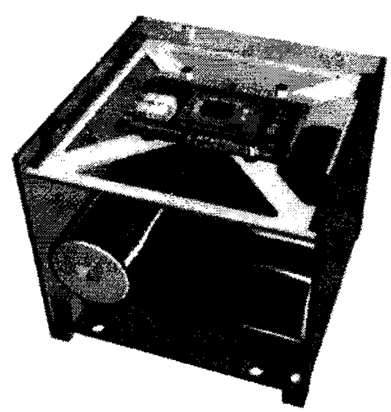

Figure 3.4.2 Disassembled CubeSat Showing Batteries and Electronics Tray

3.4.3 Future Advances

The main objective of the initial CubeSat mission will be to validate the design of the standardized deployer. Once the deployer is space qualified it will become a new option to place small payloads in space with low development time and cost. In addition, initial CubeSat missions will validate the PolySat design and will qualify a number of components that the Cal Poly team plans to use in future CubeSats. In particular, the Cal Poly team is interested in validating the spacecraft structure, the antenna deployment system, the communications package and the spacecraft thermal models. Space qualification of these components will facilitate the development of more sophisticated CubeSats in the future.

The Cal Poly team is currently working on the development of a solar powered CubeSat. Using the latest solar cell technology, body-mounted solar panels should provide around 1 W of continuous power to the spacecraft. A solar powered CubeSat would require a much smaller battery and an additional 0.2 to 0.25 kg of payload could be incorporated. New components that are currently being considered are a more powerful computer with more storage capacity, a small CCD camera and a small magnet to provide some attitude control capabilities, in addition the Cal Poly team is seeking commercial payloads to be flown in future CubeSat missions.

4. LAUNCH OPPORTUNITIES AND COSTS

The launcher tube, P-POD, being developed by Cal Poly to hold three CubeSats is designed to be attached to many different launch vehicles. The P-POD launcher will be rectangular tube about 4.5 inches square by 15 inches long and weigh about 5 kg. It would require only a small power activation signal from the last stage of the launch vehicle to activate the release mechanism and open the launcher door to release the CubeSats. Since the launcher completely contains the picosatellites, can be attached in a very small space and is lightweight, many launch vehicles can accommodate this secondary payload. Multiple P-PODs could be attached to one launch vehicle for secondary payloads.

There are several flight opportunities for CubeSats in the near future. Two launch opportunities are now available from with Thiokol Corporation in a joint Venture with Kosmotras on the converted Russian SS-18 called the Dnepr from the Russian launch site at Baikonour. The first flight is scheduled for late 2001 which as many as 18 CubeSats are proposed to be launched from it. The cost for this launch is now established at $30,000/CubeSat. These opportunities are being coordinated through One Stop Satellite Services in Ogden, Utah. It is expected that these flights will continue to occur at least twice a year.

The Aerospace Corporation, which was a partner on the OPAL projected and provided picosats for launch on that mission, is continuing picosat development with launches on the OSP-II (second Minotaur) from Vandenberg AFB, CA in 2001. Additional US launch opportunities are quite likely on many Boeing and Lockheed Martin launch vehicles.

The Air Force OSP-III (third Minotaur) in now scheduled for launch in late 2002, which may have possible CubeSat launch opportunities.

4.1 Launch Costs and Procedure

The estimated launch cost per CubeSat that weights one kilogram or less is $30,000. This is based on the known launch and integration cost using the Kosmotras Dnepr. The present arrangements being made for launches on the Dnepr is a collaborative effort between Stanford University, Cal Poly and One Stop Satellite Services in Ogden, Utah. Contractual arrangements will be made with Stanford University; Cal Poly will provide P-POD test fixture to the customer, provide the flight P-POD, integrate the CubeSat into the P-POD upon delivery to Cal Poly at San Luis Obispo, CA, perform final thermal and vacuum testing; then the P-POD will be shipped to One Stop Satellite Services at Ogden, Utah. One Stop Satellite Services will then be responsible for all export licensing, shipping to Kosmotras and integration onto the Dnepr.

5. USE OF AMATEUR FREQUENCY CONSIDERATIONS

Since is seems that the CubeSat cost of development and costs of launching being lower than any other opportunities and within the budget for universities and ham radio clubs many CubeSats may be launched in the near future.

With the launching of many of these CubeSats, a major issue is the frequency bands allocated for their use. There are several options that can be considered.

1. The educational institution and ham radio clubs could use the amateur frequency bands, in particular the VHF and UHF bands.

2. These organizations could move to the higher frequency bands used less by amateur such as the L and S bands.

3. There could be a consideration of application for use of some experimental bands that are not within the amateur bands.

All of these options have advantages and disadvantages beyond just the use of the frequencies.

Consider the use of the VHF and UHF bands.

Advantages to the CubeSat developers

a) There is a large amount of low cost technology in RF equipment for both the CubeSat and ground stations that can be use.
b) There is a worldwide network of amateur satellite stations that can be used to involve students in the local area in educational experiments.

Advantages to the AMSAT community

a) The CubeSat program will attract new generations of satellite developers and users.

b) This new attraction to satellites, space and space experimentation could be a large new group of users for potential worldwide AMSAT users.

c) This program would provide many more opportunities for present AMSAT members for use of the existing stations.

d) AMSAT could show a significant component of the frequency band usage benefiting the educational community.

Disadvantages to the CubeSat Developer

a) The present AMSAT communities through the IARU and AMSAT national organizations are totally unresponsive to the requests for university requests for frequency coordination and have exhibited hostel behavior towards consideration for university applications.

b) There is very little interest from present AMSAT organizations in supporting educational activities beyond the space shuttle and the ISS.

Disadvantages to the AMSAT community

a) Additional use of the frequencies may limit some ham activities.

Moving to the higher frequency bands will increase the costs for development and operation of the CubeSats. It will leave very few stations beyond the developers that can participate in the CubeSat operations. There would be no significant reason for the CubeSat community to be closely allied to the AMSAT community due to the limited activity of the AMSAT community at the higher frequencies. The use of the higher frequencies by the CubeSat community may encourage more AMSAT members to move to the higher frequency.

If the CubeSat community moves to frequencies outside of the amateur bands because the amateur community will not support their activities, it could put those bands in jeopardy because of this action and the lack of fully utilizing the bands.

6. CONCLUSIONS

The OPAL program demonstrated that a low cost launch system could be used to launch picosatellites. The success of The Aerospace Corporation picosatellites demonstrated the first use of these picosatellites. The new picosatellite, CubeSat, now proposed as a standard that can be launched with the launcher tube developed by Cal Poly, the P-POD will provide low cost opportunities for a new era in space experimentation.

These new CubeSats and the low cost make it practical for even universities and private groups such as amateur radio clubs to have access to space. The future of these space devices based on the CubeSat design will now depend upon how innovative the science and general community can be.

An equitable solution to the frequency allocation problem must be a mutually solved problem by both the AMSAT and the CubeSat community or they both will suffer in their program objective.

7. ACKNOWLEDGEMENTS

The initiation of the mother/daughter picosatellite work started at Stanford was done through the work of Professor Tom Kenny in the Stanford mechanical engineering department and Mr. Jim Randolf at the Jet Propulsion Laboratory. The final push to meet OPAL's mission was due to Ernie Robinson at The Aerospace Corporation and Al Pisano, the director of the MEMS activity at DARPA.

Many students at Stanford worked very long and hard at completing SAPPHIRE, which was the predecessor to OPAL, and OPAL. Foremost of these students supporting SAPPHIRE over several years were Mike Swartwout and Chris Kitts. The OPAL effort was led initially by Brian Engberg, Clem Tillier and Carlos Niederstrasser and finally by Jamie Cutler and Greg Hutchins. These two projects had more than one hundred students work on them over a five year period. SSDL has outstanding mentors group to support students in their work with much volunteer effort from John Ellis, Lars Karlsson, Dick Kors, Ron Ross, Richard Anderson and David Joseph to name a few.

Boeing, DARPA, NASA Ames Research Center, NASA Langley and Jet Propulsion Laboratory provided research support for SSDL. Lockheed Martin, Space Systems/Loral, Deskin Research and The Aerospace Corporation provided additional financial and facilities support.

The CubeSat program as done in collaboration with Prof. Jordi Puig-Suari at Cal Poly demonstrates the motivation that a space program can bring to education. The Cal Poly students like Ryan Connelly and Jeremy Schoos are examples of students excited, enthusiastic and motivated by their education. These students are the most valuable output of these programs.

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Ed Krome K9EK
Columbus, Indiana
k9ek@amsat.org
August, 2000

Phase 3D: A Primer on High Frequency Operation

With the excitement over the impending launch of Phase 3D, many people are working hard to improve existing satellite stations and add new capabilities. The AMSAT reflector is full of discussions on higher frequencies, high speed digital, all kinds of neat things! Last year, S-band (2401 MHz) downlink got a boost from the availability of Drake 2880 downconverters, readily convertible to amateur service. I expect that S-band downlink will be a very popular band, indeed.

The lower bands are all pretty well known. Even 1269 MHz uplink is much less exotic than it used to be, with the availability of plug-in modules for popular satellite transceivers. The higher bands haven't had much discussion yet; uplinks on 2401/2446 MHz and 5668 MHz and downlinks on 10450 and 24050 MHz have great possibilities. As a long time high-frequency experimenter and general AMSAT enthusiast, these bands are of great interest to me. This article will discuss some of the basics of higher frequency operation and discuss one man's approaches to operation on these frequencies. This is not supposed to be a construction article, though everything discussed has been built (and even works!), but rather to take some of the mystery out of things.

Where to start

Lesson one is that the sensible place to start is the one that costs you the least time, effort and money. The fact is that UHF receiving is a LOT cheaper and easier than transmitting. And the lower the frequency, the cheaper and more available the gear. Currently, 23 cm is the highest band supported by off-the-shelf ham gear, and that is an uplink-only band. For 13 cm and above, equipment shifts from one-piece boxes to distributed components. A fact of physics says that the higher the frequency, the greater signal loss in a piece of feedline. To a receiver, feedline loss looks like increased noise. And low front end noise is the most important part of a receiving system. The most practical method of reducing feedline loss is to eliminate the line. We do this by mounting preamplifiers (and sometimes even whole converters) directly at the antenna.

Since a 13cm downlink was active on AO13, this mode has already been well documented. A good reference, also useful on all higher bands, is "Mode S: The Book" available from AMSAT.

Higher yet

The next downlink band beyond 13 cm is 3 cm.... quite a jump in frequency and complexity. Phase 3D has 2 separate antennas and amplifiers on 10450; one of them a 60 watt TWTA (Traveling Wave Tube Amplifier), the other a 10 watt solid-state amplifier. These should provide a booming signal to a small dish and make this frequency very popular with both techies and even "normal" people!

On 10450, it may not be enough to follow the "low frequency" (like 13cm!) techniques of antenna mounted preamp and shack mounted converter. Feedline losses are so high that is will be necessary to mount the receive converter right up close to the antenna feed also. Probably the most physically satisfactory arrangement will be to mount the preamp right at the antenna feed, then use a short-as-possible length of high-quality (RG-213 or better) coax to get from the preamp, around the rotors to a weather-proof box containing the receive converter, mounted high on the tower. Then the lower-frequency connection to the IF receiver itself (in the shack) can be made through normal cable with minimal signal loss.

.Details

Following are discussions on the various parts common to S-band and higher satellite receive systems. The basic requirements are 1) the antenna 2) an antenna-mounted low noise preamplifier 3) the converter.

Antennas

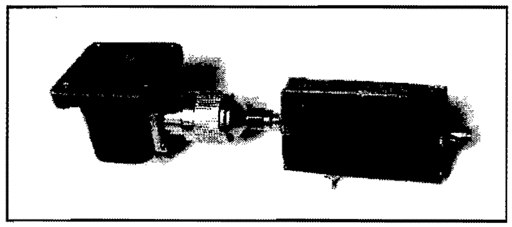
Link margins done by Frank Sperber and shown on the AMSAT-DL web site indicate anticipated antenna sizes. On 10450, a 60-cm (24" diameter) parabolic dish antenna should be adequate. While other types of antennas, such as horn and lens may find some users, the dish is probably the most readily realizable. Yagis aren't practical on 10 GHz. Dish antennas can be homebrew or purchased; sources should be advertised as P3D becomes a reality. It is possible that the small offset-feed TV dishes may be adequate, but we really won't know until P3D is up there.

Dish antenna basics

A common misconception about parabolic dish antennas is that the dish has some parasitic relationship (like the undriven elements on a yagi antenna) to the operation of the antenna. Not true; all the dish itself is is a reflector that concentrates signals on a particular point called the feedpoint. We place a small antenna of known pattern characteristics (hopefully matched to the reflective characteristics of the dish) at that feedpoint and call it a dish feed. A dish feed is never characterized by "gain" but by illumination characteristics, usually an angle between either -3db or –10db field strength points. Parabolic dishes themselves are characterized by their diameter and their f/d (focal length divided by diameter) ratio. The feed used must have an "illumination pattern" that is matched to the f/d ratio of the dish to properly utilize the area of the dish. Note that, when matching a feed to a dish, only the f/d ratio is significant, not the actual diameter of the dish itself. To give a feel for the meaning of f/d ratio, a "low" f/d such as .3 means that the feed is mounted quite close to the dish. A feed for a .3 f/d has to have a very broad beam to illuminate the dish that it is very close to. A "high" f/d such as .7, requires a narrower beamwidth feed to illuminate the dish, since the feed is mounted some greater distance in front of the dish. What is better? The "deep" dish (small f/d) tends to pick up less background noise (the feed is more shielded from the hot and noisy earth) and is mechanically easier to support, but it is more difficult to illuminate properly. "Shallow" (large f/d) arrangements tend to have larger feeds (more directional) and are physically more difficult to support and counterbalance but are generally less critical. Whatever you use, the feed characteristics must be matched to the dish. A significant determining factor is to use whatever you can get!

Another aspect of parabolic dish use is the diameter of the dish itself. The gain of a dish antenna is related to the diameter of the dish. This is all fine until one realizes that while higher gain means more signal strength, it also means narrower receiving beamwidth. For moonbounce service, a huge dish is fine, because the moon doesn't move very fast. But satellites are rather speedy. The larger the dish, the more difficult it will be to keep it pointed where you want it. Generally, the smallest dish that will give satisfactory signal strength is the most desirable.

Phase 3D signals will be right-hand circularly polarized. Ideally, your antenna should also be circularly polarized. The desired hand of received antenna circularity is right hand. Since the dish itself is only a reflector, bouncing a signal off it reverses the hand. Therefore, the dish feed itself must be left hand. Practically, it is much easier to fabricate a linearly-polarized feed. The performance penalty for linear versus circular is 3 dB, a reasonable tradeoff to mechanical complexity. Linear dish feeds usually take the form of a coax connector with probe in a short piece of WR90 (.9" x .45") waveguide, frequently with a small horn on the end to accurately control the beamwidth. The feed shown is suitable for use in a .4 to .5 f/d dish. A 10GHz preamp is attached.



Preamps

All receiving systems for the bands 70 cm and higher require special attention to minimizing noise figure. This normally requires an antenna-mounted RF preamplifier, though some converters are designed to be mounted directly at the antenna feed. It is probably best to purchase a built-and-tested preamp from Down East or SSB. Down East also has kits available for W5LUA-designed preamps that should do quite nicely. The problem with any preamp kit is that it may not function optimally as built. "Tweaking" for best noise figure is usually required.

Whatever preamp you use, the preferred mounting is right on the dish feed itself. However, some preamps may be so large that they are physically difficult to mount or may actually shadow a significant area of the dish. Just mount them as close as possible and use good line and connectors between the feed and the preamp. SMA connectors and UT-141 miniature copper hardline are preferred over N connectors and coax, though both will work.

Preamps are rated by noise figure and gain, both specified in dB. The preamp noise figure sets the weak signal performance for the entire system. On 10 GHz, a satisfactory noise figure is less than 2 dB. Gain is somewhat less important, with 10 dB being about normal for a single-stage device, assuming that the actual converter itself has 20-30 dB of gain. If you are feeding a converter mounted fairly close to the preamp, this is all that is required. If, for some reason, you want to drive a really long (and lossy) piece of coax to the converter, a higher gain preamp may be required. If your converter itself a good noise figure, mount it as close to the feed as possible and dispense with the preamp.

Converters

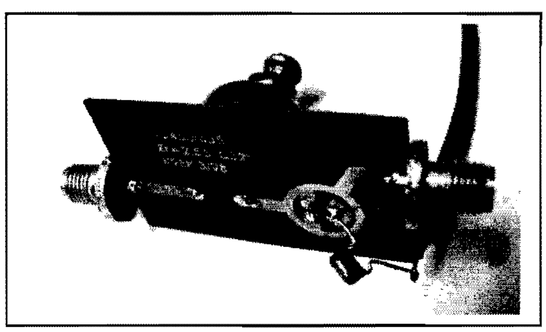
A converter converts one frequency range to another by mixing the original frequency with a fixed local oscillator signal. In this manner, we can use a common receiver with different converters ("front ends") to economically cover several bands. A transverter is the same animal, but it converts both receive and transmit signals. This is not a unique thing; the popular Yaesu FT-736 is basically a 10.7 MHz receiver with plug-in converters. There are no plug-in modules for bands higher than 23 cm, so we must use separate converters. The separate converter is also more amenable to the remote mounting (in a weather-proof box on the tower, below the rotors) as previously mentioned. Converters for 10 GHz typically use intermediate frequencies of 2m or 70 cm. It is satisfactory to plug one receive converter into another. For example, a 10 GHz converter with a 70 cm output frequency could be plugged into a 70 cm in to 10m out converter, which could be plugged into an HF receiver. Works fine. In selecting and applying a converter, one thing to watch is proper frequency conversion. Remember that the satellite allocation of the microwave bands is not the same as the weak-signal portion.... so hamfest weak-signal converters may not be useable. While most converters can be modified to move band coverage, this is generally work for those with the test equipment to make sure the converter works properly after modification. Don't guess.

Actual equipment

As a builder and experimenter, I tend to build some strange but simple gear. The 10 GHz conversion system shown consists of 3 parts; the preamp, the mixer/filter and the local oscillator.

The preamp is a 2-stage W5LUA-design bought as a kit from Down East Microwave. It will be mounted directly on the dish feed horn, under an inverted Tupperware plastic container. Fancy.

The mixer itself is built on a 3/4" x 1-1/2" piece of Teflon circuit board. It has 2 parts, a filter and what is referred to as a 6/4 printed ring mixer. The filter is a 1/2" copper pipe cap soldered to the board, with 2 short wire probes sticking up into the cap. Filter tuning is through a 6-32 brass screw in the top of the cap. These filters have been detailed by Kent Britain WA5VJB and others. They are simple, but are difficult to tune without a swept signal source. The mixer itself has 6 segments, each 1/4 wavelength long (physically shortened by the dielectric constant of the Teflon circuit board), arranged end-to-end in a ring. The length of each segment is the arithmetic mean of the RF and LO frequencies. A matched dual-diode in the center of the ring is the actual non-linear part of the mixer. The Intermediate Frequency (in this case, 70 cm) is taken out through a capacitor and fed to the following 70 cm receiver. Note that there is no filter on the output of the mixer, so I get the sum, difference, image and spur frequencies of the mixing products. This converter relies on the selective properties of the following receiver to pick the right one. Since there are not



a lot of interfering signals on 10 GHz, this should work just fine. I chose a 70 cm IF because of available shack receivers. This will drive a 70 cm to 10 m converter to an HF receiver. This mixer/filter is so small, it will probably be mounted piggy-back on the preamp at the dish feed.

The Local Oscillator is the most problematic part of the entire system. There have been many published designs for crystal controlled oscillators followed by amplifier/multiplier/filter chains to provide the 10016 MHz LO (10450 - 434) signal. They tend to be complicated. I chose a simpler though less common solution of a surplus Frequency West phase-locked RF oscillator module, re-crystaled and adjusted to provide the proper output frequency. The down side is that they are noisy, difficult to retune and require -19 VDC. This "brick" will be mounted up on the tower, under the rotors, and feed its LO signal up to the ring mixer mounted at the dish feed behind the preamp. A possible problem with this outdoor mounting will be frequency drift over seasonal temperature swings. Most of these brick oscillators have "ovenized" crystals, but unless you want to keep the LO powered up all the time, you will have to tolerate the frequency drift before stabilization. While this is considered a real problem for terrestrial and weak signal use, it might not be so bad for satellite use. We satellite users are accustomed to Doppler shift moving the frequency of our signals all over the place. This will just be one more source of frequency shift.

Uplinks

Uplinks on the higher bands get a little more complicated than downlinks. For transmitting, there seems to be an exponential relationship of cost versus frequency. While everything that was said for downlinks applies to uplinks, line loss becomes really important. It's one thing to know that you are loosing some noise figure in an overly long feedline, but think about it from a transmitting cost point of view. A 3-dB line loss between the transmitter and the antenna absorbs fully 1/2 of your transmitter output power! The two standard ways of dealing with this problem are 1) lower loss feedlines and 2) mount the amplifier closer to the antenna. Lots of opportunities for clever approaches here.

EIRP

Analyses of the power required to reliably link to the satellite are based on orbital predictions and path loss data. Here we see some strange designations, such as EIRP. When doing a link margin analysis, we really don't care what the individual values of transmit power or antenna gain are; what is important is the total signal strength being transmitted. This is referred to as EIRP, or Effective Isotropic Radiated Power. This is a number derived from the combination of transmitter power (at the antenna) and antenna gain; both referenced to a hypothetical free-space single point source antenna called an isotropic radiator. The isotropic radiator radiates equally in a sphere in all directions, so it has 0 (zero) gain. We get antenna gain by concentrating our radiation over a smaller portion of the sphere, and use a logarithmic relationship (decibels) to relate the amount of energy concentrated in that smaller portion to a similar area in the original sphere. The power is, of course, sharpest in the center and falls off toward the edges. Antenna "beamwidth" is usually defined as the angle between the points where the power level falls off by 3 dB from the highest value. Values are given for two planes (E & H) at right angles to each other. Note that some antenna gains are referred to as dBi, which is decibels relative to an isotropic radiator and some are termed dBd, which is where the gain is relative to a dipole. A dipole theoretically has 2.15 dB more gain than the isotropic radiator, so dBd numbers will appear lower than dBi numbers. To relate one to the other, simply add or subtract this difference.

As a general rule, don't get too taken up by small differences in published gain numbers. There are a lot of things that have been done to make numbers "look" better, and the antenna itself is not the whole system. In the words of Robert Heinlein, TANSTAAFL, or There Ain't No Such Thing As A Free Lunch. While some antennas are more efficient than others, larger/longer will always make more gain than smaller/shorter. So, is larger always better? Not necessarily. For our use, we have to keep our antennas pointed at a moving target in the sky that we can't see. The narrower the "beamwidth" (that reduced section of the sphere we talked about earlier), the more difficult it is to keep the antennas physically pointed at the satellite. Ideally, we want to use as low a gain antenna as will provide satisfactory communications. The tradeoff is that the lower the antenna gain, the higher the required transmitting power to maintain some required minimum EIRP.

So how much EIRP will we need for the higher bands? In 1995, Frank Sperber DL6DBN published an analysis that gives EIRP but does not include much detail on the assumptions used to get there. Franklin Antonio N6NFK's analysis (dated 7/4/00; available at http://members.aol.com/n6nkf/P3D_uplink_budget_3.xls) is much more detailed. Mirek Kasal OK2AQK published a simplified analysis (taken from AMSAT email reflector dated 7/14/00). For 1269 MHz (the band common to all three analyses), the following numbers come out: Sperber predicts 23 dBWic (10 watts to a 12-turn helix). Kasal predicts 24.4 dBWic (8.7 watts to a 15dBic short backfire antenna (like the antenna on the satellite itself) or 28 watts to a short 10 dBic helix). Antonio's numbers come out somewhat higher, but include a speech compression factor, line loss, polarization loss and pointing error: (at the risk of misinterpreting his work): 33 dBWic (20 watts to a 12 foot long Down East Microwave 45 element loop yagi (20 dBi) for a 15 dB S/N at the transponder). Note that dBWic means decibels relative to a 1-watt reference from an isotropic radiator, circularly polarized. Whatever the EIRP, we need some combination of antenna gain and transmitter output power to equal this EIRP.

EIRP assumes the same polarization (horizontal or vertical) at each end of the link. Of course, with satellite operation, such terms as horizontal and vertical are meaningless since space provides no frame of reference. Instead, most satellite signals are circularly polarized. All P3D up and downlink signals will be right hand circularly polarized, as discussed in Part 1. Therefore, we use the term EIRPc to indicate that the polarization of both ends of the link is circular. This assumes that both ends of the link are the same hand; perfect circularity with reversed hands of polarity will effect 30 dB loss. The penalty for linear polarization on one end and circular on the other is theoretically only 3 dB, though this may vary since no rotating wavefront is completely circular. As pointing angles increase, circularity becomes more elliptical, which, in effect, makes it function more like linear polarization. This can work either for you or against you. The best idea is to have enough link margin (read that as power) to compensate for changing conditions, but only use as much as required to attain the same downlink strength as the beacon.

Getting the power to the antennas

Now the practical trick is to get the transmitter power to the antenna. Large copper hardline is nice and low loss, but expensive and hard to handle. CATV hardline, the aluminum jacketed 75-ohm variety, is a useful and practical alternative. Ah, you ask, my radio is 50 ohms; what about impedance mismatch with 75 to 50 ohms? Yes, that is a problem, but that only results in a 1.5:1 SWR, which relates to some pretty insignificant power loss. A bigger problem is how to satisfactorily attach waterproof connectors to either end of the line and not introduce really bad mismatch. It is also possible to add in-line impedance converters, 61 ohm 1/4 wavelength line sections, that convert 50 ohms to 75 ohms. These are beyond the scope of this paper.

A reminder: generally, we see the satellite when it is above the horizon. This says that antenna height is not as critical as it is for terrestrial use, since antennas are usually pointing at some angle upward. One way to eliminate feedline loss is to reduce the length of the feedline by mounting the antennas close to the shack and to the ground. Having an antenna that is not useable in certain directions (houses, trees, etc.) may be a reasonable tradeoff to the problems imposed by long feedlines.

1269 MHz L-band uplink

L-band is the highest band for which commercial transmitting equipment is readily available. Plug-in modules for the Yaesu FT-736R convert it to a 23cm transverter with 10 watts output. ICOM has the IC-1271 and 1275, complete transceivers for 23 cm. Note that while both these radios are no longer manufactured, they are readily available used. Commercial offerings change frequently, so the best guides are magazines and web sites for the respective companies.

The previously mentioned link margin analyses show that, while 10 watts might provide acceptable SSB communications, there isn't much margin for feedline loss or other system problems.

Mounting an FT-736R at the top of your tower isn't something many operators would relish. A more practical alternative is detailed in the 1998 through 2000 ARRL Handbooks. The article " An Integrated L-Band Satellite Antenna and Amplifier" by K9EK suggests mounting a separate 10+ watt amplifier directly behind a 15 turn helical antenna, right up on the crossboom. A practical problem plaguing the use of helical antennas is the difficulty of physically supporting the antenna. The approach detailed in the article uses a small amplifier, mounted on the boom of the helix antenna itself but behind the cross boom, as a counterweight for the helix. The proximity of the final amplifier to the antenna virtually eliminates feedline loss. But the design takes advantage of feedline loss (yes!) by using the attenuation of the feedline from the transmitter in the shack up to the antenna-mounted amplifier to reduce the level of the signal from the shack transmitter down to the input level required by the amplifier. So, 10 watts in the shack though a 10 dB loss feedline gives 1 watt at the input to the tower mounted amp; exactly what the amplifier needs to give 10-15 watts out. See the Handbook for more details.

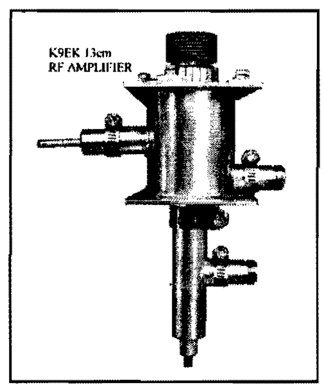
And higher still: S and C Bands

Here we enter the depths uncharted by Kenwood, ICOM or Yaesu. Gear for this band will make you intimately familiar with names like Down East Microwave and SSB Electronic. Because at this frequency and higher, they are presently the only games in town. Both carry transverters, amplifiers and antennas for higher frequencies.

Generally, transmitting on all higher bands is handled in a similar fashion. You couple a VHF transceiver to a transverter in the shack or up on the pole, then find some way to get the power to the antenna with minimum loss. UHF transverters are available with milliwatt level power outputs, where it is assumed that you will use external amplifiers, or higher levels. Each user has to evaluate his own requirements and situation and figure out what works best for them.

S-band Transmitting

The basic requirement is an S-band transverter set up for the proper frequency range. Remember that satellite operation is on 2401 (primary) and 2446 MHz, whereas terrestrial operation is on 2304 (the Americas), 2320 (UK, Europe, former Soviet Union) and 2424 (Japan, Australia). Transverters and amplifiers are available. But the trick is to get more than a watt or two at the antenna. I have explored several approaches to transmitting on this band. I build tube-type amplifiers for 13cm, using both the 7289 planar triode and a large Russian triode. Unfortunately, the finicky nature and high voltage requirements of vacuum tube amplifiers make them rather complicated to use. But if you want real power on this band, tubes are the only way to go. Since the projected link margins indicate that 5-10 watts to a small dish will be adequate, a better approach for our use is probably a 10 watt solid state amplifier, remote mounted at the antenna in similar fashion to that described for L-band. Down East Microwave has recently introduced a 1-watt in, 15 watt out amp that appears well suited to this application. As with L-band, you will have to pay attention to matching the output power of your in-shack transverter less feedline loss to the input requirement of the amplifier.

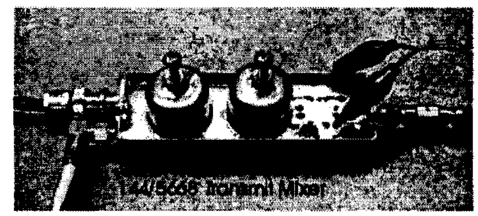


An alternative is to remote mount the entire transverter up on the tower. S-band is probably the highest frequency where you might get away with not remote mounting the entire transverter, as feedline losses can still be manageable.

C-band transmitting

Feedline losses on 5668 MHz are so high that I don't think that there is any alternative to mounting the entire transverter and final amplifier right out at the antenna. Or mounting the antenna right at the shack. Both Down East and SSB Electronic will offer 3-watt amplifiers for this band. Occasionally, some really useful amps appear on the surplus market. These were used by the telephone companies for point-to-point links on C-band. I was fortunate enough to find one a few years back (it took me a year of active searching) that has over 40dB gain and puts out 10 watts. It is as large as a shoebox and quite heavy. This amp requires -48 VDC at 3 amps, hardly something you can pick up at your local Radio Shack. This amplifier has so much gain, that I can work around some feedline loss.

As a personal solution, I designed and built a transmit mixer, similar to the previously discussed device that I built for 10450 MHz reception. It uses the same arrangement of a 6/4 wavelength ring mixer to combine a 146 MHz IF signal with the output of a Frequency West brick phase locked oscillator. C-band bricks are much more common at hamfests than are the X-band versions. All the same problems of the need to be re-crystaled and tuned apply, as does the -19 VDC requirement. The remainder of the transmit converter consists of a pair of 3/4" pipe cap filters that select the desired mixing product and route it through a pair of Mini-Circuits ERA series MMIC's. The entire package puts out -2 dBm on 5668 MHz and provides a satisfactory driver for the "shoebox" amplifier, but without much headroom for line loss. It really needs another stage of amplification. My intent is to "package" the amplifier, mixer and brick LO in a box that I can haul up my tower and hang in place when I want to experiment on C-band,



Multi-band Antennas

Sperber has conveniently related most of his high frequency transmission and reception to a 60cm parabolic dish antenna. Which of course begs the question: can I use the same 60cm dish for more than one band? I think that the answer is both yes and no. For reception, we have already said that mounting more than one dish feed in one dish is satisfactory. But transmitting is different. The power transmitted from one feed will be picked up by the second feed, even if the frequencies are widely different. Solid state devices do not like large amounts of thermal energy applied to their junctions. You can burn out a junction from the back door also.

The commercial method of getting around this problem is through the use of ferrite isolators and filters between the output devices and the antenna feeds. Isolators are 3-port non-reciprocal devices allow transmit energy to pass from an input port to an output port with little loss. But energy incident on the output port is routed to a terminating resistor and isolated from the input port. Clever devices, but not common in "normal" channels. Also, they don't have extremely wide bandwidths, so a 10 GHz isolator might not protect a 10 GHz preamp from a strong 2400 MHz transmitter signal. A more practical method is to use relays that disconnect the unused transmitter output or receiver input. These should generally be wired so that the transmitter output or receiver input is terminated in a 50-ohm load to ground. There just isn't any really good way to operate full duplex where both bands use a single dish.

The only alternative to isolators or multiple high-priced relays is not to use the same dish for transmitting on more than one band or for both transmitting and receiving. Multiple dishes get physically cumbersome, but are a practical method to allow full duplex operation, as well as keeping one transmitter from killing another.

Summary

The higher bands on P3D offer some great opportunities and challenges. Following is DL6DBN's complete predictions of up and downlink station requirements.

See you on P3D!

Equipment for the Groundstation

Downloaded from http://www.amsat-dl.org/gndstn.html

By Frank Sperber, DL6DBN

Uplink:

Band	EIRPc	TX-power	Antenna
146 MHz	20 dBWi	10 W 50 W	7 Element X-Yagi Crossed Dipoles
435 MHz	21 dBWi	10 W 40 W	10 Element X-Yagi Crossed Dipoles over Reflector Plane
1270 MHz	23 dBWi	10 W	12 turn Helix
2400 MHz	27 dBWi	5 W	60 cm Parabolic Dish
5670 MHz	34 dBWi	10 W	60 cm Parabolic Dish

Downlink:

Band	GND-PEP/QSO	Antenna	S/N
146 MHz	-155 dBWi	7 Element X-Yagi Crossed Dipoles over Reflector Plane	23 dB 16 dB
435 MHz	-157 dBWi	10 Element X-Yagi Crossed Dipoles over Reflector Plane	24 dB 13 dB
2400 MHz	-167 dBWi	60 cm Parabolic Dish 14 turn Helix	26 dB 18 dB

10450 MHz	-184 dBWi	60 cm Parabolic Dish	24 dB
24 GHz	-197 dBWi	60 cm Parabolic Dish	13 dB

Note: The above is the best estimations from the AMSAT-DL (AMSAT-Germany) web site. Following are notes on the various types of antennas indicated and terms.

1) "Crossed dipoles over a reflector plane" is a pair of center-fed dipoles, 90 degrees to each other, fed 90 degrees out of phase, to produce right hand circular polarization, suspended over a reflective sheet. A very simple circularly polarized antenna with a predominantly vertical radiation pattern. Tracking not required.
2) "X-Yagi" is a right-hand circularly polarized yagi antenna made with 2 sets of elements at right angles to each other. Also referred to as a "cross yagi". A "7-element X-yagi" has 2 sets of 7 elements in each set on a single boom. A relatively small, directional yagi. Must track the satellite.
3) "60 cm parabolic dish" is a 24-inch diameter parabolic dish antenna with the appropriate feed for the band in use. Must track the satellite.
4) "GND-PEP/QSO" is the signal strength of the satellite's signal on the ground.
5) "EIRPc" is Effective Isotropic Radiated Power, circularly polarized, in decibels (dB) relative to 1 watt. This is effective transmitted power from a combination of actual transmitter watts and antenna gain, referenced to an "isotropic" (fictitious point source) radiator.

Useful information and tracking programs:

AMSAT-NA
850 Sligo Avenue, Suite 600
Silver Spring, MD 20910-4703
(301) 589 6062
www.amsat.org
Tracking Software: www.amsat.org/amsat/catalog/software.html

High frequency equipment sources:

Down East Microwave
954 Rt. 519
Frenchtown, NJ 08825 USA
(908) 996-3584
www.downeastmicrowave.com

SSB Electronic USA
124 Cherrywood Dr.

Mountaintop, PA 18707
(570) 868-5643
www.ssbusa.com

Hamtronics
65 Moul Rd.
Hilton, NY 14468-9535
(716) 392 9430
www.hamtronics.com

Commercial Equipment:

Yaesu: www.yaesu.com
Icom: www.icomamerica.com
Kenwood: www.kenwood.net
AOR: www.aorusa.com

Estimating Keplerian Elements for New Satellite Launches

By Ken Ernandes, N2WWD
n2wwd@amsat.org
http://www.mindspring.com/~n2wwd

ABSTRACT

Satellite tracking software requires a mathematical orbit description to predict a satellite's location and motion. An important pre-launch activity for new satellites is estimating Keplerian elements for tracking the satellite in the early stages, before more refined orbital data is available. The estimation process uses available information including the launch site location, launch date and time, and planned orbit (apogee and perigee altitudes and inclination angle). Since launch date and time may change one or more times, the method presented develops the orbit as a time-independent position and velocity state vector that can be readily used produce the corresponding Keplerian elements once the launch date and time is known. The methods for producing the time-independent state vector as well as for computing the Keplerian elements are provided. Both stages of the process are encapsulated in software tools available for download from the Internet.

INTRODUCTION

Keplerian elements (and equivalent mathematical models) provide the basis for tracking; the tracking data, in turn, is used as feedback to refine and update the Keplerian elements. A preliminary (or estimated) set of Keplerian elements are a useful tool for predicting the satellite's orbital flight progress before more refined Keplerian elements are available.

The estimation is a two-stage process: first estimating the time-independent state vector and second computing the Keplerian elements from the state vector and the launch date and time. Given the timeliness of communications provided by the Internet, estimated orbital data can be distributed to all interested stations around the world. Generally, one person or agency should accomplish the state vector estimation and distribute this data to all interested stations. The predicted launch date and time are provided either with the vector or subsequently, allowing stations to compute their estimated Keplerian elements and make updates should the launch time change. When the launch actually occurs, stations may update the estimated Keplerian elements based on the launch time information.

STATE VECTOR ESTIMATION

Estimating the state vector involves basic orbital mechanics, most of which may be found in standard orbital mechanics textbooks. The computations are encapsulated in an Excel® spreadsheet. The mathematics will also be presented for the benefit of the interested reader and those who wish to improve the spreadsheet or create an equivalent product using another media. Those not interested in the mathematics can ignore the equations and simply make the required entries into the spreadsheet.

Input Parameters

The input parameters for estimating the state vector are:

- Apogee and Perigee altitudes
- Orbital inclination angle
- Booster insertion altitude
- Booster general flight direction (North or South)
- Booster downrange flight distance (kilometers or Earth-central degrees) and time
- Launch site location (Latitude and Longitude)

These parameters are entered into the input block in the upper left corner of the spreadsheet. The results are available in the Earth-fixed state vector.

SPREADSHEET EQUATIONS

The following sections provide the underlying equations used by the spreadsheet. If you're not interested in the equations, skip ahead to the section titled *COMPUTING THE KEPLERIAN ELEMENTS.*

Launch Site Location

The Earth-fixed position vector is computed for the launch site using the World Geodetic System of 1984 (WGS-84) ellipsoid:

$$R_n = \frac{a_E}{\sqrt{1-e_E^2 \cdot \sin^2 L}}$$

where:
R_n = radius of curvature of the local normal to the WGS-84 Earth ellipsoid
a_E = semi-major axis of WGS-84 Earth ellipsoid (i.e., 6378.137 km)
e_E = eccentricity of WGS-84 Earth ellipsoid (i.e., 0.08181919085)
L = launch site latitude

$$X = (R_n + h) \cdot \cos\lambda \cdot \cos L$$
$$Y = (R_n + h) \cdot \sin\lambda \cdot \cos L$$
$$Z = (R_n \cdot [1 - e_E^2] + h) \cdot \sin L$$

where:
h = Launch site height above the reference WGS-84 ellipsoid

λ = Launch site longitude

Note that if the launch site's height above the ellipsoid is unknown, this parameter can be approximated by the height above sea level or defaulted to zero.

The launch site location is normalized to form a unit vector pointing from the Earth's center to the launch site:

$$\hat{u}_{LCH} = \frac{1}{R} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} u_x \\ u_y \\ u_z \end{bmatrix} \qquad \text{where: } R = \sqrt{X^2 + Y^2 + Z^2}$$

Launch Azimuth

The launch azimuth (Az) is determined from the launch site latitude (through the $\hat{u}$ vector), the inclination, and the booster North or South flight direction. An error condition exists if the inclination (or its supplementary angle) has a lower absolute value than the launch site latitude, since this is an impossible condition for a direct orbital injection.

$$\sin(Az) = \frac{\cos(i)}{\sqrt{1-u_z^2}}$$

The cosine of the azimuth is computed by:

$$\cos(Az) = \pm\sqrt{1-\sin^2(Az)}$$

The algebraic sign (±) on the cos(Az) is determined by the following rule:

- cos(Az) is *positive* if injection direction is North
- cos(Az) is *negative* if injection direction is South

The launch azimuth is computed using a two argument inverse tangent function that has quadrant checking:

$$Az = a\tan 2(\cos(Az), \sin(Az))$$

Ground Track

The unit vector ($\hat{v}_{LCH}$) describing the booster's ground track from the launch site is computed using the launch azimuth and the local North and East unit vectors. These vectors are computed by:

$$\hat{N} = \begin{bmatrix} -\frac{u_y}{\sqrt{u_x^2+u_y^2}} \\ \frac{u_x}{\sqrt{u_x^2+u_y^2}} \\ 0 \end{bmatrix} = \begin{bmatrix} N_x \\ N_y \\ N_z \end{bmatrix}$$

$$\hat{E} = \begin{bmatrix} -u_z \cdot E_y \\ u_z \cdot E_x \\ u_x \cdot E_y - u_y \cdot E_x \end{bmatrix} = \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix}$$

The ground track vector is computed by:

$$\hat{v}_{LCH} = \hat{N} \cdot \cos(Az) + \hat{E} \cdot \sin(Az) = \begin{bmatrix} N_x \cdot \cos(Az) + E_x \cdot \sin(Az) \\ N_y \cdot \cos(Az) + E_y \cdot \sin(Az) \\ E_z \cdot \sin(Az) \end{bmatrix} = \begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix}$$

The angular momentum unit vector ($\hat{w}_{LCH}$) is then computed using the vector cross product:

$$\hat{w}_{LCH} = \hat{u}_{LCH} \times \hat{v}_{LCH} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ u_x & u_y & u_z \\ v_x & v_y & v_z \end{vmatrix} = \begin{bmatrix} u_y \cdot v_z - u_z \cdot v_y \\ u_z \cdot v_x - u_x \cdot v_z \\ u_x \cdot v_y - u_y \cdot v_x \end{bmatrix} = \begin{bmatrix} w_x \\ w_y \\ w_z \end{bmatrix}$$

Downrange Flight

The downrange flight can be expressed in either Earth-central degrees or kilometers. If expressed in Earth-central degrees, it's converted to radians. Otherwise, the equivalent angle θ in radians is computed as the ratio of the downrange flight to the Earth's radius.

Once the downrange angle is determined, the launch site's unit vector is rotated downrange to the injection position as follows:

$$\hat{u}' = \hat{u}_{LCH} + \hat{u}_{LCH} \times (\hat{u}_{LCH} \times \hat{w}) \cdot \sin(\theta) + \hat{w} \times (\hat{u}_{LCH} \times \hat{w}) \cdot (\cos(\theta) - 1)$$

The booster injection ground track is then computed by:

$$\hat{v}' = \hat{w} \times \hat{u}'$$

Note that the downrange flight does not include the effects of Earth rotation from launch to orbital insertion, as the spreadsheet computations are merely an approximation. Earth rotation could be included in an improvement considering the latitudes of the launch site and injection location.

Position Vector

The injection position vector is approximated using the injection position unit vector, the Earth's radius, and the injection altitude as follows:

$$\vec{r}_{inj} = (a_E + alt_{INJ}) \cdot \hat{u}'$$

where $(a_E + alt_{INJ})$ is the magnitude (r_{INJ}) of the radius vector.

Velocity Vector

The magnitude of the velocity vector is computed by the following equation:

$$v_{INJ} = \sqrt{\mu \cdot (\tfrac{2}{r_{INJ}} - \tfrac{1}{a})}$$

where a is the orbit's semi-major axis

$$a = a_E + \tfrac{1}{2} \cdot (alt_{APO} + alt_{PERI})$$

The orbit's eccentricity is computed from the following formula:

$$e = \frac{alt_{APO} - alt_{PERI}}{2 \cdot a_E + alt_{APO} + alt_{PERI}}$$

The injection flight path angle (ϕ) is computed from the following equation:

$$\sin(\phi) = \frac{e \cdot \sin(\theta)}{\sqrt{1+e^2+2 \cdot e \cdot \cos(\theta)}}$$

The velocity vector is then computed by:

$$\vec{v}_{INJ} = v_{INJ} \cdot [\hat{u}' \cdot \sin(\phi) + \hat{v}' \cdot \cos(\phi)] - \vec{\omega} \times \vec{r}_{INJ}$$

where the $\vec{\omega} \times \vec{r}_{INJ}$ is the Coriolis component of velocity ($\vec{\omega}$ is the Earth rotation rate directed through the z-axis).

COMPUTING THE KEPLERIAN ELEMENTS

The state vector output by the spreadsheet is input to the Vector to Two-Line Elements (VEC2TLE) software to compute the corresponding Keplerian elements. This section describes:

- Setup of the program to produce a formatted time-independent vector file
- Entering and changing the launch date and time
- Computing Keplerian elements in both the NORAD TLE and ***AMSAT*** formats

VEC2TLE is available for download from the ***AMSAT*** Web site http://www.amsat.org or from the Orbitessera Web site http://www.mindspring.com/~n2wwd. This software may be used free for amateur/hobby purposes.

VEC2TLE Setup

VEC2TLE produces the time-independent vector file. The path and name of the vector file needs to be specified under the **Vector Output File** selection under the **File** menu as shown in **Figure 1** (or alternatively by the *Alt-P* shortcut). Selecting this menu item initiates a standard dialog box that allows you to create a new file or open an existing file, which is used to store the state vector information. This same dialog box is also used for specifying the output Two-Line Elements (TLE) and ***AMSAT*** formatted Keplerian elements files.

More detailed instructions for setup are available in the VEC2TLE User manual and in the step-by-step VEC2TLE User Instructions. Both of these documents are included electronically with the VEC2TLE software.

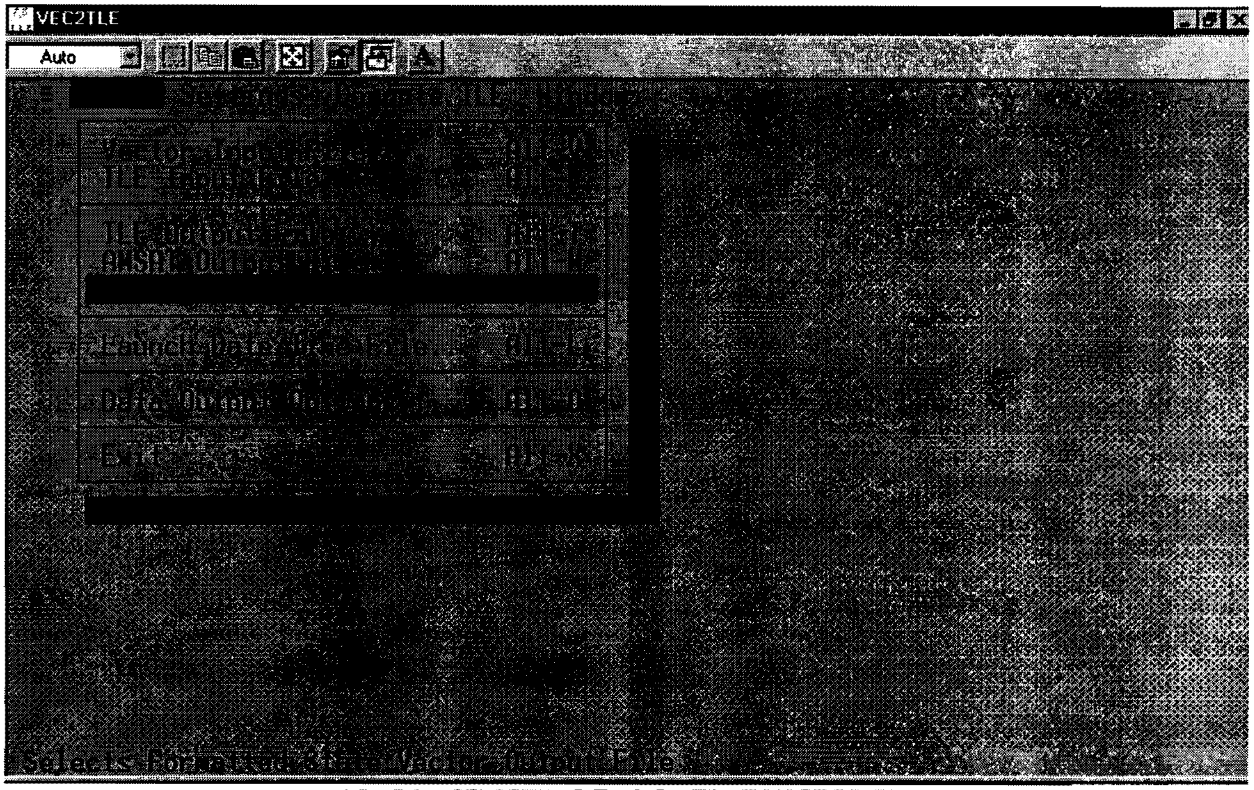


FIGURE 1 SELECTING THE OUTPUT VECTOR FILE

Figure 2 shows the default settings for producing the time-independent state vector. This dialog is initiated by the **Defaults** selection under the **Settings** menu (or alternatively by the *F2* shortcut).

The meaning of each of the radio buttons is as follows:

- The **Inertial Reference** is not relevant since we will be using Earth-fixed state vectors.
- The **Vector Type** is set to Earth Fixed Greenwich (EFG), also known as Earth-Centered, Earth Fixed to maintain time-independence.
- The **Time Format** specifies time as hours, minutes, and seconds, or fractions of a day.
- The **Epoch Control** is set to the vector time for clarity.
- The **Vector Reference Time** is set to Mission Elapsed Time (MET) to maintain time-independence.

Thus the two most critical settings are the Vector Type as EFG and the Vector Reference Time as MET, since these specify the time-independence for the state vector.

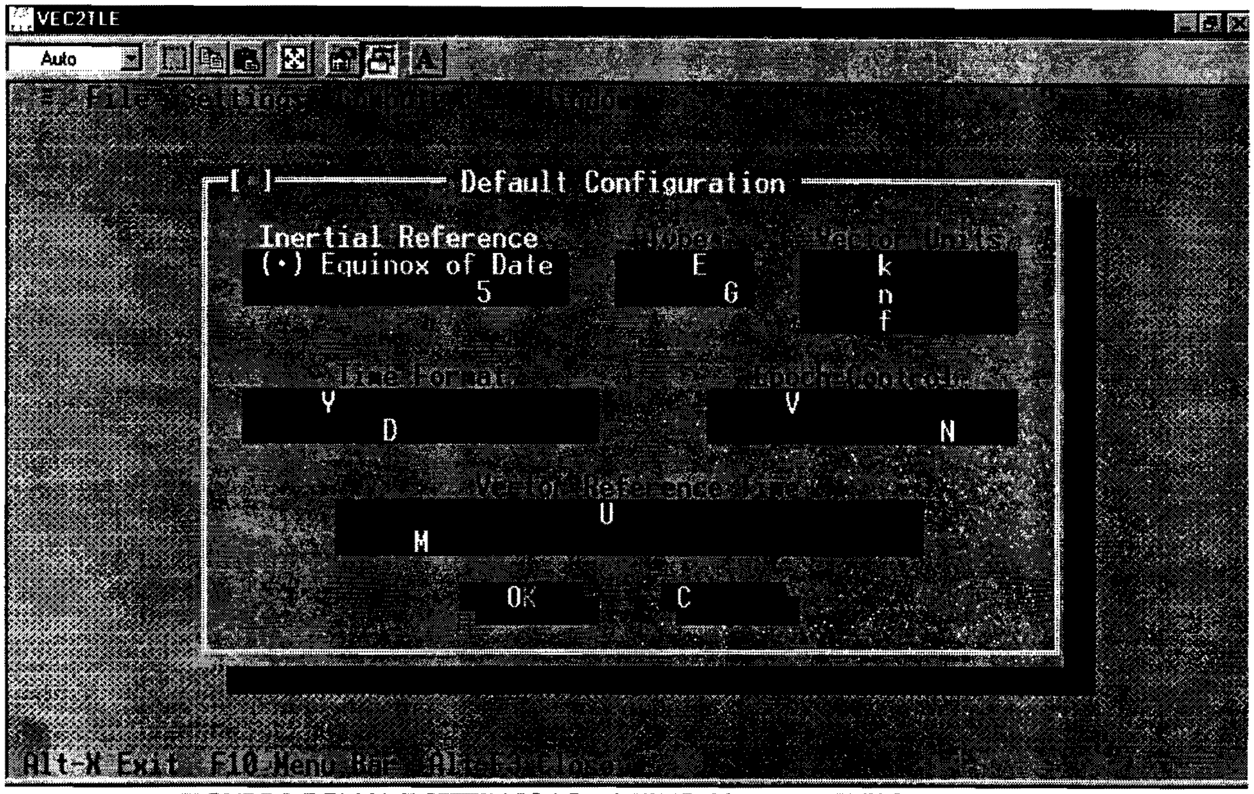


FIGURE 2 DEFAULT SETTINGS FOR A TIME-INDEPENDENT STATE VECTOR

Figure 3 shows the dialog in which the vector information is entered. This dialog box is initiated by the **Input State Vector** selection under the **Compute TLE** menu (or alternatively by the *Alt-I* shortcut). The three components of the position vector are entered in the X (km), Y (km), and Z (km) inputs. Likewise, the three components of velocity are entered in the X dot (km/s), Y dot (km/s), and Z dot (km/s) inputs.

The time from launch to orbital insertion is entered in the Vector Time (MET) input. Note that this time can be entered in either days, hours, minutes, seconds, and fractions of seconds or in days and fractions of days as shown.

A five digit Catalog Number must be entered to produce a formatted set of Keplerian elements. While any five digit integer is acceptable, a temporary number beginning with "9" is recommended to avoid confusion with an existing satellite.

The Satellite Name or ID input is self-explanatory.

The recommended values for the remaining inputs (ndot/2, nddot/6, Bstar, Element Set #, and Rev #) are shown in the example dialog box.

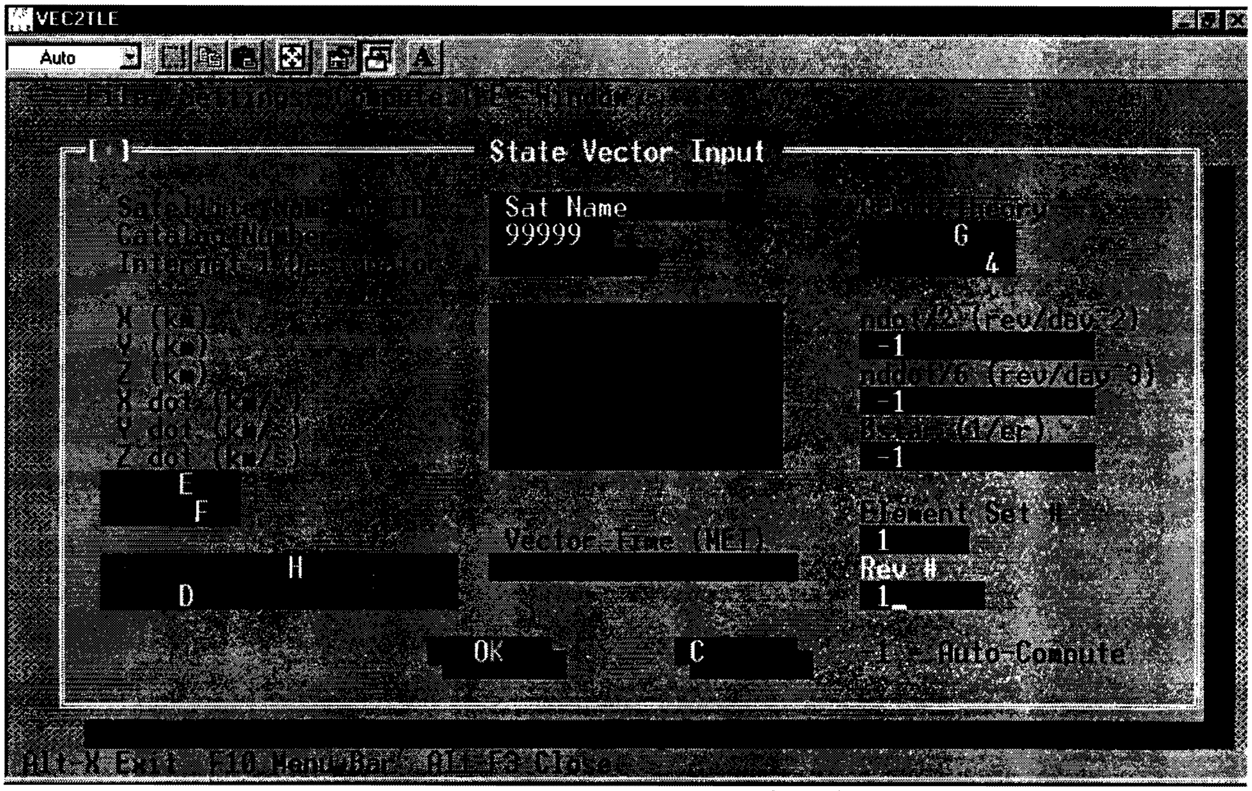


FIGURE 3 VECTOR ENTRY DIALOG BOX

Changing Launch Date and Time

A key part of the process described in this paper is that the state vector generated is time-independent; the vectors are valid regardless of the launch time. VEC2TLE therefore needs to know the launch date and time to be able to compute the Keplerian elements. While this may seem like an unnecessary extra step, the time-independent vector file produces valid Keplerian elements corresponding to *any* launch date and time. The changes in right ascension of the ascending node (RAAN) and epoch time are computed automatically by VEC2TLE for the corresponding launch date and time.

The launch date and time are entered under the **Launch Date/Time** selection under the **Settings** menu (or alternatively by the *F7* shortcut). Note that VEC2TLE associates the launch date and time to the five-digit catalog number.

Computing Two-Line Elements (TLEs) and *AMSAT* Keplerian Elements

The Keplerian elements can be computed once the state vector file is created and the launch date and time are specified. As with the vector file, output files need to be specified for the NORAD formatted TLEs and ***AMSAT*** Keplerian elements. The TLE file is identified under the **TLE Output File** selection under the **File** menu (or alternatively by the *Alt-T* shortcut) as shown in **figure 1**. Likewise, the ***AMSAT*** Keplerian elements file is identified under the **AMSAT Output File** selection under the **File** menu (or alternatively by the *ALT-M* shortcut).

The actual computation of the Keplerian elements is done by reading in the vector file using the **Read Vector File** selection under the **Compute TLE** menu (or alternatively by the *ALT-R* shortcut). When this selection is made, the vector will appear in the dialog box shown in **figure 3**. Selecting *"OK"* initiates computation of the Keplerian elements, which are automatically saved in the TLE and/or ***AMSAT*** Keplerian element files.

Spreadsheet Limitations

The spreadsheet approximates an injection state vector for direct orbital insertion by a launch booster. However, it does not accommodate multiple orbit launch profiles (i.e., a launch profile with multiple boost phases separated by free-flight orbital phases of the spacecraft.

Downloading the Spreadsheet

The Microsoft Excel® spreadsheet is available on the Orbitessera Web site at http://www.mindspring.com/~n2wwd on the State Vector page or from the corresponding file transfer protocol (FTP) site at ftp://ftp.mindspring.com/users/n2wwd/orbdata/.

SUMMARY

Given basic information, Keplerian elements may be estimated for new satellite launches. Input information includes the launch site location, booster ascent profile information, orbital inclination, and the apogee and perigee altitudes. In the first stage of this process, this information is entered into a spreadsheet that computes a time-independent position and velocity state vector. The second stage of the process uses the state vector in VEC2TLE to compute the Keplerian elements in TLE and/or ***AMSAT*** format. It is in this second stage that VEC2TLE uses a specific launch date and time to apply the time-dependency to the Keplerian elements. Therefore, once a valid state vector is generated, it may be used for any launch time for determining the corresponding Keplerian elements.

Amateur Radio Packages on OS-II

Randolph Kohlwey, N7SFI

n7sfi@amsat.org

Abstract:

Amateur radio packages are being built to fly on the new OS-II satellite being developed by One Stop Satellite Solutions (OSSS) of Ogden, Utah. The satellite will be based on the JAWSAT (OS-I) design. The communications packages will differ from those flown on JAWSAT's Attitude Controlled Platform (ACP). It will be split into several simpler packages. The first package will be a student developed UHF beacon and an independent telemetry system. The second package is a dedicated command and control system using a 9,600 bps V/U digital link. The third package will be an experimental 153,600 bps mode S downlink to be used for downloading JPEG images. A forth package will be an experimental FM voice L/U bent pipe. This paper will describe the preliminary design of each package and give examples of the equipment needed on the ground for satellite operation.

Background:

The Center for Aerospace Technology (CAST) at Weber State University and One Stop Satellite Solutions recently completed the JAWSAT (OS-I) mission. The mission successfully proved that the Multi Payload Adapter (MPA) was a viable space frame structure. The Attitude Controlled Platform (ACP) experiment was a part of the mission that was not tested. Signals were received on the first orbit indicating that much of the hardware survived the trip into space. The attitude control software was not able to be uploaded to the satellite to test the ACP.

Changes are being made to the communications systems to improve its reliability and to allow independent design, construction and testing of each package. This will allow the experimental packages to be added without affecting the critical command and control system.

Telemetry Beacon:

The telemetry beacon is currently being designed as this paper is being written. The design goals are to provide a low power UHF downlink of telemetry data independent of the flight computer. It will monitor one of the uplink receivers for shut down commands. It will run until such a signal is received or its batteries run down. An option may be added to the flight computer to recharge this second independent set of batteries.

It has not been decided if the telemetry will be set as a CW, 1200 baud AFSK or 9600 FSK signals. A study is underway to find the most power efficient way of transmitting the data and still have the beacon easily found during the first few orbits. The format of these packets has not been chosen. If CW is used they may be sent with an alphabetic character ID followed by the 3 or 4 digit value. If CW is not used then either the APRS telemetry or PACSAT telemetry formats may be used.

The beacon can downlink up to 16 channels of data. It will monitor the solar panel voltages, main battery voltage, telemetry battery voltage and various temperatures. Most of these are 8 bit resolution but a few will be 12 bit. The gain, offset and units needed to map the unsigned integers to the measured values will be published on the Web before launch.

Command and Control:

The command and control mode U/V date link will use AX-25 9600 baud FSK (G3RUH) packets. The uplink will be on 2 meters and the downlink will be 2 watts on 70 cm. The downlink frequency will be published before launch but the uplink will not be published until the initial commissioning of the satellite is completed. The commissioning is planned to take place in the first few months after launch. The satellite will be opened for general amateur use once the satellite is checked out and operational. Code will be uploaded at that time that will allow UI packet digipeating. No BBS operation is planned from the satellite using this package.

From time to time the digipeating may be turned off while the satellite is over the command station in Utah. During these times new software can be uploaded and other housekeeping tasks will be done. It is hoped that this can be kept to just a few passes per month. The amount of time the digipeating will be enabled will depend on the satellite power budget. The orbit the satellite will be in and the size of its solar panel has not been set yet. The plan is to have more solar panels and have them on most sides of the satellite. On JAWSAT there was just one panel that covered only one side of the satellite.

Any station capable of working the current crop of 9600 baud digital satellites (UO-22, KO23, KO25, etc) should be able to receive the downlink. The format of the Space to Earth packets will be published on the web before launch. This downlink will also include beacon and telemetry packets compatible with WISP and other PACSAT software. The current software that is available for digipeating UI packets on the current digital packets should also work on OS-II when the digipeating is enabled.

High Speed Data Download:

The experimental high speed S-band downlink will run at 153,600 bps FSK (G3RUH). Two different output levels are being considered. When more is known about the power budget the decision will be made on which one to fly. The most likely would be a 2 watt transmitter. This would allow the system to be on more of the time but the most popular receiving setup will not have enough gain to receive the high speed downlink. It is estimated that they will need new antennas with an additional 5 dB of gain. If a 5 watt transmitter is flown, some of these stations will be able to receive the downlink but it will not be able to be on very much because of the power load it will put on the satellite batteries.

Two different download modes will be available for the satellite. The first would use the PACSAT protocol that is being used on the 9600 baud packet BBS satellites. The second is a similar protocol but with a smaller and different header format. The packet length may also be increased. The software will respond to file fill request but only the first will respond to directory fill requests. These requests can be made using 9600 bps FSK (G3RUH) on the 2 meter uplink frequency.

Most amateur satellite operators will face problems trying to receive this down link. The first is getting the additional receive gain needed by the 300 kHz bandwidth required for the 153,600 bps downlink. The second is finding radios with the flat 300 kHz filters needed to pass the downlink. The third is finding modems for TNC's that can do the 153,600/9600 split. The fourth is finding TNC that can handle that speed. The fifth is getting greater than 115,000 baud link between the computer and TNC. The sixth is getting PC software to support a faster serial port speed. Some solutions to these problems will be presented next.

Receive Gain

It requires 12 dB more gain to receive 153,600 bps than that needed for 9,600 bps. This will be less if greater RF power and gain antennas on the satellite. It also can be solved with bigger antennas on the ground. It has been demonstrated that UO-36's one watt 38,400 bps S-Band downlink signal can be received on a 1 meter dish. We hope to be able to fly a gain antenna on OS-II but it will depend on what other payloads will fly. If we have the power budget we will fly a 5 watt transmitter. If a 2 watt or less transmitter is flown we will add a new 3 meter diameter or greater dish to the command station.

Radios with 300 KHz digital filters

We have found two solutions to this problem. The quickest way is to just go out and buy a digital radio. One that we have found and will try in the future is made in Germany by SYMEK Datensysteme und Elektronik GmbH. They make the TRX4S 435 MHz Transceiver that can both send and receive FSK up to 153,600 bps. This transceiver is geared for high speed packet with 0.5 millisecond TX-Delay and up to 20 Watts out RF. It is 160 x 100 x 25 mm in size and is fully programmable via RS232. It has been used to receive UO-36 at 38,400 kbps. We are going to use it as a 153 kbps transmitter until we get our S-Band transmitter. After that we will use it with a S-band to 70 cm Downconverter as an IF receiver. We will use the RS-232 link to adjust for Doppler. The transceiver also has a narrow mode for data rates up to 19.2 kbps.

The second solution is to modify a commercial transceiver. The same company has a module that can be inserted into the IF of a radio. They have modules for FT736, TS790, IC821, TM-V7E and other standard amateur radios. The IFD wideband FM high speed data receiver / demodulator is being used by several US amateurs for receiving UO-36's 38,400 bps downlink. When you order these modules you need to specify your radio as well as the bandwidth. To receive the OS-II downlink you will need the 153,600 Baud 300 kHz filter. This one could also be used to receive UO-36 at 38,400 baud but will require 6 dB more of receive gain than using the 80 kHz filter. A side benefit of a wider filter is that you do not have to adjust for Doppler as much. We soon will check if the popular M2 and KLM cross yagis will have enough gain to do this. We will also soon test this using the FT-736 for our receiver and the TRX4S radio at low power into a dummy load as the transmitter.

153 kbps Modems

The same company also has the FSK-9601 modems that can do the required 153,600 bps receive and 9,600 bps transmit. When ordering you have to specify the data rates and if NRZ or NRZI coding is required. If you are going to use the modem in a TNC-2 you need the NRZ coding but I have not found one of those TNCs that can do 153 kbps. If you use one of the new 16 bit SYMEK TNCs you need the NRZI version. Specify the TNC or HDLC serial card you are going to use the modem with when ordering.

TNC RS-232 115 kBaud limit

The one way to get around the maximum serial baud rates is to skip the TNC and RS-232 serial card. One can hook the modem to a HDLC card directly. We will try to use a 153 kbps transmit and 9.6 kpbs receive modem connected with an Ottawa PI-2 card in a PC. This will be the hardware platform we will develop satellite software on. I do not believe WISP supports such cards.

Most of the TNC-2 based TNCs have a maximum baud rate of 38,400 baud and a few have 57,600 baud. The current SYMEK 16 bit modems (TNC3S and TNC31S) have a specified RS-232 maximum data rate of 115 kBaud. We will soon do an experiment to see if these modems will work with this limitation when receiving 153 kbps on the radio side. We have requested SYMEK to allow for greater than 115 kBaud on the RS-232 serial ports of their 16 bit TNCs.

PC RS-232 115 kBaud limit

Once again if the modem is connected to a HDLC card this is not a problem. There are new PCI cards that can do much greater than 115 kBaud. There are also USB to Serial converters that can also run at greater speeds. We are in the process of testing some of these solutions. We are first going to try a 4 port PCI serial card made by SIIG (JJ-PO40011). It uses 1 IRQ for all 4 ports. It uses a 16850 UART that has a 128 byte transmit/receive FIFO. They also make an IDE card that uses an IRQ per each port. There are other companies that manufacture similar cards.

PC software 115 kBaud port speed limit

The last problem is that some of the popular PACSAT programs do not let you specify port speeds greater than 115,200 baud. I have request for WISP to be fixed to allow faster TNC port speeds in its satellite setup window. We also hope to have an open source example of a program that can receive the JPEG images downloaded using both download formats.

Experimental L/U bent pipe:

The last package will be the first to be dropped if we run into mass or power budget problems. It is planned to be a 23 cm FM receive coupled to a 70 cm FM transmitter. The low power transmitter is planned to be around 1/2 watt. We would rather fly a L/U transponder if anyone has one looking for a ride or if we have time to develop one.

Conclusion:

The satellite design is not fixed until we have a confirmed launch and know what orbit we will be placed into. We are developing the amateur package now so it can be well tested before it is integrated into the satellite. In this paper we have hoped to give the AMSAT community a look into what we hope to fly and what they will need to work and receive the satellite. For updates and the results of our tests please check my web page at: http://www.xmission.com/~kohlwey/osiisat.html

WWW references:

Information on OS-II satellite and data formats
http://www.xmission.com/~kohlwey/osiisat.html
Information on JAWSAT satellite and data formats
http://www.xmission.com/~kohlwey/jawsat.html
Packet-Radio with SYMEK Packet-Controllers
http://symek.com/tnc-g/main.htm
Sources of PCI multiport high speed serial cards
http://www.wcscnet.com/Hardware.htm
http://www.siig.com/io/

HDLC cards

http://www.paccomm.com/	Search for Gracilis PackeTwin PC Card under Commercial Product Pricing Information
http://hydra.carleton.ca/info/pi2.html	The Ottawa PI2 (Packet Interface 2) Card

Information on APRS and satellites

http://web.usna.navy.mil/~bruninga/astars.html

The PACSAT Protocol Suite

http://www.amsat.org/amsat/sats/nk6k/msatpro.html

Distributed Processing Goes Galactic

by H. Paul Shuch, N6TX
Executive Director, The SETI League Inc.

Abstract

Are we alone, the sole sentient species in the cosmos, or might there be others, among whom we can take our rightful place? If there is indeed an interstellar internet, might we someday log on? And what are the protocols for cosmic communication? For the first time in human history we now have the technology to ask, and perhaps begin to answer, these questions. In this paper we explore the strengths and weaknesses of SETI@home, the most ambitious distributed computing experiment on this planet. We learn how thousands of amateur radio telescopes are forming a global net to snare that elusive fish in the cosmic pond. And we explore how the lessons learned from the SETI@home experience can be brought to bear on the problem of massive data collection and analysis. The author believes it is the world's radio amateurs and computer hobbyists who will ultimately bring in signals from the stars.

SETI 101: An Introductory Course

SETI, the electromagnetic Search for Extra-Terrestrial Intelligence, is a relatively young science with a colorful history, which seeks to detect direct radio evidence of other technological civilizations in the cosmos. For forty years, its dominant paradigm has been the use of giant radio telescopes using sensitive microwave receivers and powerful computers, to scan nearby stars for artificially generated signals of intelligent alien origin. Once funded through NASA, SETI research in the United States lost its government support seven years ago, and now continues as a privatized venture conducted by various grass-roots nonprofit organizations.

Giant radio telescopes (such as the 1000-foot spherical reflector of the Arecibo radio observatory in Puerto Rico) achieve part of their sensitivity by directing an extremely narrow beam on the heavens. Such instruments view perhaps one millionth of the sky at a given time, reducing the received background noise (and hence improving the signal to noise ratio of any detected radio artifact) by a factor of a million, relative to an omnidirectional (isotropic) antenna. Hence, if you have such an antenna hooked up to the right kind of receiver, which is tuned to precisely the right frequency, at exactly the instant when The Call comes in, there is about a 99.9999% chance it will be pointed the wrong way.

But since we don't know what exactly that "right frequency" is, the problem of SETI success is complicated further by our need to tune our receivers systematically across a wide spectral range. If a SETI receiver is to achieve reasonable sensitivity, its desired bandwidth of reception is of necessity quite narrow. This is because radio noise and natural interference phenomena are spectrally broad, while one of the hallmarks of artificiality which intelligently generated emissions can be expected to demonstrate is high spectral coherence, resulting in narrow bandwidth (on the order of a fraction of a Hertz.) But that narrow signal can fall anywhere within several GHz of potential spectral real estate.

By reducing receiver bandwidth, we once again improve our signal to noise ratio. But if we wish to find an artificial signal with a bandwidth of, say, 1 Hz, and if to locate it we must scan, for example, 10 GHz of spectrum, then we have a temporal problem equivalent to our previously stated spatial one. If we are pointed in exactly the right direction, at the very instant when The Call comes in, there is something like a 99.99999999% chance we'll be tuned to the wrong frequency!

Problems associated with the spatial dimension of SETI are partly overcome by constructing phased arrays of a great many antennas, operated so as to look in many directions at once. And to address the spectral challenge, SETI engineers concentrate much of their efforts toward developing elaborate multi-channel spectrum analyzers (MCSAs) capable of monitoring many millions of narrow channels simultaneously. Yet despite these technological advances, SETI critics rightly point out, after forty years of SETI, we have yet to detect a single confirmed signal of intelligent extraterrestrial origin.

The SETI@home Experience

Yet in those forty years of searching, SETI proponents counter, we have not only failed to scratch the surface, we haven't even felt the itch. Our massive antennas and multi-channel spectrum analyzers generate more data than we can ever hope to analyze, even using Planet Earth's most power supercomputers. Digital signal processing efforts, necessary to separate the cosmic wheat from the galactic chaff, depend upon an ability to crunch numbers at an ever increasing rate. And right now we are generating more SETI data than we can ever hope to analyze.

It has been argued that if we are to be limited at all, computing power is the place to be limited. Since computer power seems to double every year or so, we need merely wait until our computer power is up to the task, in just a few more years -- or decades -- or centuries.

One group of SETIzens, lead by Prof. Woody Sullivan at the University of Washington, and Dan Werthimer, David Anderson and David Gedye at Berkeley, got tired of waiting. Last year they launched SETI@home, planet Earth's most ambitious distributed processing experiment. They have harnessed the idle processing power of 1.85 million personal computers around the world, and in so doing have created the world's most powerful supercomputer. Tied to a Project SERENDIP microwave receiver at the Arecibo Observatory, the SETI@home network has crunched more data in a few short months than has been analyzed by all the world's prior SETI efforts, combined.

After pre-processing on site, SERENDIP cranks out data at the rate of more than a MegaByte per second. That's just over 100 CD-ROMs per day worth of data generated by one receiver alone, truly an example of drinking from the fire hose. Until now, most of that data would simply have gone un-analyzed.

SETI@home's power derives from clever software that parses this massive data stream into bite-sized chunks, for Internet distribution and off-line data analysis. This is done by first filtering and dividing the receiver's 2.5 MHz bandwidth into 256 individual audio channels, each a manageable (and easily digitized) 9756.6 Hz wide. 107 seconds worth of data from just one of these audio channels can be stored in a digital file a mere 341 kBytes in size (about the capacity of a 1980s-vintage single sided, single density 5 1/4 inch floppy disk).

At 56 kBaud V.90 dial-up connect speeds, it takes about a minute and a half to transfer such a packet to a SETI@home user via the Internet, after which a modest computer running the SETI@home analysis software can thoroughly analyze it offline. On a typical Pentium III class PC, this analysis takes roughly ten hours, after which the user uploads a results file to the SETI@home server at Berkeley, downloads another packet, and starts all over again.

Working together is certainly working! Today one and a half million home computers are devouring data from the world's largest radio telescope, TeraBytes at a time. Still, while the screen saver churns away in the background, the appetite for involvement is not sated. "I'm no rocket scientist," I hear you saying, "but I want to do more than wait for my Pentium to claim the prize. Where can I go from here? The software is fully capable of discovering that elusive needle. Only, where do we find the haystack?"

SETI@home has some impressive strengths, offset by one significant weakness. Its nearly two million home computers are crunching data from a single source, an antenna which in turn sees only a tiny fraction of the sky at any time. To avoid missing the call, we really need about a million such radio telescopes, coordinated so as to point in all directions at once. But at a cost of perhaps a hundred million dollars apiece, we've just exceeded the Gross Planetary Product.

Fortunately, there is another way.

Project ARGUS and the Amateur Radio Astronomer

Launched in 1996, Project Argus is an amateur-run all-sky survey, which attempts to accomplish something which NASA SETI never contemplated: see in all directions at once. This major initiative of the membership-supported, nonprofit SETI League seeks to harness the power of 5000 small radio telescopes worldwide, in a coordinated search of all four pi steradians of space. Its amateur radio telescopes, typically built around discarded satellite TV antennas for a few hundred to a few thousand US dollars, achieve sensitivities on the order of 10^-23 watts per square meter, roughly equivalent to the best research-grade radio telescopes of the late 1970s. As personal computers and digital signal processing software become more powerful, this two-decades gap between professional and amateur capabilities is beginning to narrow.

One argument for the validity of Project Argus is the example set by amateur optical astronomers in their discovery of numerous comets, supernovae, and other highly intermittent astrophysical phenomena. It is not, after all, the world's great observatories which typically detect these events, but rather such dedicated amateur astronomers as Allen Hale and David Levy (both using

14 inch Schmidt Cassegrain telescopes), Tom Bopp (who doesn't even own a telescope, but discovered his comet with one he borrowed from his astronomy club), Hyakutaki (the comet that bears his name was discovered with a pair of high-power field binoculars!) and the late Gene Shoemaker, a geologist by trade, but a longtime and avid amateur skygazer.

Regrettably, the analogy breaks down when one considers equipment availability. In most cities of the world an aspiring comet-hunter can walk into a local optical shop, write a check for a thousand dollars or so, and walk out with a telescope that would have turned Galileo green with envy. Amateur radio astronomers aren't quite so fortunate. You can't walk in to your local Radio Shack ® store and buy a radio telescope. At least, not yet. The SETI League is trying to change that, by designing the hardware (licensed for commercial manufacture) and software (distributed as shareware via the internet) to turn a surplus 3 to 5 meter TVRO dish and a home computer into a credible research instrument. Already about 100 radio amateurs, microwave hobbyists, electronics experimenters and computer hackers around the world have succeeded in putting their Argus stations on the air. Hundreds more are now under construction, and every year the dream of all-sky coverage (whereby no direction on the sky shall evade our gaze) comes closer to reality.

Details on the construction of a Project Argus radio telescope may be found in the SETI League Technical Manual, available in hardcopy for a modest contribution, or free on the web (www.setileague.org).

Global and Galactic: The ARGUS@home concept

Current Project Argus instruments each scan about 22 kHz of frequency spectrum at a time (a small fraction of the 2.5 MHz instantaneous bandwidth of the SERNENDIP receiver at Arecibo.) They break that spectrum down into typically 8192 simultaneous channels, each about 2 1/2 Hz wide. One such instrument generates on the order of 44 kBytes per second of data. This is a small fraction of the data gathered by the SETI@home experiment at Arecibo. On the other hand, the existing 100 Argus stations, collectively, already exceed the data output of the SETI@home receiver. By the time Argus reaches full strength, its combined network of 5000 amateur radio telescopes will, collectively, generate as much data as hundreds of Arecibos!

The SETI@home packet your PC is processing came from the world's largest radio dish. So did everybody else's. Which means that nearly two million PCs are being serviced by a single data source. A powerful source to be sure. But with lotteries all over the world, why buy all our tickets for a single drawing? Remember that Arecibo achieves its sensitivity by scanning a slim slice of the celestial sphere. No software in the world is going to find photons that didn't hit the fan. No matter how many computers are running it.

Perhaps that's where the eyes of Argus can really shine. Imagine a global network of thousands of amateur radio telescopes, scanning the entire sky in real time. Now imagine something akin to SETI@home, software which will let you scan that data via the Internet. Only instead of archival data recorded weeks ago, we're talking live data which your computer can capture in real time. So you need not wait for the evening news to hear the winning numbers.

ARGUS@home won't happen overnight, any more than SETI@home did. In addition to the multitude of small radio telescopes required, we still need to come up with a SETI@home-compatible data block format, and find a way for Project Argus software to parse out the gathered data for internet distribution. Then there's the challenge of collecting and correlating all those processed packets. The SETI@home experiment has already solved many of these problems; it remains for The SETI League to adapt their solutions to amateur practice. We hope that by the time SETI@home drinks the Arecibo well dry, we will have risen to these technical challenges.

Conclusion

Project Argus went online just four years ago with only five small amateur radio telescopes. Today we're running about a hundred. It's going to take us a few more years before the Argus network grows to truly global proportions. Until then, there's always Arecibo.

The distributed computing concept pioneered by SETI@home is very adept at finding needles. The global network of Argus telescopes will be ideal for finding haystacks. Seems to me, it's a marriage made in heaven.

About the Author

Dr. SETI ®, as H. Paul Shuch is known to his intimates, is something of a cross between Carl Sagan and Tom Lehrer (he sings like Sagan and lectures like Lehrer). The aerospace engineer credited with the design of the world's first commercial home satellite TV receiver, Paul now directs his microwave interests toward the search for life in space. Dr. Shuch received his Ph.D. in Engineering from the University of California, Berkeley, and taught for 24 years. He is the founding Executive Director of The SETI League, Inc., a membership-supported educational and scientific nonprofit which has emerged as the leader in a grass-roots Search for Extra-Terrestrial Intelligence.

As a radio amateur, N6TX has been active on all 20 ham bands between 1.8 MHz and 24 GHz. Paul is the author of over 250 publications. He is a Fellow of the British Interplanetary Society, serves as a fellowship interviewer for the Hertz Foundation, a manuscript reviewer for several peer reviewed journals, has been an advisor to the National Science Foundation, and is a military program evaluator for the American Council on Education. Paul's honors include the Robert Goddard Scholarship, the Hertz Fellowship in the Applied Physical Sciences, the Horonhjeff Grant, the Hertz Doctoral Thesis Prize, the EAA Safety Achievement Award, the John Chambers Memorial Award, the ARRL Technical Achievement Award, and the Dayton Hamvention Technical Excellence Award.

Dr. SETI lives on a radio-quiet hilltop north of Williamsport PA (grid square FN11lh) with three radio telescopes, his wife Muriel Hykes, and five of their seven recombinant DNA experiments.

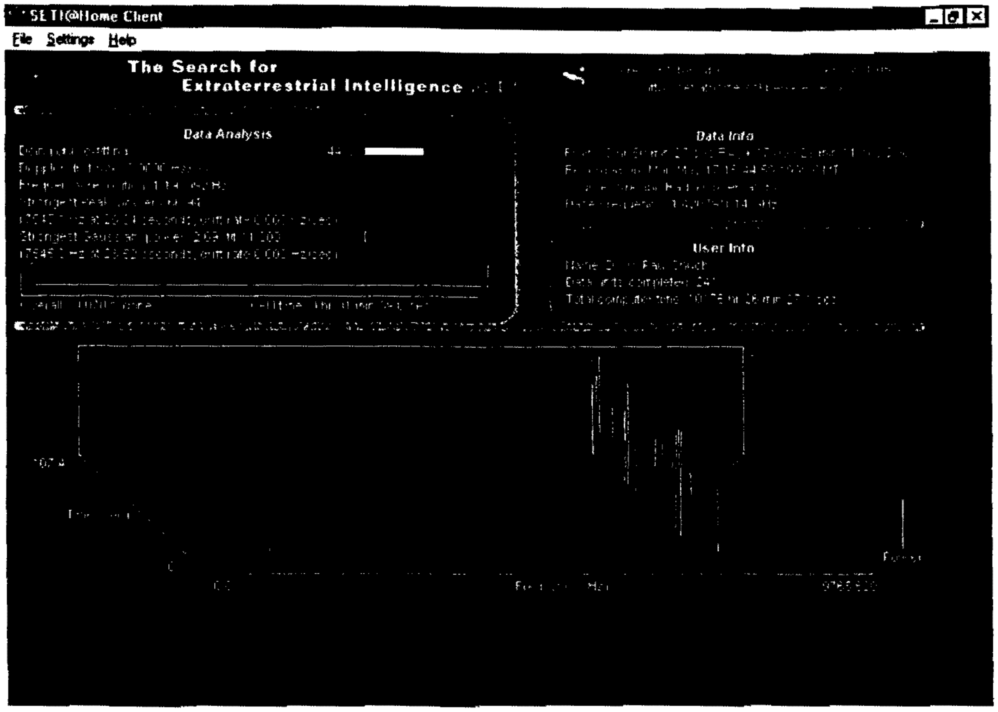


Figure 1: Strong, coherent signals such as this one quicken the pulse of many a SETI@home project participant. Unfortunately, all so far have been generated not by ETI, but by terrestrial interference, or by the Wizards of Arecibo as they inject test signals to verify the proper operation of their equipment.

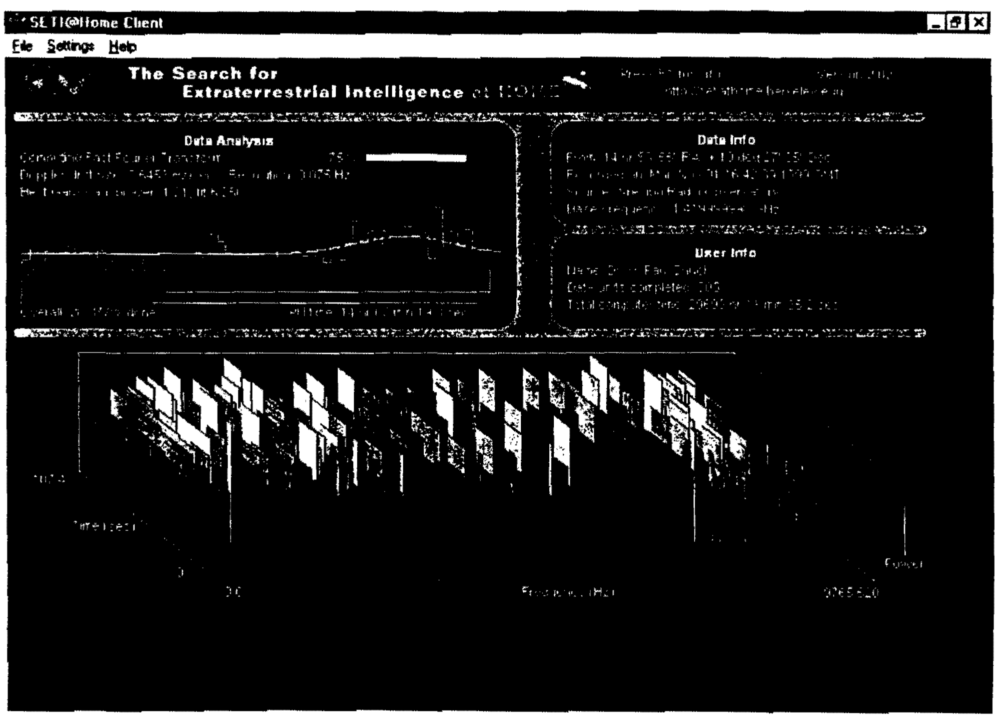


Figure 2: The SERENDIP receiver at Arecibo has a 2.5 MHz instantaneous bandwidth. For SETI@home processing, its output is parsed out into 256 sub-bands each 9765 Hz wide. Notice how the amplitude of the noise rolls off at both the top and the bottom frequency ends of this analysis spectrogram. The curve seems to follow the frequency response of an audio bandpass filter optimized to the desired sub-channel bandwidth.

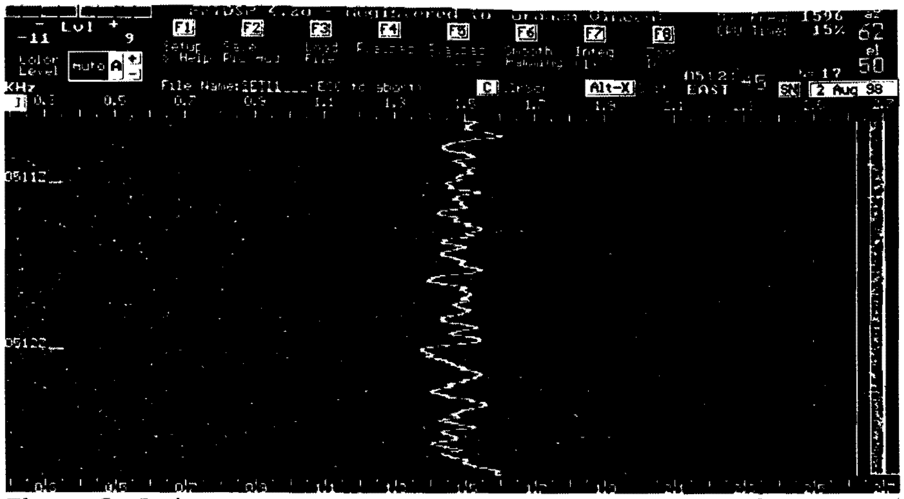


Figure 3: Graham Vincent, SETI League volunteer coordinator for New Zealand, received this intriguing signal on 2 August 1998, at a frequency of 1281.919 MHz USB (in the 23 cm amateur radio band). The appearance of the signal is similar to a class of anomalies detected by the SETI Institute's Project Phoenix targeted search. Dubbed "wigglers" by the SETI Institute's Dr. Jill Tarter, their detections have always proved to be cases of radio frequency interference. Graham's signal is no exception. It turned out to be computer rfi, generated within the very computer which he was using to run his signal analysis software. England co-coordinator Ken Chattenton, who has had similar experiences, recommends that if a signal is strong enough to be audible, one should turn off the computer and see if it goes away.

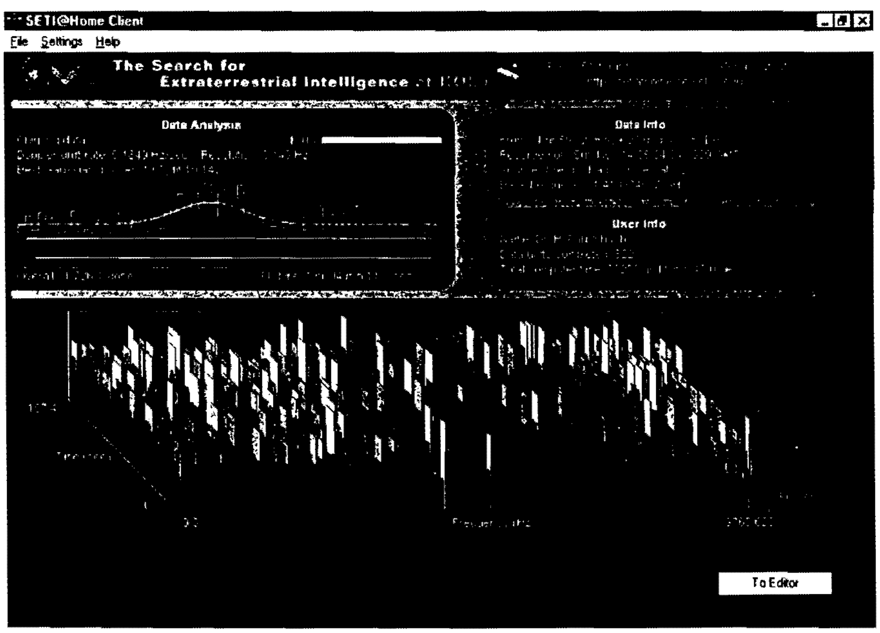


Figure 4: Here's a signal with a fairly good Gaussian fit, which is not evident from viewing just the 3D spectrogram (bottom window). The SETI@home client divides the 9765 Hz wide data block into housands of very narrow bins. The amplitude of the signal in each individual bin is analyzed over time, and the bin with the best fit to the antenna's expected drift-scan time series is displayed as a ragged trace in the data Analysis (upper left hand) window. The smooth trace represents an ideal Gaussian curve (normal Distribution) corresponding to the pattern of the Arecibo antenna. The two curves are statistically compared. The closer the fit, the more credence is given a candidate signal. Of course, the Gaussian test is only one of many hurdles a signal must pass before it is considered to be of extra-terrestrial origin.

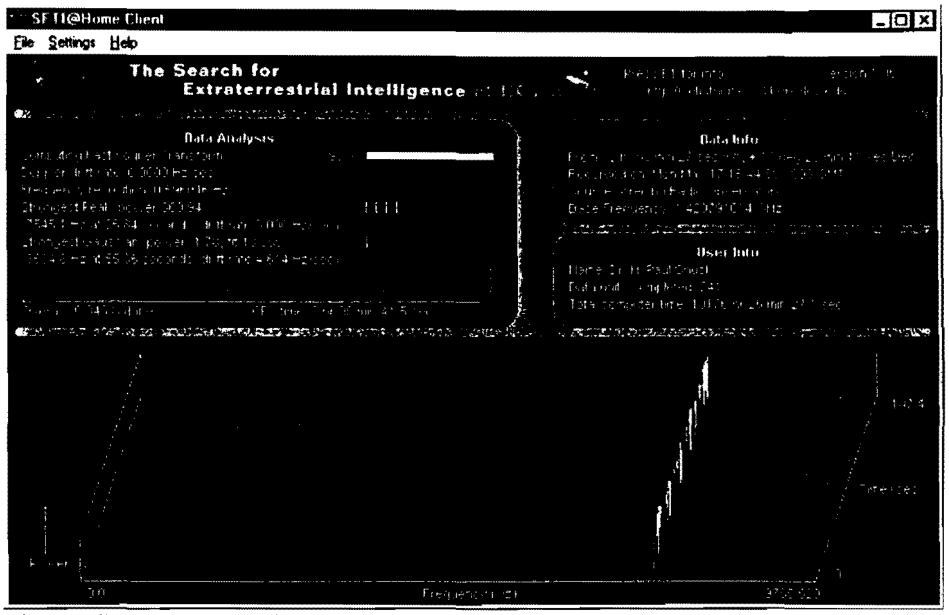


Figure 5: SETI@home's nearly two million users continue to see occasional anomalies such as this one, observed by the author in December 1999. Members sometimes call or email The SETI League, requesting that we check out such signals (most of which turn out to be terrestrial interference). Unfortunately, there's nothing we can do from here to analyze these detections, since all verification is performed by the SETI@home team at Berkeley CA. Be sure to uploaded your analysis files to them, and rest assured that they will indeed follow-up on all interesting candidate signals, and inform you if yours is The One.

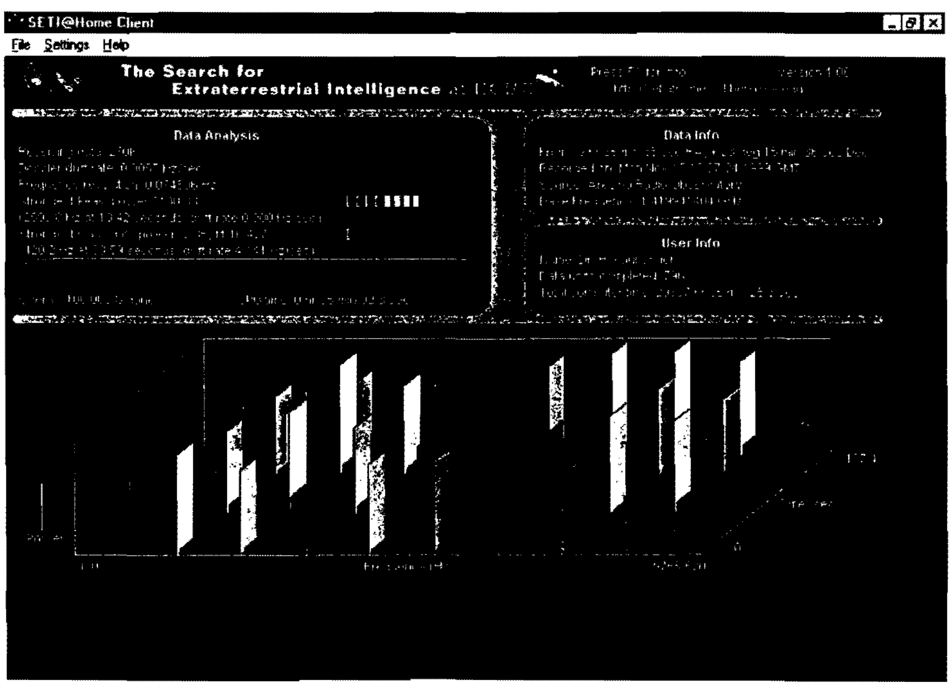


Figure 6: The typical computer takes tens of hours to fully analyze a single SETI@home data block. Occasionally, strong, wideband terrestrial interference obliterates any useful information. When that happens, the SETI@home client determines that no further analysis of that data block is possible, quickly terminates analysis of that particular file, and requests another one for analysis. SETI@home gave up on this file after just five minutes of attempted analysis.

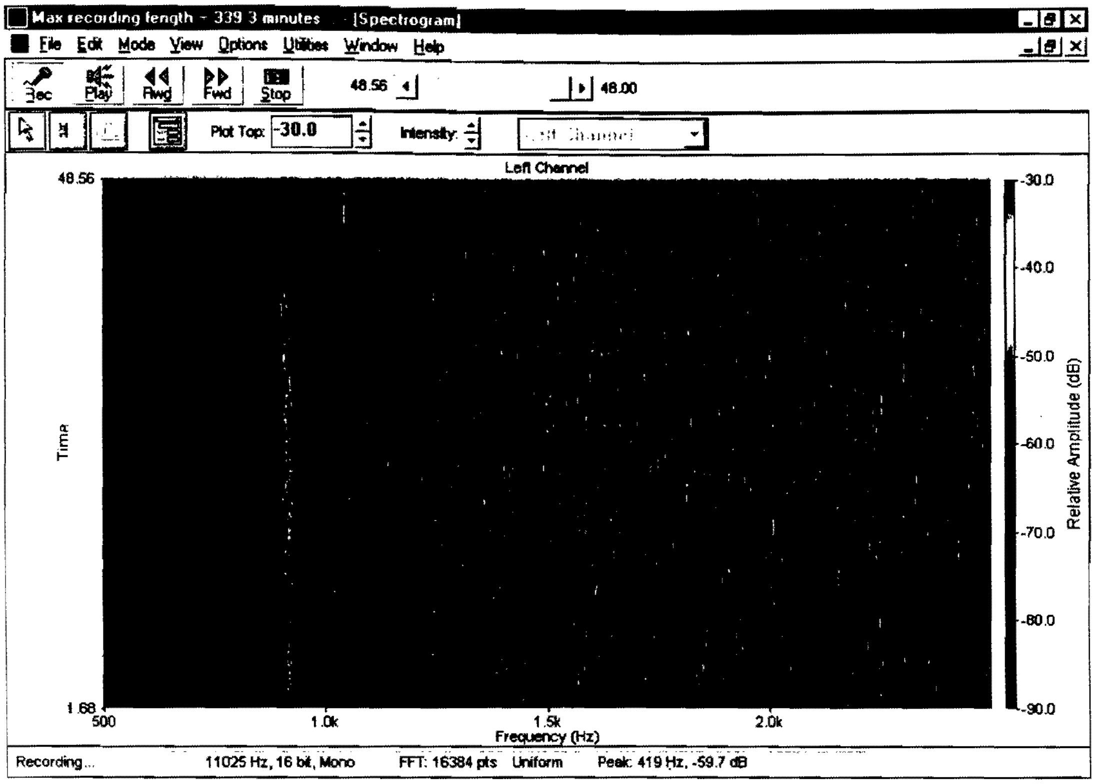


Figure 7: EME (moonbounce) contests provide Project Argus participants with an opportunity to detect weak amateur microwave signals reflected off the lunar surface. This unusually strong 1296.015 MHz EME echo from the 30 foot dish of Jay Leibmann, K5JL, was received at Argus station FL11LH during the 30 October 1999 ARRL EME contest.

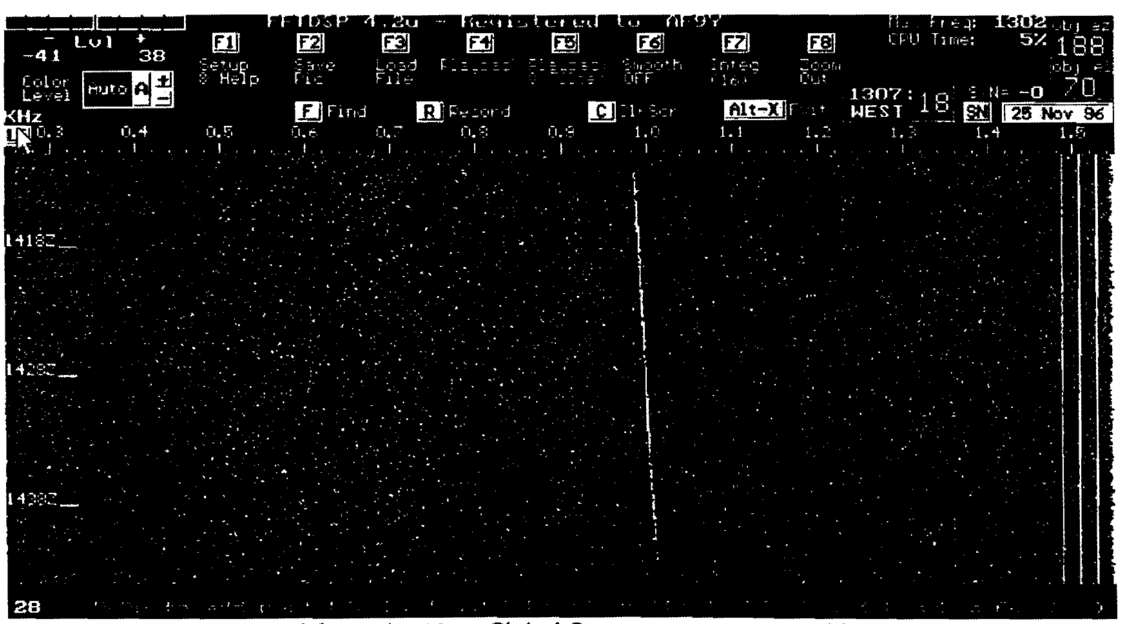


Figure 8: This CW signal from the Mars Global Surveyor was received by SETI League member Mike Cook on 25 November 1996, while the spacecraft was about 5 million km from Earth. The satellite's 1.3 Watt beacon transmitter, into an omnidirectional antenna, provided SETI enthusiasts with an excellent dry run to verify the operation of their receivers and digital signal processing software. Several other SETI League members were also able to recover the signal utilizing Mike's FFTDSP shareware program.

Tricks Hints and Tips for a Portable Satellite Operator.

Charles, "Chuck" Duey, KI0AG
ki0ag@amsat.org

Abstract:

Portable operation of amateur radio satellites can be challenging and rewarding in making good contacts. While the Rubber Duck antenna is generally sub-optimal, there are a few interesting techniques to make the signals better by using local objects and the ground. Arrow Antenna's satellite antenna has quite a few proven techniques to make low elevation passes work well. While the Single Side Band birds are not thought of as portable, a small pack can be set up with everything needed to make contacts on these satellites as well. With the best portable equipment there are always places where it is difficult to hear the satellites over the din of the other terrestrial radio signals. There are a few places to try and avoid and a few small items to help filter out the problem signals. With these tricks, hints and tips the portable satellite operator can hear and work the satellites from almost anywhere.

Introduction:

Working amateur radio satellites from remote or unique locations can provide a rewarding experience for both the traveler and the contacted stations. Working other stations as part of a vacation or business travel shares the experience of the trip with other operators. There are many tricks to making contacts that are clear and predictable. With a few added items to a briefcase or suitcase it is very easy to work even the lowest of passes. Some locations require more creative tricks to prevent the local signals from interfering with the satellite signals.

For a successful contact two things must happen, hear the satellite and have the satellite hear your signal. Most stations that have difficulty making contacts have problems hearing the satellite. If the satellite can be heard clearly, making contact is just a matter of the right transmit frequency and timing of the transmission. As the old saying goes: "If you can hear it you can work it." This is very true for satellites.

There are stations on satellites that cannot hear the satellite and yet try to work it. These stations are also known as "Alligators". In order not to become an alligator it is very important to hear the satellite reliably and hear your own transmission. Yes, your own transmission, but on the downlink. Once your own down link is heard, it is easy to verify that the signal is making the round trip.

On most of the FM satellites in populated areas there are a large number of stations that are all trying to work the satellite. During the part of the pass with the most population, it can be quite difficult if not impossible for a portable low power station to get in. When operating a low power station on weekends and holidays, it does take some patience to get in. Working passes low on the horizon with fewer stations give more contacts to a portable station than at any other time.

Working with HT Antennas(Rubber Ducks and Whips):

While most HT antennas do not have enough gain to hear much of a satellite pass, there are a few that can give a portion. In years past it was very difficult to hear AO-27, but UO-14 and SO-35 have much stronger downlink signals making it easier to hear. The higher gain antenna is better. The longer the better for most of these antennas. SO-35 has a 2-meter down link, which for the same antenna gain will have nine times less path loss than 70 cm. However this means the SO-35 uplink will suffer from the same loss as the AO-27 and UO-14 down links. On UO-14 and AO-27 with the HT antenna the 70 cm frequency is the one to concentrate on.

On AO-27 and UO-14 the downlink is on 70 cm, which makes receiving more difficult. To hear these two satellites the local objects and terrain can be used. One of the most common tricks to hear UO-14 or AO-27 is to turn the radio upside down. With the radio inverted the signals from the ground reflections help boost the signal. Using headphones the radio can be moved up and down to find the best position. This works well to receive, but transmission with out a remote microphone is difficult. Without a remote microphone, the radio needs to be moved to speak losing the downlink and the important reception of the returned signal. The upside down radio works well in the 10 to 30-degree elevation part of the pass. For more overhead passes holding the radio about 4 inches from a vehicle roof or hood works well. Some passes the radio gets twisted and moved around several times just to find the best location second to second.

There is a sequence that works well with a Diamond RH77CA or equivalent whip and an average rental car. The car is best parked when it is in a North to South direction, with the hood towards the direction of the satellite's rise. At the start of the pass hold the antenna about 4 inches from the front of the hood. Often a good reflection at the start of the pass can be found here. Soon after the satellite rises and get up to 15 degrees in elevation there is a sweet spot between the hood and the windshield. The antenna held vertically with the connector at roof level works for the overhead and some of the medium elevation part of the pass. Towards the end of the pass move to the trunk area where there is usually some good spots there. At the end of the pass parallel to the back of the car often shows a good signal. This 'rental car' technique works very well on UO-14 and is marginal on AO-27.

Picture of KI0AG Working a Satellite off a Vehicle.

On both UO-14 and AO-27 having a rubber duck or whip is quite a disadvantage during crowded passes. While normally AO-27 can be worked with 100 mW and a rubber duck, the FM capture effect makes it such that the station with the most powerful signal is heard. It is very unlikely to get into AO-27 or UO-14 during a field day pass in North America with an HT and a Rubber Duck antenna. Choose the passes carefully to have some stations but not a whole continent.

SO-35 can be heard very easily on a rubber duck, but is more difficult to get the transmission correct. The transmission frequency must be adjusted for the Doppler shift. Without this adjustment it is impossible to work SO-35 even with no other stations. To ensure the transmission is working properly a set of headphones and a full duplex operation is strongly suggested. The Doppler on AO-27 and UO-14 can be adjusted by hearing the downlink, but on SO-35 experience and hearing one's own downlink is the key. The following table of frequency adjustments should help in getting the correct frequency for SO-35 as Well as AO-27 and UO-14.

Satellite	AO-27		UO-14		SO-35	
Time	Transmit	Receive	Transmit	Receive	Transmit	Receive
AOS (start)	145.850	436.805	145.975	435.080	436.280	145.830
AOS+3 Minutes	145.850	436.800	145.975	435.075	436.285	145.830
Zenith (maximum)	145.850	436.795	145.975	435.070	436.290	145.825
Zenith+1 Minute	145.855	436.790	145.980	435.065	436.295	145.825
LOS-3 Minutes	145.855	436.785	145.980	435.060	436.300	145.825

While hearing SO-35 can be easily done while in a hotel room or basement with a rubber duck antenna, the 70 cm uplink to SO-35 and 70 cm downlink signals of AO-27 and UO-14 are nearly impossible. Most commercial buildings have metal wall studs or metal re-enforced concrete. If getting out in the open is not possible a window or even better a balcony will do. Several contacts have been made using the balcony rail as a reflector.

The Arrow Satellite Antenna:

The Arrow Antenna used for satellite is a simple concept, two antennas on one boom. This concept has been around for sometime but the use of arrow shafts makes the antenna very light and portable. To make a similar antenna, use a 3 element 2 meters and a 7 element 70 cm at right angles and that is it. While this can be done with just about any manufactures antenna it is the ease of assembly that makes the Arrow Antenna so portable.

Having orthogonal antennas on the transmit and receive typically does not pose a problem. If the satellites were ground based and the antennas on the bird were both the same polarity, it would be a problem. Signals from the satellite that pass through the Ionosphere change polarity due to Faraday Rotation[2]. This rotation affects the 2 meter and 70 cm signals differently. The 70 cm signal can change polarity up to 1.5 times, while the 2-meter signal can change up to 14 times. By the time these two signals get down to Earth, there is little left of the original polarity. For higher frequency signals this rotation decreases to 1.1 degrees at 10 GHz. If the 2 meter and 70 cm link signals happen to be the same polarity, a slight twist of the antenna will compromise the 70 cm side by a small amount and bring 2 meter signal up to par. While this is rare to have 2 meter uplink probelms, a hand held antenna is easy to change polarity with a twist of the wrist.

On AO-27 the Arrow Antenna's 7 elements on the 70 cm antenna allows operation of AO-27 down to the horizon with no obstructions. UO-14 has a stronger downlink so operations can be made with some obstructions. SO-35 can be worked horizon to horizon with 3 watts as well as long as there are no other stations transmitting at the same time. The antenna also works for the FO-20/29 satellites as well, although it adds more complexity to the operation. At perigee AO-10 can be worked with the antenna, but for safety reasons do not hold then antenna when operating more than 10 watts.

Low to horizon passes are one of the most exciting passes to use the Arrow Antenna. These passes give the best distance and are typically less crowed. It is very easy to use most of the distance in the satellite's footprint. As the satellite skims the horizon hold the antenna close to the ground. Holding the antenna close to the ground does affect the SWR on 2 meters, but it captures some of the reflections off the ground. It has been noted several times on these passes the signal strength has an enhancement just before Loss of Signal (LOS). This technique allows a station in Barrow, Alaska to contact stations in the lower 48 with ease. The flat tundra is ideal for generation of reflections. Mountain tops, while having a good horizon do not have a good reflecting surface. The tops of mountains tend to result in severe picket fencing off surrounding terrain.

When using any antenna it is very important to look at the surrounding terrain and sky. Watch the sky for thunderstorms. A good rule is no thunderclouds overhead and no strikes within 5 miles. Look up and see if there are power lines or trees in the way. Power lines tend to interfere and can be dangerous to work close to. Also look on top of the local building or mountaintops for antennas. Look down and see if the spot is good and there are no cables tangled. Finally look around and mentally trace out the pass. With just a little planning even urban settings can provide near horizon-to-horizon passes. During the pass keep in mind the surroundings, be sure to keep safe.

To work any of the satellites with a linear antenna, start with the antenna pointed towards the direction that the satellite should rise. On FM satellites the receiver starts to quiet, but don't transmit yet. A slight twist of the wrist tunes in the polarity and then peak the signal moving the antenna. As the satellite rises above the horizon the signal should come in strong and clear. On crowed passes the very start of the pass often yields more contacts than overhead. As the satellite moves up in the sky, slowly track by once again peaking the signal first with polarity then with position. AO-27 on overhead passes tends to have a low signal zone just after the zenith. If the signal suddenly drops down the satellite does not move far, so twist the antenna and search in the area of the sky it was just in. UO-14 has the same fades, but are more random as to when and where and are usually shorter lived. SO-35 with its strong down link is usually not a problem with fading. Towards the end of the pass, if there is a good horizon where the satellite sets, don't be surprised if there is some ground enhancement as the satellite sets. The signal will come out of the noise for about 30 seconds and then suddenly stop when it sets.

SO-35 with the Arrow Antenna is more difficult to point than on AO-27 and UO-14. There are only 3 elements on 2 meters and 7 elements on 70 cm. This difference causes the beam widths on the two frequencies to be very different. When working SO-35 it takes a bit more practice to center in the 2-meter downlink for the best signal, so that the 70 cm antenna will also be centered. Once the 2-meter signal is peaked and there is a good time to transmit, be ready to do some adjustments. Since the polarity of the 70-cm antenna is not yet adjusted, a quick twist of the wrist might be needed at the start of each transmission to be heard.

Working the SSB Satellites Portable:

The 2 meter and 70 cm SSB satellites can also be worked portable. While there are no good SSB 2 meter and 70 cm dual band Handy Talkies, there are a few good radios. The Yeasu FT-847 and the ICOM IC-821 are both small enough and light enough to fit in a backpack or suitcase for travel. If there is a vehicle available, use a power cable with jumper cable clips on the end. The average rental car has a nice battery in it, but the cigarette lighter plug usually does not have the capacity to run the radio well. If a convenient vehicle is not available, a good 18 Amp-Hour gel cell battery works well. While gel cell batteries are more expensive and slightly heaver, not having acid spill in the backpack is very important. With the radio and the power, now all that is needed is an antenna. The Arrow Antenna works well for this as well, but a tripod might be desired.

Working the SSB satellites are a bit more difficult than the FM birds. The frequency must be adjusted almost continuously for Doppler Shift. Also finding the satellite can be difficult because of no FM carrier to listen to. To start the pass it is best to have the memory in the radio set up for the initial Doppler shift. That is find the starting frequencies for the start of the pass using a fixed station and use them to start for the portable station. While using a tripod for the antenna helps greatly freeing up a hand, the antenna still needs to be adjusted. As the pass starts and ends, the antenna can stay in one place for 2 to 4 minutes. In the middle of the pass it might be required to move the antenna quickly to keep the signal. It is a common occurrence to loose track of the satellite as it goes overhead. The circularly polarized antennas of FO-20 and FO-29 do work well with a linear antenna, but it is not always perfectly circular. It is some times needed to twist the antenna as well on FO-20 and FO29.

Interference:

It is always best to get away from the cities and any high-powered RF sources. It is not always an option to get away from these sources. Before working a pass of a satellite it is best to take a quick listen around and see if there is any interference. There are three different types of interference that occur, receiver overload, intermodulation products, and harmonic interference. Receiver overload is the easiest to understand. The first amplifiers in the radio get too much signal, so that the desired signal does not get though. On 70 cm a common offender is 450MHz Business and Public Safety repeaters and TV Channel 14. At some swap fests there is an ATV station on 70 cm. Intermodualtion products can come from either near by sources or from stations several miles away. Harmonic interference comes from near by sources frequency multiples or transmission splatter. All of these types of interference can be heard in most major cities and close to major broadcasting sites.

To over come receiver overload, just reduce the offending signal. This can be done by pointing the antenna away from the offending source. This only works for some of the weaker interference sources. For sources that cannot be worked around filters help out. Par Electronics makes a very nice notch filter for 152 MHz. Notch filters work if the offending source is known. Interdigital band pass filter like the one in the *ARRL UHF/Microwave Projects Manual* make an excellent interference blocker[1]. Also Digi-key has some helical filters at the 70 cm band. While all of these filters help reduce the interference, there is always an insertion loss that reduces the desired signals as well.

Intermodulation can come from receiver overload creating distortion in the front end, or the mixing of two other sources. To understand intermodualtion, just a few quick basics. When two signals **f1** and **f2** are mixed, the first order harmonics are produced at **f1-f2** and **f1+f2**. The front ends of most radios have a band-pass filter and then a mixer, where the local oscillator is mixed in to generate the Intermediate Frequency (IF). One common problem with the Yeasu FT-530 is the IF on the 2-meter side is 15.25 MHz. With a repeater at 147.300 MHz and NOAA-Weather at 162.550 MHz they mix in the front end to generate 15.25 MHz. This causes problems when both transmitters are in range. To fix this problem, one of the two signals needs to be blocked. Since 147.300 MHz is in the Amateur band, it is easiest to notch out the 162.550 MHz with the Par Electronics filter.

Harmonic interference can usually only be fixed at the source. While pointing the antenna away from the source helps, it usually does not reduce the problem enough to work a good pass. An example of harmonic interference is a station at a swap fest at 145.600 MHz will have some 3rd harmonic output at 436.800 MHz. There is not much that can be done other than asking the other station to hold off during the satellite pass. It is common to have -60 dB down 3rd harmonic which when the transmitter near by is more than enough to swamp the downlink signal. On the other hand there have been some cases were a commercial transmitter was splattering all over the 440 MHz band, clearly out of the limits. Once the station was contacted, they immediately fixed the problem, so the next day it was clear.

The best way to get over all interference is to move away form the source. When choosing a spot to work the satellites from first listen at the down link frequency and point the antenna around. Just a mile down the road or just over the next ridge the interference can go from S9 to S0! This is not always possible but listening first helps to get ready for what is needed for the pass.

Conclusion:

There are many ways and methods to work the armature radio satellites portable. Just remember amidst the din of interference and high-powered stations to have fun!

Catch Ya' on the Birds
73
Chuck (KI0AG)

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A Spread Spectrum Wideband Transponder for the International Space Station

Matthew Ettus, N2MJI
matt@ettus.com

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Abstract

A satellite payload for the International Space Station is proposed, which would provide high-bandwidth, wide-area data communications capabilites for radio amateurs. Key features of the system are a simple space segment and low cost ground stations. Varying tiers of service can be provided depending on end-user equipment investment, from low-cost paging, through digital voice, video, and high-speed data communications.

1 Introduction

1.1 Vision and Goals

The design, construction, and deployment of an experimental payload for the EXPRESS Pallet on the International Space Station (ISS) is proposed. The payload, to be known as the Spread Spectrum Wideband Transponder (SSWBT), is designed with the following goals in mind:

- Low cost digital voice communications
- Digital Videoconferencing
- High bitrate, low-latency data transfer
- Development of Spread Spectrum technology in the amateur community
- Open space communications to the average amateur
- Room for future growth and expansion

We envision four general tiers of use for the SSWBT:

Ultra-low bitrate ($<$ 1 kilobits/second) These would be handheld size stations, with simple patch antennas. These would be useful for paging, position reporting/homing (APRS), emergency distress beacons, and vehicle and property location systems. These systems could be made without receiving equipment if that functionality was not needed.

Low bitrate (~10 kb/s) Full duplex digital voice and data communications. With modern vocoders, 10 kb/s can provide quality better than that typical of FM repeaters. The system will be capable of both user-to-user (QSO style) full duplex, as well as roundtable (repeater or traffic net-style) communications. These stations could be mobile-mounted, portable, or simple home stations. Small patch antennas would be used, thus avoiding the need for aiming or moving the antennas.

Medium bitrate (~150 kb/s) Digital Videoconferencing, web serving, and other modern internet-style applications. These will be stations which are more well equipped, and most likely, not mobile. These will require moderately sized (~1 foot) dish antennas and some mechanism for aiming them.

High bitrate (~500 kb/s) There will not be many of these stations, perhaps 6-10 per continent, placed at strategic locations so at least one is visible during any part of a satellite pass. These stations can transmit large quantities of data, typically requested by the lower bandwidth user stations. These could be internet access points, and could also broadcast (or multicast) high quality video feeds. This would be ideal for applications such as broadcasting meetings or other important amateur events. These stations may require large dishes with accurate pointing systems, and higher power amplifiers

One of the greatest features of the SSWBT concept is that while more complex and expensive systems with high power and gain will be necessary to transmit at the higher bitrates, nothing extra will be necessary to receive these transmissions. Thus, the low bandwidth systems, besides being useful for voice communications between comparable users, can be effectively used for such applications as web browsing, and file retrieval (ftp). Ten kilobits per second is plenty of bandwidth for requesting web pages, which would be served by the medium or high bandwidth systems. Highly asymmetric links are very useful for these applications.

1.2 Why ISS and EXPRESS Pallet

What has often held back amateurs from deploying more advanced digital communications systems has been the problem of critical density. High bandwidth often requires microwave frequencies and line of sight propagation. These are difficult to achieve in terrestrial systems unless there are enough users in a particular area. By using a satellite, these good paths can be guaranteed, while at the same time providing tremendous coverage area which would be impossible otherwise. The need to reach critical densities for deployment is avoided.

The International Space Station represents the ideal satellite carrier for the SSWBT. Because it will be placed on the ISS, the SSWBT can be quickly and inexpensively deployed, without the development of its own launch vehicle. It will serve as an ideal testbed for a possible future network of microsatellites, and local terrestrial transponders to provide complete earth coverage. Since the satellite will be accessible worldwide, technology and development can be shared, improving the economies of scale, and making it more likely that the system will catch on in significant numbers.

The EXPRESS Pallet is ideal for this type of experimental payload. The SSWBT will be small and light, due to its tiny patch antennas and very simple electronics. It will consume little power, probably less than 100W, due to the relatively low and nearly circular orbit of the ISS. It will require no interaction with other systems on the ISS, and its only controls will likely be to enable or disable it. The SS transmissions of the SSWBT will not interfere with the other experiments on the Pallet or the rest of the ISS. The nadir-pointing attribute of the Pallet makes line of sight contact possible.

2 Technical

2.1 Features

- Direct Sequence Spread Spectrum (DSSS) Modulation
- 2.4 GHz Band Uplink
- 5.7 GHz Band Downlink
- 10 MHz wide signal bandwidth
- Automatic Power Control
- Scalable bitrate

2.2 Capabilities

This system will be able to accommodate over 100 digital voice conversations, dozens of high bitrate video conferencing sessions, and a high speed data link, all at once. Stations within 400 miles of the point directly below the ISS will be able to access these facilities, providing a coverage area of about half a million square miles. It can provide high data rate, asymmetric data links to small mobile users, with tiny patch antennas. User systems will have low power consumption.

2.3 General Architecture

In order to receive and demodulate SS signals from hundreds of users at one time, hundreds of demodulators would be necessary on the ISS. Instead, the SSWBT simply amplifies and retransmits the signals which it receives. This allows the ground stations to each pick out and demodulate their own signals.

A key advantage of the SSWBT is its very simple space segment. The payload will consist of a linear transponder, and a simple "carrier" signal generator. All of the complexity will be in the ground stations. This allows for easy changes to the modulation format, and avoids the need for complex and expensive radiation-hardened DSP components.

2.3.1 Modulation and Coding

DSSS Modulation will be used, with binary phase-shift keying (BPSK). The manner in which spreading codes are assigned will be discussed below. Whatever the bit rate which a station is transmitting at, it will always use the same chipping rate, 25 MHz. Thus, all signals will have the same occupied bandwidth of 10 MHz, and processing gain will be inversely proportional to bit rate. Nyquist filtering will be used to keep the occupied bandwidth to less than 10 MHz. Effective radiated power will be in direct proportion to bit rate, so that energy per bit is constant for all stations.

In order to provide more reliable communications, with lower power, and higher user capacity, forward error correction (FEC) will be used extensively. The most likely candidate is Convolutional coding and Viterbi decoding. ASICs are commonly available now which are capable of high data rates with rate 1/2, and 1/3 codes and constraint lengths of 7 or 9. Other options might include combining convolutional codes with Reed-Solomon codes, or even using turbo codes. Again, these are all issues for the ground stations, and so could be changed without touching the transponder. Different FEC systems could even be used for each of the different data rates, although that would probably not effectively reuse components. Multiple schemes could be used concurrently, allowing experimentation to coexist with normal use.

Different spreading codes correspond different "channels" of communications. Each station will have an assigned "hailing code," to which it will always be listening. When station A wishes to transmit to station B, station A will transmit using B's hailing code. In this first packet, A will send a code pair, one for a to use when talking to B, one for the reverse link. They will then use these codes for the duration of their communication. As long as the set of all codes is sufficiently large, collisions (different transmitters using the same codes at the same time) can be avoided.[1]

2.3.2 Automatic Power Control

Automatic power control (APC) is necessary to make this system work. Without it, stations closer to the satellite would swamp out the ones further away. APC guarantees that all signals will be received at the same strength, maximizing the number of them that can be decoded successfully.

The pilot signal will be used as the reference power level. When a station is transmitting, it must simultaneously receive and decode its own signal, as well as the pilot signal. The transmitting station must constantly adjust its power up or down to make its downlink signal equal in power[2] to the pilot signal. The actual downlink power received will vary, but the relative levels of the many signals and the pilot signal will remain the same.

[1]In the case of two stations transmitting on a third's hailing channel at the same time (a collision), both should detect it. Normal random backoff procedures would be used. High bandwidth, high utilization base stations should have multiple hailing channels to avoid this.

[2]Actually, energy per bit will be controlled. This will allow signals with varying bit rates on the same channel.

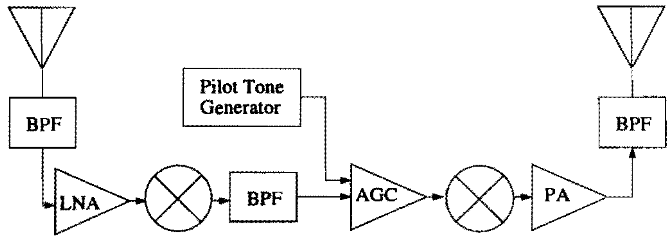

Figure 1: Transponder Block Diagram

2.3.3 Space Segment

The space module, the SSWBT itself, is a simple linear transponder, with only one addition. A simple (and small) 6 dBi, circularly polarized patch antenna receives the many uplink signals at 2.4 GHz. After being amplified and filtered, they are downconverted to IF. At IF, the signal passes through a 10 MHz wide channel filter, and an AGC amplifier. Then a pilot signal is injected, and the combined signal is then upconverted to 5.7 GHz. After it is amplified (about 25W output), it is retransmitted back to earth via another 6dBi circularly polarized patch antenna. Figure 1 shows a block diagram of the transponder.

The pilot signal is very crucial to the operation of the system as a whole. It allows the ground stations to have a reference power so that they are able to provide near perfect power control. It also provides a signal timing and doppler reference which the ground stations can also use to ease the problem of getting code and data synchronization.

2.3.4 Ground Segment

A minimal ground station, capable of transmitting digital voice, will be the typical end-user system. Such a station will use circularly polarized patch antennas, just like the satellite. It must have at least three despreading channels. One to monitor the pilot signal, one to monitor the station's own transmitted power and timing, and one for useful reception of signals from other stations. Since all of the signal processing associated with despreading channels will be done in digital logic in FPGAs or ASICs, adding more will not be difficult. Additional channels will be useful for receiving many datastreams at once. Figure 2 shows a block diagram of a ground station.

For transmitting, a power output of 1 Watt (and the capability to reduce that output power) is all that is necessary for communication. Stations of this class should cost well under $1000, and could easily be made mobile. Again, while these stations will only be able to transmit at low bitrates, they can receive at the highest rates.

A high end home station, if it is to transmit at 150 kbit/s, would need to produce 15 times the effective power output. Most of this gain would to be provided by the antenna, so that commonly available integrated power amplifiers in the 3-5 W range could be used. This implies the need to point the antenna, however, and that may add to the cost of some installations. Otherwise, all hardware would be the same as the standard end user system. The receive antenna could still be the same patch as used by low end stations.

High bandwidth, regional base stations, which need to transmit in the 0.5 Mbps range, would have to have moderate sized dishes, and power outputs in the 10-25W range (this can be traded off against antenna gain). The receive antenna could again be the same small patch, but better results on distant passes, near the horizon, could be had with small, aimable dishes. This would give a regional base station more coverage, increasing the probability that one is always in view of the satellite.

Receive equipment on the regional base stations would be similar to the user stations, with the addition of many more despreading channels in the hardware. This would allow many more simultaneous connections and requests, allowing the station to keep its transmitter busy supplying data.

3 Conclusions

The SSWBT will open up a whole new world of digital communications to the amateur radio community. By taking advantage of underutilized spectrum, and advanced communications techinques, we will finally be able to interconnect the ham world with a high bitrate, integrated network. This will open up the possibility of digital videoconferencing, digital voice communications, and high speed data transfer. The ISS and the EXPRESS Pallet will make this all possible by solving the problems of line-of-sight propagation and geographic coverage.

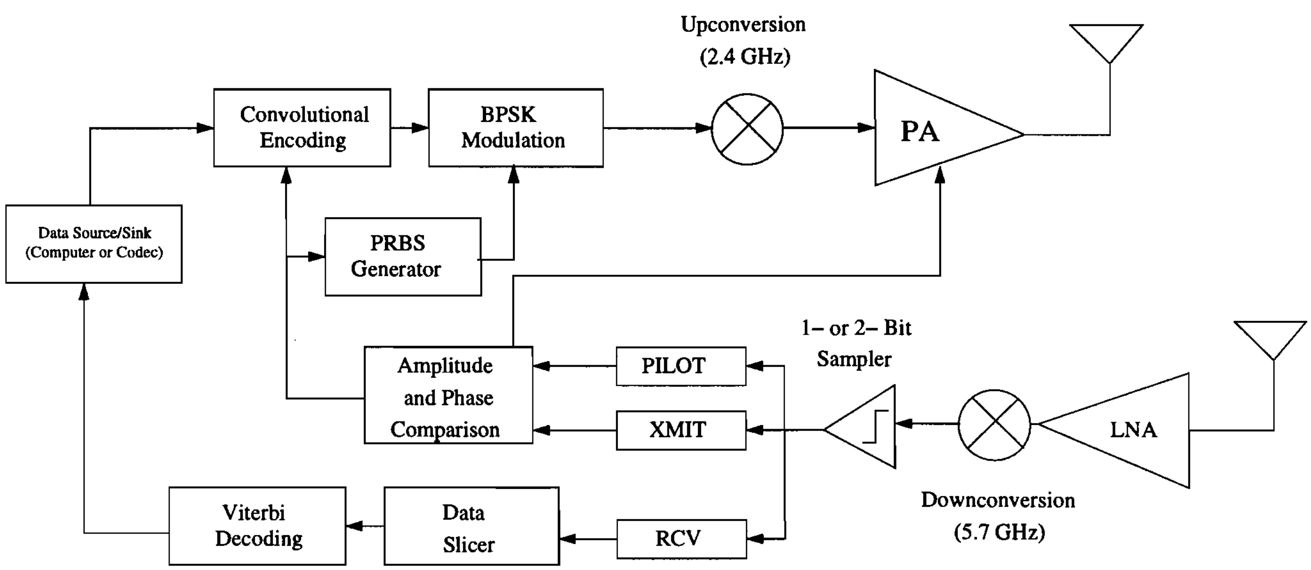

Figure 2: Ground Station

*Instant*Tune for the FT-100

Anthony Monteiro, AA2TX
aa2tx@amsat.org

Abstract

***Instant*Tune is a software package that automatically tunes radios for satellite operation. It was designed to work with AMSAT's *Instant*Track. The author has recently updated this software to include support for the Yaesu FT-100 *Field Commander*. Since the FT-100 is not a "satellite radio," certain design difficulties arise and compromises must be made. However, by supporting the FT-100 in *Instant*Tune, many new operators may get a chance to explore the world of satellites without needing to invest in a new radio. Additionally, by relieving the operator of the task of tuning for Doppler-shift, satellite *mobile* operation can become a real possibility.**

Introduction

A major difficulty in operating through a satellite is in tuning the earth-station receiver and transmitter. Because of the constantly and often rapidly changing *Doppler-shift*, determining and maintaining the proper frequency relationships can be quite tedious.

By automating the radio-tuning task with a computer, operating through satellites can be made dramatically easier. With automatic tuning, a computer is used to predict the Doppler-shift, calculate the proper up link and down link frequencies, and set the radios to these frequencies.

*Instant*Tune is a software package that performs this automatic radio tuning. You use the radio's tuning dial to tune the receiver and the computer does everything else including tune both the up and down links for Doppler-shift. This technique maintains a constant frequency pair at the satellite transponder eliminating frequency drift problems inherent in manual tuning techniques.

The author has recently updated this software to include support for the Yaesu FT-100 *Field Commander*. This diminutive radio tunes all amateur bands from 160 meters up to 2 meters plus 70 centimeters and provides operation on all modes. The radio's tiny size and remote front panel allow it to be used in even the most pressing mobile situations including the author's two-seater. Unfortunately, it was not designed to support satellite operation and will not run in full duplex mode. With *Instant*Tune however, it is possible to work the satellites *without* the need for full duplex.

Radio Tuning for Satellites

If satellites were not moving, operating through them would be similar to using a traditional repeater. The operator would tune their receiver to the satellite output or *downlink* frequency and tune their transmitter to the satellite input or *uplink* frequency.

However, the satellites *are* moving at speeds generally in excess of 10,000 miles per hour. This motion causes the wavelength, and thus the frequency, seen at an earth station receiver to be different from what was sent by the satellite transmitter. Similarly, the frequency of the signal seen at the satellite receiver is also different from what was sent by the earth station transmitter. This frequency change is called the *Doppler-shift*. The Doppler-shift is dependent on the motion of the satellite relative to the earth station and as such is generally different for each earth station.

Depending on the transponder frequencies, the Doppler shift can be quite significant. For mode J satellites like FO-20 and FO-29, it can be as much as 9 to 10 kHz on the downlink. The rate of change of the Doppler shift can also be quite high with mode J getting up to the 100 Hertz per second range. This can make it tough just to keep the other station tuned in. When we add in the difficulty of also tuning our own transmitter, it is easy to see why staying on frequency is not a simple task. It is also the reason satellite QSOs are sometimes known to "walk their way" across the transponder pass-band.

In an article published in the OSCAR Satellite Report titled, "*The One True Rule for Doppler Tuning,*" Paul Williamson, KB5MU, discussed Doppler-shift tuning in detail and described some of the current schemes that are in use to manage the Doppler-shift. A copy of this paper is available on the AMSAT web site, www.amsat.org, and is highly recommended. Paul describes the *only* rule that actually properly corrects for Doppler-shift:

"Tune both the transmitter and the receiver to achieve a constant frequency at the satellite"[1]

While it is virtually impossible for a human operator to do this correctly, it is quite easy to do on a computer. *Instant*Tune was designed to implement this scheme with an algorithm that allows the operator to tune the receiver using the radio's tuning dial while taking care of everything else. With *Instant*Tune, satellite operation is almost as easy as working the local repeater.

How it works

When you first load the *Instant*Tune TSR program into memory, it looks for the OrbitDRV TSR in the vector table and inserts itself in between *Instant*Track and OrbitDRV. *Instant*Tune then monitors all the messages between *Instant*Track and OrbitDRV.

When the operator starts real-time tracking, *Instant*Track gets the satellite name and Keplerian elements from its database and sends them to OrbitDRV. *Instant*Tune intercepts this message and uses the satellite name to look-up the radio tuning information in its own configuration file, "itune.cfg."

*Instant*Tune uses the information in its configuration file to create a satellite transponder model (i.e. an *object*) in memory that mimics the behavior of the satellite transponder. It has built-in models for linear, linear-inverting, and fixed frequency transponders as well as compound transponders with multiple downlinks like RS-12's Mode KA. *Instant*Tune also loads drivers for the radio(s) specified in the configuration file for the selected satellite. It then commands OrbitDRV to send it satellite velocity information. Thereafter, OrbitDRV sends *Instant*Tune the velocity of the satellite every second.

Every second, *Instant*Tune checks the receiver VFO to see if the operator has changed the VFO frequency. If the user has re-tuned the VFO, *Instant*Tune recalculates the Doppler-shifts and determines the frequencies at the satellite. It remembers these frequencies and sets the radio transmitter to the correct up link frequency. If the user *has not* changed the receiver VFO, it updates both the receiver and transmitter VFO frequencies to reflect the current Doppler-shift.

For a more in-depth discussion of the theory of operation of *Instant*Tune, please see *"An object Oriented Approach to Automatic Radio Tuning."*[2]

The FT-100 CAT Interface

Hats-off to Yaesu for having the forethought to put a Computer-Aided Transceiver (CAT) interface on what is essentially, a *mobile* rig. Two more points for having a command to *read* the VFO! These things make it at least possible to use the FT-100 for satellites. However, since it was not designed as a "satellite" radio, making it work as one is difficult and requires certain programming tricks.

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[1] Paul Williamson, *"The One True Rule for Doppler Tuning,"* OSCAR Satellite Report #284, January 1, 1994.

[2] Anthony Monteiro, *"An Object Oriented Approach to Automatic Radio Tuning,"* Transactions of the AMSAT-NA Space Symposium 1997.

The first problem is that you cannot control the transmitter and receiver VFOs independently. You can only set the frequency of the VFO that is currently selected. Second, the radio ignores any command that changes or sets the VFO when the radio is transmitting. These two problems make it impossible to set the transmit frequency without disturbing the receiver.

To get around these two problems, the software sets the radio to run in "split" frequency mode. It uses VFO-A for receiving and VFO-B for transmitting. The radio will automatically select VFO-B when the operator presses the PTT button. Since the software cannot set the VFO-B (transmitter) frequency when transmitting, it sets it only when *receiving*. To do this, it temporarily selects VFO-B, sets the VFO frequency, and then re-selects VFO-A. Since the software can do this quite quickly, it would not be too bad except that the radio also blanks the audio for a brief moment. This is annoying but you get used to it. The software attempts to reduce this as much as possible by only tuning the FT-100 transmitter to the nearest 100Hz. On receive, the FT-100 does not blank the audio so the software maintains proper tuning to the nearest 10 Hz.

Note that the radio's CAT interface will not allow tuning updates while you are transmitting so the operator had best keep transmissions short!

Another side effect is that there is some chance that the operator hits the PTT button just as the software had just started a transmit frequency update. If this happens, then the command sent by the software to switch the radio back to VFO-A might be ignored. This will cause you to transmit on the downlink (yuck!) Unfortunately, the software cannot do anything about this. The operator must give the front panel a quick glance to make sure this has not happened and if it does, release the PTT button. The software will detect this condition and re-sync with the radio within 2 seconds after the PTT button is released and the operator can try again. Fortunately, the window for this condition is quite short so it should not happen very often.

There are several other issues with the CAT interface. The most annoying to the author is that the actual behavior of the radio, on some commands, bears only limited resemblance to what is specified in the manual. The author had to resort to writing special test software in order to determine what the radio actually does versus what is documented in the manual.

Fortunately, the operator does not have to worry about CAT programming and can instead enjoy the satellites for in spite of the programming difficulties; the resulting operation is actually quite usable. You just tune the receiver using the main tuning knob. The software sets the transmitter to the correct frequency for you. While operating, the software adjusts the Doppler-shift for you so you do not need to constantly re-tune. If you want to change the mode, you just change it on the receiver from the front panel as you normally would and the software will change the transmitter for you. Except for the occasional problem with transmitting on the downlink, it really cannot get much easier!

Getting Started with *Instant*Tune

*Instant*Tune does not require a fancy new PC. It will run on an AT class machine with a minimum 80386 CPU and 1 Meg RAM. Under DOS 5.0 or later or it can be run as a FULL-SCREEN, DOS session under Windows. It does not require or use a math coprocessor, nor does it need any special cards or hardware. It uses standard PC COM ports making it ideal for use with laptop computers. It *does* require that you have already installed and configured *Instant*Track.

To install *Instant*Tune, download the software from the AMSAT web site www.amsat.org. You can find it under "*Instant*Track Utilities." Copy it to your *Instant*Track directory and "unzip" it. The following files will be unpacked:

File Name	**Description**
itunetsr.exe	RadioDRV TSR program

```
itune.exe      command-line control program
itune.cfg      satellite configuration file
itune.847      configuration file for FT-847 (copy of default itune.cfg)
itune.100      configuration file for FT-100
itune.doc      User's Guide
itstart.bat    A batch file to load all TSR's and start InstantTrack
it.pif         Program information file for use with Windows
it.ico         A satellite icon for use with Windows
itunesrc.zip   The source code
```

*Instant*Tune is pre-configured to use the Yaesu FT-847 on COM 1 for all satellites. To change this for the FT-100, replace the configuration file named "itune.cfg," with the file named "itune.100." If you prefer, you can instead edit the "itune.cfg" file. This is a plain-old ASCII text file so you can use any text editor such as "edit" or "notepad." The directions for changing radios are at the top of the file. If you need to use a different COM port, the directions for this are also at the top of the file.

The order of setting environment variables and loading the TSR programs is critical for proper operation. The included batch file "itstart.bat" will do all of this for you, just type "itstart" at the dos prompt. The "itstart.bat" file is set up to run the co-processor version of the *Instant*Track program. If you need to run the no co-processor version, edit the "itstart.bat" file and read the comments in the file for directions.

Similarly, the "itstart.bat" file is set up to use the dummy rotor driver, "dummykct.com," included with *Instant*Track. If you use a real rotor driver, just replace "dummykct.com" with the name of the real driver in the "itstart.bat" file.

Congratulations, You have completed installation of *Instant*Tune! To connect the PC to the radio, you need a special cable from Yaesu. After you connect the radio to the PC, you are ready to go.

*Instant*Track and *Instant*Tune can also be run as a DOS session under Windows. **It must be run in a FULL-SCREEN or it will not work correctly**. To run under Windows, complete the installation for DOS as described above. Then, you can just open a full-screen DOS session in your *Instant*Track directory and type "itstart." If you want to be fancy, the included "it.pif" file can be added to your menu bar and you can change the icon to use the "it.ico" file that has an icon resembling a micro-sat. See your Windows manual if you need help doing this.

Operating with *Instant*Tune and the FT-100

Operating with *Instant*Tune and the FT-100 is simple. From an *Instant*Track real-time tracking screen, select the desired satellite and hit the "r" key on the PC keyboard to start tracking and tuning. *Instant*Tune will set the FT-100 receiver to the satellite beacon frequency.

When you can hear the beacon, just tune the main tuning knob to listen to a station or to find a clear spot in the transponder pass-band. *Instant*Tune will automatically set the transmitter to the proper frequency. While you are listening, *Instant*Tune will adjust the receiver VFO frequency to correct for Doppler-shift on the downlink. When you find a station or clear frequency, hit the PTT button and transmit, *Instant*Tune will have already set the transmitter to the proper frequency. If you select a new receive modulation mode, *Instant*Tune will set the transmitter to the appropriate mode depending on the type of the satellite transponder.

Remember to keep transmissions short. Due to the CAT limitations of the FT-100, the frequency will not be updated to track the Doppler-shift while you are transmitting. Also, remember to check to make sure you are not transmitting on the downlink. This can happen if you hit the PTT button at the same moment while *Instant*Tune happens to be adjusting the transmitter frequency. If this occurs, release the PTT button and wait for the radio to switch back to VFO-A. This will happen within 2 seconds and then you can try again.

Due to the way that the FT-100 works, you cannot use the "clarifier" to correct for errors in the frequency translation. If you find that your transmit frequency is way off for some satellite, you may need to adjust the transponder translation constant in the "itune.cfg" file.

When you are done with a pass, hit the "r" key again to stop tracking and tuning. You can then select a new satellite and start again.

A Few Words about Mobile Operation

Normally mobile operation is hard enough without trying to tune for satellites. With *Instant*Tune doing the tuning for you however, satellite operation is almost as easy as operating on HF and mobile operation is a real possibility. To operate mobile, you will need a PC that can work in your car and an antenna system that can transmit and receive on two bands at once, in addition to the radio of course.

The author has installed such equipment in his Mazda RX-7. An ancient but perfectly serviceable 20MHz, 386SX laptop was rescued from retirement and pressed into service running *Instant*Track and *Instant*Tune. The original 12VDC, cigarette lighter, power-adapter makes it easy to re-charge the laptop batteries but any 12V inverter could be used with the AC adapter.

An issue with PC-mobile operation is that the clock on the laptop keeps terrible time, a result of the wide temperature extremes in the car. Since accurate time is essential for proper tracking and tuning accuracy, the author uses the wide-band receive capability of the FT-100 to tune the 10MHz and 15MHz WWV transmissions to set the clock every day.

The author has installed the Yaesu Automatic Tuning Antenna System (ATAS) on the vehicle and it has proven to be a good performer for satellite operation. It can be tuned to any one HF band at a time and it will simultaneously operate on 2 meters and 70 centimeters. With reduced receiver sensitivity, it can also be tuned to 15 meters and still receive ok on 10 meters. This allows operation on transponder modes A, B, J, K, and T.

At the current time, the easiest satellites to work from the car are RS-12/13, FO-20, FO-29, AO-27, and UO-14. Of these, RS-12/13 on mode A is by far the easiest because of its strong downlink. The ATAS antenna is tuned for the 10-meter downlink frequency for maximum sensitivity and 2 meters is used on the uplink. The major difficulty on RS-12/13 seems to be QRM from stations inadvertently getting into the satellite transponder from the 15-meter input. On the other satellites, a high-elevation-level pass is needed in order to hear the downlink and to get a sporting chance to contend for the uplink on the FM repeater satellites.

Regardless of which satellites you are interested in, it is important to pay attention to the road and other cars while operating mobile. If the signals are weak or the traffic is fierce, pulling off the road into a rest stop or parking lot may be a good idea. Besides allowing more attention to be paid to the radio, using headphones will likely help to hear weaker signals. Similarly, CW signals are much easier to hear than SSB. The author is not sufficiently off the deep (yet) to transmit CW from the car, but using SSB to transmit while receiving CW has been tried and is not too difficult. Have fun and be safe!

Summary

*Instant*Tune makes tuning for satellite operation easy by acting as an operators helper. It reads the receiver VFO frequency from the main tuning dial and automatically sets the transmitter frequency for you. In the background, it corrects for the Doppler-shift on both the up and down links so you do not need constantly re-tune. This works so well that an ordinary transceiver may be used for satellite contacts, eliminating the need for a special "satellite" radio. The author has used this software to control a FT-100 quite successfully in a mobile environment.

*Instant*Tune

Automatic Radio Tuning Software

User's Guide

Version 1.07

aa2tx@amsat.org

***Instant*Tune** works with AMSAT's *Instant*Track software to provide "transparent" Doppler Shift Tuning[1] for satellite operation. This means you just tune your receiver to the desired station or frequency and the ***Instant*Tune software** does the rest, no need to manually correct for Doppler shift or to tune your transmitter.

HOW IT WORKS

With ***Instant*Tune**, you use your receiver's VFO knob to tune in a desired station or frequency. ***Instant*Tune** detects when you are tuning and waits for you to finish. When you stop tuning, it remembers that frequency.

Based on your receiver's frequency, the current satellite velocity, and a satellite configuration file, ***Instant*Tune** calculates the proper up link frequency and tunes your transmitter to that frequency.

About once per second, ***Instant*Tune** re-calculates the up link and down link Doppler shifts and fine-tunes *both* your receiver and transmitter to compensate, maintaining a constant transponder frequency pair at the satellite. This method is superior to manual techniques that tune only the transmitter or receiver. With ***Instant*Tune** you can be sure you are on frequency and not drifting through the satellite pass band.

FEATURES

Sets Transmitter Frequency and Mode

***Instant*Tune** sets your transmitter frequency to track your receiver frequency and sets the proper transmitter modulation mode to track the mode you select on your receiver including opposite side-band selection on inverting transponders.

Doppler Shift Tuning

Once a second, ***Instant*Tune** fine-tunes both your receiver and transmitter to compensate for Doppler shift.

Sets Main Receiver to Satellite Beacon and Mode

When you select a new satellite to track, ***Instant*Tune** sets your receiver to the proper frequency and modulation mode to monitor the beacon while you wait for the satellite to come into range.

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[1] Paul Williamson, "*The One True Rule for Doppler Tuning,*" OSCAR Satellite Report #284, January 1, 1994.

Auxiliary Receiver

InstantTune lets you use a second receiver with automatic tuning and Doppler correction to monitor a second down link from the satellite. This lets you easily monitor both down links on dual transponder satellite or monitor an engineering beacon while using your main receiver to make contacts.

Frequency Converters and Transverters

InstantTune supports transmit and receive frequency converters. Both up and down converters may be used.

*Easy to Use with Instant*Track

InstantTune is a DOS TSR program and is a companion to AMSAT's popular *Instant*Track software. Radio tuning is automatically controlled from the *Instant*Track graphics or text satellite-tracking screen. When you select rotor tracking, **InstantTune** intercepts the messages so it knows which satellite to use with no special pop-up screens. You can use it with or without an antenna rotor. You can even check its status from the *Instant*Track TSR status screen.

InstantTune supports background operation allowing you to exit from *Instant*Track and run other DOS programs while continuing to track and tune the satellite.

Easy to Setup and Maintain

InstantTune comes pre-configured for use with the Yaesu FT-847 and current amateur satellites. The configuration file is plain ASCII text making it easy to add satellites as they are launched or to change or add new radios. There is no limit to the number of satellites or transponders and you can configure multiple transponders for each satellite.

No Special PC Hardware

InstantTune uses ordinary PC serial and parallel ports. No special cards or hardware is required making it ideal for use with laptop and notebook computers. **InstantTune** does not use a floating-point processor either so it will run on older PC's.

Works with Popular Radios

InstantTune supports the Yaesu FT-847, FT-100, and FT-736, Kenwood HF radios, and mic-button radios[2].

InstantTune allows you to mix and match radios at the same time. For example, you can use a Kenwood TS-450 as a receiver with a Yaesu FT-736 as a transmitter for mode-A satellites.

---

[2] Drivers were also written for ICOM CI-IV and CI-V radios and the Kenwood TS-790. They were not tested and are not supported in this release. The author will entertain requests for these or other radio types.

INSTALLATION

What You Need

- PC/AT class machine with **minimum** x386 CPU, 1 Meg RAM, DOS 5.0. ***InstantTune*** will also run in a FULL-SCREEN, DOS window under Windows 3.1, Windows95, or Windows98.
- AMSAT's *Instant*Track software package
- ***InstantTune*** installation file "install.exe". This is a self-extracting pkzip file.

Step 1

Copy the ***InstantTune*** "install.exe" file to your *Instant*Track directory. This will usually be c:\it. Run "install.exe" from the *Instant*Track directory. The "install.exe" file will unpack itself. Don't worry, "install.exe" will NOT modify your "autoexec.bat" or "config.sys" files or modify your environment. It will add the following files to your *Instant*Track directory:

itunetsr.exe	The RadioDRV TSR program
itune.exe	A command-line control program
itune.cfg	The satellite configuration file
itune.847	copy of the above (with FT-847 as the default radio)
itune.100	configuration file for the FT-100
itune.doc	This User's Guide
itstart.bat	A batch file to load all TSR's and start *Instant*Track
it.pif	Program information file for use with Windows
it.ico	A satellite icon for use with windows

Step 2

InstantTune is pre-configured to use the Yaesu FT-847 on COM 1 for all satellites. If you want to use a different radio or different COM port, you will need to edit the itune.cfg file. This is an ASCII text file so you can use any text editor to change it. The file "itune.100" is a copy of the itune.cfg file with the radio changed to a FT-100 on COM 1 so it can be used as-is by replacing the "itune.cfg" file with the "itune.100" file.

For simple changes, such as a different COM port, follow the directions in the comments in the "itune.cfg" file. To setup a more complex configuration, review the commands in the detailed technical reference part of this manual.

Step 3

The order of setting environment variables and loading the TSR programs is critical for proper operation. The environment variables must be set first, then the rotor driver must be loaded, then the OrbitDRV TSR, and finally the ***InstantTune*** radio driver TSR. After these are loaded, you may start *Instant*Track. Note that the radio driver TSR will refuse to load if it can not find OrbitDRV.

The included batch file "itstart.bat" will do all of this for you, just type "itstart" at the dos prompt. The "itstart.bat" file is set up to run the co-processor version of the *Instant*Track program. If you need to run the no co-processor version, edit the "itstart.bat" file and read the comments in the file for directions.

Similarly, the "itstart.bat" file is set up to use the dummy rotor driver, "dummykct.com," included with *Instant*Track. If you use a real rotor driver, just replace "dummykct.com" with the name of the real driver in the "itstart.bat" file. Congratulations, You have completed installation of ***InstantTune***!

Running under Windows

*Instant*Track and ***InstantTune*** can be run as a DOS session under Windows 3.1, Windows95, or Windows98. **It must be run in a FULL-SCREEN or it will not work correctly**. If you minimize the DOS session, ***InstantTune*** operation will be suspended. When you switch back to a full screen, satellite tracking and tuning will resume.

To run under Windows, complete the installation for DOS as described above. To run, you can just open a full-screen DOS window and type "itstart."

If you want to be fancy, the included "it.pif" file can be added to your menu bar and you can change the icon using the included file "it.ico" which has an icon resembling a micro-sat. See your Windows manual if you need help doing this.

OPERATION

InstantTune was specifically designed to work with *Instant*Track. In most cases, you do not have to do anything special to activate radio tuning on a satellite.

To use ***InstantTune***, type "itstart" at the DOS command prompt or double-click on the satellite icon. This will load all the required drivers and start *Instant*Track.

Select a Satellite

Choose an *Instant*Track text or graphics real-time tracking screen and select a satellite to track.

Start and Stop Radio Tuning

Type the "r" command from a real-time tracking screen. *Instant*Track will start rotor tracking and ***InstantTune*** will start radio tuning on the selected satellite. To stop rotor tracking and radio tuning, type the "r" command again.

*Operating with Instant*Tune

When you start tuning with the "r" command, you should see your receiver VFO change to the satellite beacon or digital down link frequency. Then, about a second later, it will retune to correct for the Doppler shift. The receiver should continue to track the beacon or down link frequency unless you manually tune it to another frequency. If you have a transmitter configured, the transmitter VFO will also change to the correct up link frequency.

InstantTune detects when you re-tune your receiver. Once you have stopped tuning, ***InstantTune*** will maintain the proper frequency for you by fine tuning the receiver to compensate for Doppler shift.

For satellites with analog transponders, ***InstantTune*** will tune your transmitter to track your receive frequency and will also adjust the transmit frequency to compensate for up link Doppler shift. ***InstantTune*** will maintain a constant transponder input-output frequency pair at the satellite. If you change the modulation mode on your receiver, ***InstantTune*** will automatically set the proper transmitter mode including selecting the opposite sideband on inverting transponders.

For fixed frequency transponders (i.e. AO-27) or digital satellites, ***InstantTune*** tunes your transmitter to the up link frequency and sets the proper modulation mode for the satellite. ***InstantTune*** will fine-tune the transmitter frequency to compensate for the Doppler shift. Although this is not always required, it can help improve the effectiveness of your up link signal. Tuning your receiver or changing the receive modulation mode will not change the transmitter frequency or mode on these satellites.

Due to errors in the published transponder parameters, satellite Keplerian elements, or the frequency accuracy of your radios, you may need to adjust the transmitter or receiver VFOs to bring your transmit and receive signals together. For the FT-847, you use the sub-band tuning knob to adjust the transmit frequency. You cannot use the "clarifier" function. For all other radios, you can use either the receiver independent tuning (RIT) or transmitter independent tuning (XIT) functions.

If you find the signals consistently off-frequency or beyond the range of your RIT/XIT controls for a given satellite, you will want to change the transponder translation constant in the "itune.cfg" file for that satellite. Specific instructions are in the technical reference section.

Checking Tuning Status

Selecting "TSR Status," item 9, on the *Instant*Track, main menu shows the status of the RotorDRV and OrbitDRV TSR's. ***InstantTune*** controls the tuning status of OrbitDRV so it will reflect the current state of radio tuning.

Selecting a Specific Transponder Mode

By default, ***InstantTune*** selects the first transponder listed for a satellite in the "itune.cfg" file. Since most satellites only have one mode, this is usually sufficient. Some satellites like Phase 3D support many different transponder modes. You can tell ***InstantTune*** to use a specific transponder mode instead of the default. When you select a specific transponder mode, ***InstantTune*** saves your selection in a file named "itune.sel." Once you select a specific transponder, it remains selected until you change it, even after you power off your computer. You can reset all transponders of all satellites back to the default by deleting the "itune.sel" file.

Here are the instructions for selecting a specific transponder mode instead of the default:

Step 1
Quit from *Instant*Track putting you back to the DOS prompt.

Step 2
At the DOS prompt type:

    itune mode *SATELLITE MODE* <ENTER>

where *SATELLITE* is the name of the satellite and *MODE* is the desired transponder mode. For example, to set RS-12/13 to use mode A, type:

    itune mode RS-12/13 A <ENTER>

To specifically select the default mode, use the same command without specifying a transponder mode. For example to select the default mode for RS-12/13, type:

    itune mode RS-12/13 <ENTER>

You can set the mode in this way at any time. You do not have to have *Instant*Track running or even have the radio driver TSR loaded.

Step 3
Type "it" at the DOS prompt to re-start *Instant*Track. When you start rotor tracking again on the selected satellite, it will use the transponder mode you selected instead of the default. Note that this will not affect any radio tuning that may be already in progress.

Background Tracking and Tuning
Once you have started rotor tracking and radio tuning, they can be run in the background. You can quit from *Instant*Track with tracking and tuning running and run other DOS programs in the same DOS session such as terminal emulators, digital satellite software, or telemetry decoding programs. Note that you CANNOT run Windows programs and have tracking and tuning continue in the background. Tracking and tuning will cease if you change the DOS prompt Window from a full-screen.

OPERATIONAL NOTES FOR SPECIFIC RADIOS

YAESU FT-847
The FT-847 works great with automatic tuning. You just tune using the transceiver's tuning knob and select whatever receiver modulation type you want. ***Instant*Tune** does the rest. You may want to fine tune your transmit frequency initially to compensate for errors in the Keplerian elements. To do this, use the "sub-band" tuning function not the "clarifier" function.

Before starting up ***Instant*Tune**, make sure that the built-in tracking function in the satellite mode is turned off and the receiver VFO is set to the main tuning knob.

The FT-847 does not support mode K satellite transponders.

YAESU FT-100

The FT-100 is not a "satellite" radio and as such, there are certain limitations with the CAT interface. To get around these limitations, the software sets the radio to run in "split" frequency mode. It uses VFO-A for receiving and VFO-B for transmitting. The radio will automatically select VFO-B when the operator presses the PTT button. Due to a limitation of the CAT interface, the software cannot set the VFO-B (transmitter) frequency when transmitting so it sets it only when *receiving*. To do this, it temporarily selects VFO-B, sets the VFO frequency, and then re-selects VFO-A. Since the software can do this quite quickly, it would not be too bad except that the radio also blanks the audio for a brief moment. This is annoying but you get used to it. The software attempts to reduce this blanking as much as possible by only tuning the transmitter to the nearest 100Hz. On receive, the FT-100 does not blank the audio so the software maintains proper tuning to the nearest 10 Hz.

Note that the above CAT limitation means that the transmitter frequency tuning updates stop when the PTT button is depressed, so it is a good idea to keep transmissions short!

Another side effect of the CAT problem is that if the operator hits the PTT button just as the software had just started a transmit frequency update, then you might end up transmitting on the downlink. Unfortunately, the software cannot do anything about this so the operator must give the front panel a quick glance to make sure this has not happened. If it does, the operator has to release the PTT button and the software will detect this condition and re-sync with the radio within 2 seconds after the PTT button is released. The operator can then try again. Fortunately, the window for this condition is quite short so it should not happen very often.

In spite of the CAT limitations, the resulting operation is actually quite usable. You just tune the receiver using the main tuning knob. The software sets the transmitter to the correct frequency for you. While operating, the software adjusts the Doppler-shift for you so you do not need to constantly re-tune. If you want to change the mode, you just change it on the receiver from the front panel as you normally would and the software will change the transmitter for you. The FT-100 will operate on all satellite transponder modes up to 436MHz including mode K.

YAESU FT-736

The CAT interface on the FT-736 is limited; you cannot use computer control and the front panel at the same time. Therefore, ***InstantTune*** supports the FT-736 by using your PC keyboard to control the receiver VFO. Keyboard control becomes active after you start tracking/tuning from *Instant*Track. This works as follows:

- To enable the keyboard for tuning, turn on <CAPSLOCK>.
- To disable keyboard tuning, turn off <CAPSLOCK>.

Once you have turned on <CAPSLOCK>, the following keys are used to control the radio's RECEIVE frequency:

<RIGHT ARROW>	UP VFO
<LEFT ARROW>	DOWN VFO
<UP ARROW>	UP RIT
<DOWN ARROW>	DOWN RIT

The frequency step size depends on the modulation mode and can be increased by holding down a modifier key. The tuning steps are as follows:

	Main Tuning		**RIT**	
modifier key	**CW/SSB**	**FM**	**CW/SSB**	**FM**
none	50 Hz	500 Hz	10 Hz	100 Hz
<CTRL>	500 Hz	5 kHz	100 Hz	1 kHz
<SHIFT>	5 kHz	50 kHz	1 kHz	10 kHz
<SHIFT> + <CTRL>	50 kHz	500 kHz	10 kHz	100 kHz

You can set the receive modulation mode by using the following keys:

<F>	FM
<C>	CW
<L>	LSB
<U>	USB

You may need to set the satellite mode VFOs to the proper bands before starting radio tuning or the FT-736 may refuse the CAT commands.

The FT-736 always uses the COM port at 4800 BPS regardless of COM port speed settings in the "itune.cfg" file.

KENWOOD HF Radios

Kenwood HF radios work nicely with ***InstantTune***. You just tune the receive VFO using the transceiver tuning knob and select whatever receive modulation type you want. ***InstantTune*** does the rest. You may want to fine tune your transmit or receive frequency to compensate for errors in the Keplerian elements. To do this, you just use the RIT or XIT controls as you normally would.

InstantTune has a special tuning algorithm for Kenwood radios that dramatically reduces audio blanking. This allows you to use an unmodified radio to receive digital satellites. Of course, for HF radios you generally would also need to use a down converter.

On the HF radios, this algorithm is disabled if you try to use both the transmitter and receiver at the same time. However, you CAN use a single HF transceiver to operate mode K in split mode (i.e. half-duplex.)

On HF radios, FINE-TUNE is turned ON by ***InstantTune*** in FM or AM modes and turned OFF in SSB/CW/FSK modes. This is to maintain a 10 Hz tuning step. For proper operation, do not change this setting.

Kenwood radios always use the COM port at 4800 BPS, regardless of COM port speed settings in the "itune.cfg" file.

Mic-Button Radios

Mic-Button radios do not have a CAT interface. However, ***InstantTune*** can work with these radios by activating the up/down mic-buttons using the PC parallel port. This interface is limited in functionality and user convenience. Mic-button radios can only be used as either a receiver or a transmitter; they cannot be used as both at the same time. When used as a transmitter, Mic-Button radios are a bit slow in tuning but otherwise work fine. For receiving, Mic-button radios can be tuned from the PC keyboard much like the FT-736. This works but is cumbersome!

Keyboard tuning control becomes active if you have configured the radio as a receiver and you start tracking/tuning from *Instant*Track. This works as follows:

- To enable the keyboard for tuning, turn on <CAPSLOCK>.
- To disable keyboard tuning, turn off <CAPSLOCK>.

Once you have turned on <CAPSLOCK>, the following keys are used to control the radio's RECEIVE VFO:

<RIGHT ARROW>	UP VFO
<LEFT ARROW>	DOWN VFO
<UP ARROW>	UP RIT
<DOWN ARROW>	DOWN RIT

The frequency step default is 100Hz. You can change the default step to anything your radio will support by setting the proper parameter in the "itune.cfg" file. You can tune faster by holding down the shift keys while tuning with the arrow keys. The tuning steps are then multiplied as follows:

key	**STEP**
none	x 1
<CTRL>	x 10
<SHIFT>	x 100
<SHIFT> + <CTRL>	x 1000

You can set the RECEIVE VFO modulation by using the following keys:

<A>	AM
<F>	FM
<C>	CW
<L>	LSB
<U>	USB

This will NOT change the receiver modulation mode of course, as the UP/DOWN buttons cannot do this. This function is used to tell ***InstantTune*** that you have changed it manually so that the software can properly set the transmitter mode.

To use a mic-button radio, you need to provide an electrical interface from the PC parallel port to your radio. The following leads are used on the parallel port:

FUNCTION	**SIGNAL NAME**	**PIN on DB-25 LPT port**
UP step	DATA 0	2

DOWN step	DATA 1	3
Tuning Complete	DATA 2	4
Signal Ground	GND	18 - 25

All signals are normally LOW (0 Volts) and pulse High (+5 Volts) when active. The PC parallel port signals will directly drive a 6N139 optical coupler when used with a 4.7K Ohm series resistor. The 6N139 outputs will drive most modern radios when tied in parallel with the mic-buttons. Observe the proper polarity. No external power supply is needed.

The "Tuning Complete" signal can be used to drive an LED for a positive visual indication that tuning is complete. When large frequency changes are made, tuning can take several seconds depending on the step size. You can watch your radio's frequency display to see when it stops changing, but the indication is a nice convenience. This signal is set HIGH to directly drive a low power LED when the radio tuning is finished; no external power supply is needed.

No IRQs are used with the parallel port. You may re-use the LPT IRQ for your serial ports if you need them. ***InstantTune*** supports LPT1, LPT2, and LPT3.

To operate with a Mic-button radio, set the radio to the initial frequency before starting Tracking/Tuning. The initial frequency is the one you configured in the "itune.cfg" file for this radio. Also, be sure to set the step size on the radio to match the step size you selected, 100Hz is the default size. When you start Tracking/Tuning, the radio will start step tuning to set the proper up link or down link frequency. You can "fine-tune" using the radio's tuning dial if needed.

CONFIGURATION

InstantTune is very flexible and allows you to specify as many different radio setups and as many satellites and transponders as you want. It uses the file "itune.cfg" to tell it about the satellite transponders and about your radio setup. This file is a human-readable, plain old, ASCII text file. You can use whatever text editor you prefer to view or modify it including the one that comes with DOS and Windows called "edit."

As supplied, this file includes information about all satellite transponders that were available when the software was released. As new satellites are launched, you will want to add the transponder information so that you can operate with these new satellites.

Similarly, the supplied "itune.cfg" file specifies a Yaesu FT-847 on COM 1 at 4800 BPS for all satellites. If you just want to change the COM port, you do not need to read this section of the manual. Instead, look at the comments in the "itune.cfg" file. The instructions for changing the COM port are in there. Comments are indicated by a semicolon. Everything on a line after a semicolon is ignored.

It may be helpful to review the supplied "itune.cfg" file before reading the rest of this section. The basic structure of this file consists of an optional COM port configuration section followed by a default radio configuration section followed by the satellite transponder section. You may over-ride the default radio configuration for each transponder.

After you have finished editing the "itune.cfg" file, you can check your work by typing:

```
itune verify
```

at the DOS command prompt. This checks the "itune.cfg" file for proper command syntax.

COM Port Configuration

If you use your radio at its factory default bit rate and on COM ports 1 or 2, you do not need to specify a COM port configuration.

To use COM ports 5 through 12, or if you have changed the default IRQs or I/O Addresses for COM ports 1 to 4, you must specify the COM port configuration so that ***InstantTune*** can use them.

Due to the nature of the PC architecture, there are some constraints when using COM ports 3 or 4. By default, IRQ 4 is used for COM ports 1 and 3 and IRQ 3 is used for COM ports 2 and 4. However, the PC architecture does not allow IRQ sharing. This means that you cannot use COM 1 and 3 or COM 2 and 4 at the same time. If you can change the COM 3 or 4 port configuration in your PC to use unique IRQs, you can avoid problems with using these COM ports. The LPT2 IRQ is often available for such re-assignment. Otherwise, you will need to select your radio configuration carefully so that you do not use COM 1 and 3 or COM 2 and 4, at the same time. This includes using them for a mouse, TNC, or modem.

For example, if you have HF, VHF, and UHF radios that each need a COM port, you could use COM 1 for HF, COM 2 for VHF, and COM 3 for UHF. That way you can use satellite transponder modes A, B, and J without IRQ conflicts. In this case, you do not need to specify the COM port configuration.

You can put several radios on the same COM port with an A/B switch as long as they are not all active at the same time. To specify a COM port configuration, use the following command:

```
comport PORT RATE IRQ ADDRESS
```

Where:

```
PORT = serial port number 1 to 12
RATE = bit rate; 300 to 19200 BPS is supported
IRQ  = IRQ line 1 to 15
ADDRESS = base address of serial port in hexadecimal
```

To use the default value, set the parameter to 0 (zero.) When you select the default ADDRESS or IRQ, ***InstantTune*** reads your PC's BIOS to find the values. This will generally work for COM ports 1 to 4 but it will not work on COM ports 5 to 12. The default bit rate is the factory default for the currently active radio. This 4800 BPS for Kenwood and Yaesu radios.

EXAMPLES:

1. Change COM 3 to use IRQ 7, no other changes

```
comport 3 0 7 0
```

2. Add COM 12 using IRQ 15, at address 7fe, default bit rate

```
comport 12 0 15 7fe
```

3. Change COM 1 to use 9600 BPS instead of radio default rate

```
comport 1 9600 0 0
```

Configuring Radios

InstantTune is very flexible and allows you to specify everything from a single radio for all satellites, to unique radios for each transponder of each satellite.

The command syntax to specify a radio is as follows:

```
COMMAND RADIO PORT {SPECIAL PARAMETERS}
```

The COMMAND values are:

COMMAND	Radio use
rx	receive main transponder
rx2	receive auxiliary transponder
tx	transmit to main transponder
xcvr	receive and transmit to main transponder

The RADIO types and SPECIAL PARAMETERS are:

Manufacturer	Model	RADIO	SPECIAL PARAMETERS
any	mic-button	micbutton	INITIALFREQ STEPSIZE
Kenwood	all HF	kenwood	
Yaesu	FT-100	ft100	
Yaesu	FT-736	ft736	
Yaesu	FT-847	ft847	

Notes:

- For mic-button radios, the INITIALFREQ parameter is the frequency that you will set the radio to before starting radio tuning in MHz. For analog transponders, a frequency that is just below the pass-band is a good choice. For digital satellites, the nominal uplink/downlink frequency is a good choice.

- For mic-button radios, the STEPSIZE is the frequency step of the UP/DOWN buttons in Hz. The minimum step size is 1 Hz. The tuning rate is 9 steps per second. A good compromise between speed and precision is 100 Hz step size. If you do not specify this parameter, the default is 100 Hz.

- The PORT parameter is the COM or LPT port number. ***InstantTune*** accepts COM ports 1 to 12 and LPT ports 1 to 3.

EXAMPLE 1:
Kenwood TS-450 on COM 1 used a receiver

```
rx kenwood 1
```

EXAMPLE 2:
Yaesu FT-847 on COM 2 used as a transceiver

```
xcvr ft847 2
```

EXAMPLE 3:
Mic-button radio on LPT 2 used as a transmitter, initial frequency 145.825 MHz, 100 Hz step size

```
tx micbutton 2 145.825 100
```

Configuring Frequency Converters

You can add frequency converters by using the following commands:

```
rxconverter  TRANSLATION ; receive converter
rxconverter2 TRANSLATION ; receive converter for auxiliary rx
txconverter  TRANSLATION ; transmit converter
```

The frequency TRANSLATION parameter is calculated by **subtracting the antenna frequency from the radio frequency in MHz.** Note that receive up-converters and transmit down-converters will have negative TRANSLATION parameters.

EXAMPLES:
1. Add a 437 to 28 MHz receive down converter

```
rxconverter 409.0
```

2. Add a 144 MHz to 1296 MHz transmit up converter

```
txconverter 1152
```

Setting a Default Radio Configuration

To specify a default radio configuration for all satellite transponders, use the above commands before any satellite transponders in the "itune.cfg" file.

To over-ride the default for a specific transponder, use the above commands directly after the desired transponder configuration in the "itune.cfg" file.

Configuring a Satellite Transponder

To configure a satellite transponder, you need to provide the name of the satellite, the name of the transponder mode, and the specifications for the transponder.

The name of the satellite must match EXACTLY the name in the *Instant*Track satellite database. ***InstantTune*** uses the *Instant*Track name to find the transponder specification. Thus if the *Instant*Track database has a satellite named "RS-12/13" in it, you cannot use "RS-12," you must use "RS-12/13." However, ***InstantTune*** will ignore the capitalization so the "rs-12/13" will match "RS-12/13." This allows you to use both NASA and AMSAT format Keplerian elements. As with *Instant*Track, satellite names may be up to 20 characters long.

The name of the transponder mode can be any character string up to five characters long. You can use the traditional mode names like "A, B, J, KA, or K/T" or the new mode names created for P3D, such as "V/U" and "L/S." ***InstantTune*** uses the mode name to uniquely identify the transponder; it does not make any assumptions about the transponder frequencies based on the mode name.

InstantTune supports linear transponders such as that found on AO-10 as well as fixed frequency transponders such as those on AO-27 or KO-25.

Additionally, ***InstantTune*** can support a second auxiliary down link. This down link can be used for a fixed frequency such as a beacon or it can be another tracking linear transponder. An example of a tracking linear transponder is RS-12/13 in mode KT. This mode has a 21 MHz up link with a 28 MHz down link and a simultaneous, tracking, 144 MHz down link.

To specify a new satellite transponder name and mode, the following command is used:

```
satellite NAME MODE
```

The keyword "satellite" must be lower-case. The satellite NAME can be up to 20 characters long and the MODE can be up to 5 characters long. If a satellite transponder has only 1 mode, you do not need to specify a MODE.

This is followed immediately in the file by the transponder parameters. To specify the transponder parameters, the following commands are used:

```
transponder TRANSLATION ; linear transponder
transponder2 TRANSLATION ; tracking auxiliary linear transponder
beacon FREQUENCY MODULATION ; beacon for linear transponder
downlink FREQUENCY MODULATION  ; fixed down link
downlink2 FREQUENCY MODULATION ; auxiliary fixed down link
uplink FREQUENCY MODULATION    ; fixed up link
```

Some examples will be helpful:

Linear Non-Inverting Transponder

To specify a linear transponder, use the *transponder* and *beacon* commands. For a non-inverting transponder, the transponder TRANSLATION parameter is the **DIFFERENCE** between the down link and the up link frequencies in megahertz. You can also specify the nominal beacon frequency and modulation mode (am, fm, usb, lsb, cw, fsk.)
The default mode is cw.

```
Example: RS-12/13 mode A

satellite  RS-12/13  A
transponder  116.502
beacon  29.4081  cw
```

Linear Inverting Transponder

To specify a linear transponder, use the *transponder* and *beacon* commands. For inverting transponders, the transponder TRANSLATION parameter is the **SUM** of the down link and the up link frequencies in megahertz followed by the key word "invert." You can also specify the nominal beacon frequency and modulation mode (am, fm, usb, lsb, cw, fsk.) The default mode is cw.

```
Example: AO-10 mode B

satellite  AO-10  B
transponder  581.004 invert
beacon  145.81  cw
```

Fixed frequency Transponder

Fixed frequency transponders have fixed up and down link frequencies. All digital satellites are of this type. To specify a fixed frequency transponder, use the *uplink* and *downlink* commands. After the command word, specify the frequency and modulation mode (am, fm, usb, lsb, cw, fsk) of each link.

```
Example: AO-27, FM repeater

satellite  AO-27
downlink 436.80 fm
uplink 145.85 fm


Example: PACSAT AO-16, fm uplink, usb downlink

satellite AO-16
downlink 437.0513 usb
uplink 145.9 fm
```

Auxiliary Tracking Linear Transponder

An auxiliary, tracking, linear transponder provides a second down link that tracks the primary down link. This type of auxiliary link can only be used if the primary transponder is a linear type. You use the tuning knob on the main receiver to control the primary down link. The frequency and mode of the second receiver will be set for you by ***InstantTune***. To specify an auxiliary tracking linear transponder, use the *transponder2* command. The TRANSLATION parameter is calculated in the same manner as for the *transponder* command.

```
Example: RS-12/13 mode K/T

satellite RS-12/13 KT
transponder -8.2008     ; main transponder, 10 meter down link
transponder2 -124.706   ; auxiliary transponder, 2 meter down link
```

beacon 29.4081 cw

Auxiliary Fixed Transponder

An auxiliary fixed transponder provides a second down link with a fixed frequency and mode. You can use an auxiliary fixed transponder with either a linear or fixed main transponder. This allows you to use a second receiver to monitor a satellite beacon while simultaneously using the main transponder. To specify an auxiliary fixed transponder, use the *downlink2* command followed by the nominal frequency and mode (am, fm, usb, lsb, cw, fsk.) The default mode is cw.

Example: RS-12/13 mode K plus cw robot downlink

```
satellite RS-12/13 K
transponder -8.2008
beacon 29.4081
downlink2 29.454 cw
```

COMMAND LINE CONTROL PROGRAM

The command line program "itune.exe" allows you to control certain aspects of the ***InstantTune*** driver. The included "itstart.bat" batch file uses it to load the driver. You can use this program if you want to change the default satellite transponder or to verify your "itune.cfg" file after you have edited it. The other commands are provided for debugging and experimentation.

You execute commands one at a time by typing at the DOS prompt:

    itune COMMAND PARAMETERS <ENTER>

The COMMANDs are as follows:

COMMAND	PARAMETERS	Action
		help - lists commands
check		Check radio driver TSR status
debug		prints version number
halt		Stop tuning
load		Load radio driver TSR
mode	SATELLITE MODE	select a specific transponder mode
select	SATELLITE	select a satellite
tune	VELOCITY	tune radios using new VELOCITY
verify		check "itune.cfg" for syntax errors

PARAMETER DEFINITIONS:

    MODE   = Satellite transponder mode in "itune.cfg"
    SATELLITE = Satellite Name in "itune.cfg"
    VELOCITY   = Satellite velocity divided by the speed of light

You can get the list of all commands and parameters by typing "itune" with no parameters at the DOS prompt. You can abbreviate commands by typing only the first letter instead of the complete word.

TROUBLESHOOTING

*Instant*Tune *TSR Will Not Load*

InstantTune uses INT64 by default for its radio driver interface. If another program or driver is using INT64, the "itune.exe" control program will print an error message and ***InstantTune*** will refuse to load. If possible, change the other program or driver to use a different interrupt. Otherwise you will have to use a different interrupt for ***InstantTune***.

To change interrupts, set the environment variable "itrad" to the desired interrupt in hexadecimal. For example, to set the interrupt to INT62 use DOS command line:

```
set itrad=62 <ENTER>
```

Do this before loading ***InstantTune***. You can edit the "itstart.bat" file to do this automatically. The instructions are in the "itstart.bat" file.

If you change the ***InstantTune*** command interrupt, you must also change the OrbitDRV configuration to use this interrupt for radio tuning. See the OrbitDRV documentation for details.

InstantTune looks for OrbitDRV at INT63 and hooks this interrupt to automatically turn on radio tuning when tracking is enabled. If you use a different interrupt for OrbitDRV, you must set the environment variable "itorb" to the desired interrupt in hexadecimal. For example to set the OrbitDRV interrupt to INT61, use dos command line:

```
set itorb=61 <ENTER>
```

Do this before loading ***InstantTune***. You can edit the "itstart.bat" file to do this automatically. The instructions are in the "itstart.bat" file.

Note that *Instant*Track will not work with any OrbitDRV interrupt other than INT63. If you cannot use INT63, you will only be able to use the ITRACK command line program. See the documentation for OrbitDRV for details.

You can prevent ***InstantTune*** from hooking the OrbitDRV interrupt and prevent automatic tuning control from *Instant*Track by setting the "itorb" environment variable to 0. This can be useful for experimenting.

No Radio Tuning

Check the TSR status, selection 9, from the *Instant*Track main menu. If it shows tuning disabled, it means that ***InstantTune*** could not communicate with your radio.

- Verify your "itune.cfg" file.
- Check the RS232 cable and connection. This is by far the most common source of problems.

- Check to see that the COM port specified in the "itune.cfg" file matches your actual radio setup.
- Make sure you do not type "itstart" more than once per DOS session. If you type itstart more than once, you will end up with multiple copies of OrbitDRV and RotorDRV TSR's. This will not work and it uses up memory. To restart *Instant*Track from the same DOS session, just type "it."
- Check your "itune.cfg" file, you may have entered the wrong radio type or transponder information. Note that the "itune verify" command only checks for syntax errors, it will not detect an improper configuration.
- Check the operational notes for your radio to see if there is anything special that you need to consider.

Acknowledgements

The author regrets not remembering all the names of those who have provided support for this project over the past 5 years and apologizes to those he has left out here. If you have been forgotten, please send an email so you can be acknowledged in future releases. In particular, a fellow from HP provided significant help with the user manual. The author would like to thank the following people for their help and support:

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What's Next?

By Jeff Davis N9AVG

INTRODUCTION

The launch of Phase 3D will signal the beginning of its operational life, but it also brings to close over a decade of coordinated effort to design, build, and obtain a launch for the most ambitious project in amateur radio history. When it finally clears the launch pad, our thoughts will naturally shift to, "what's next?"

Trying to "top" P3D is not a mission objective that most would care to take on. In fact, I would suggest that we have no immediate need to build a more sophisticated bird, rather, we should carefully consider how we could best nurture and grow the worldwide AMSAT community. After all, that community will fund future projects, so it's in our best interest to ensure its vitality.

With P3D on the ground and AO-13 gone, there's been no serious "workhorse" for long-haul DX since early 1996. Few satellite operators having since joined the hobby have experienced real satellite DX. The LEOs give a taste of the excitement this facet of amateur radio offers, but it's no substitute for an hour long QSO with a station on another continent.

I'd like to propose that we consider a new generation of satellite. A less sophisticated one. A satellite that would include analog linear transponders in a high-altitude, elliptical orbit that would provide long-range communication for extended periods of time. A satellite smaller than 100kg, whose size and design would provide the maximum opportunity to obtain a launch over the next decade.

WHY ANOTHER SATELLITE?

You may ask why we need another project to follow closely behind P3D.

There are several reasons but the most compelling is the need to provide satellite operators with viable communication options. Given the investment required to assemble a groundstation for P3D use, we need to provide some assurances to operators that their money was well spent.

While the projected operational life for P3D is ten to fifteen years (the tenacity of AO-10 is testament to superb engineering), over the years we have experienced all sorts of typical system failures after launch that have ranged from an antenna that didn't open properly, to the loss of a transponder and worse.

Even with P3D in orbit and operating flawlessly, we need to commit resources today, to reduce the possibility that we are ever again without a long-haul DX workhorse in orbit or awaiting a launch. The commitment to maintain useful assets in space will permit prospective satellite operators to invest in ground station equipment with confidence. Those new operators are the future of our service.

Generally, operators who have made an investment in groundstation equipment are more likely to become members of AMSAT, remain members and financially support new project initiatives.

It's also worth mentioning that the operating schedule for P3D will make it unavailable to some parts of the world on certain days. And some days it may be visible but not operating in a mode that's usable for certain operators. In those cases, wouldn't it be nice to have another option?

We need to also consider the long lead-time associated with developing a working concept and raising the necessary funds to build a new satellite. Add to that the time required designing, fabricating, testing and obtaining a launch, and it could easily be five years or more from project inception to operational reality.

It would be a mistake to wait too long to begin work on the 'Next' satellite project.

WHY NOT AN ANALOG FM SAT?

The low earth orbit FM satellites have been popular due to their ease of use and low cost of entry. Making space communication available on a handheld radio is an interesting concept that has no doubt attracted many new operators.

Their actual usefulness for communication is questionable. A single channel repeater flying overhead provides five to fifteen minutes of visibility per pass which isn't necessarily a problem--but when you consider that only one QSO can take place at a time it does become problematic.

Add to that the capture affect of FM where the strongest signal "wins" and we realize a temptation for higher than necessary EIRP. There has been much editorializing about the proper "etiquette" for FM satellite operation but the fact remains that the ground stations are not the problem--the concept is simply faulty. We see the same problem with wide-area terrestrial FM repeater systems; too many users vying for a single channel creates QRM, bickering and strife.

The low-earth satellites offer an excellent platform for digital work, experimentation, position reporting and the like. We need to encourage and assist Universities and other organizations that are willing to continue building and launching satellites which may be used by radio amateurs, but it makes little sense to allocate AMSAT funds for such limited use projects as analog FM repeaters in the sky.

HOW ABOUT A P3C CLONE?

That was the very question I asked the worldwide amateur satellite technical community. Having been a very satisfied user of AO-13 for several years, it seemed logical that we could build another like it using the exact same plans.

My query was quickly answered. It seemed that while it may be desirable to clone P3C, it wouldn't be practical to do so today for a variety of reasons including that its physical dimensions were such that it would likely require a costly launch adapter not unlike the one used with P3D.

Continuing this discussion with the technical community we began to consider the possibility of a new generation of satellite. Something weighing less than 100kg. For simplicity, we'd spin stabilize the satellite and make minor attitude adjustments by magnetorquing. To make it even simpler, we would forego any propulsion system. No motor, no fuel. Add multiple linear transponders and we're set.

Once completed, such a satellite could be picked up by two people and transported in an automobile. The absence of a propulsion system means there is no handling of fuel or the complications associated with it.

We would launch it to geostationary transfer orbit, and leave it there.

YOU CAN'T REALLY DO THAT (CAN YOU?)

A launch from Kourou, French Guyana aboard an Ariane 5 would inject the craft into geostationary transfer orbit with an inclination of about 6 degrees. The perigee would be nearly 600km. We could expect an orbital period of nearly 12 hours. Overall, the orbit would be somewhat similar to that of AO-10 except that with an inclination of 6 degrees the apogee will not disappear in the south for stations farther north.

With a 36,000km apogee the bird would provide long haul DX communication for hours at a time. The 600km perigee provided by the Ariane 5 vehicle would assure a sustainable orbit over the life of the satellite even without a propulsion system.

To see what the orbit might look like on such a launch, try these Keplerian elements in your tracking program (courtesy of Stacey Mills, W4SM).

Satellite	NEXT-1
Catalog Number	00001
Epoch Time	00181.0000000
Element Set	000
Inclination	06.0000 degrees
RA of Node	180.000 degrees
Eccentricity	0.725000
Argument of Perigee	315.0000 degrees
Mean Anomaly	0.0000 degrees
Mean Motion	2.210000000 rev/day
Decay Rate	0 rev/day^2
Epoch Rev	0
Checksum	056

READY, SET, GTO

Arianespace is the commercial launch services leader, holding more than 50% of the world market for satellites to geostationary transfer orbit. AMSAT has a long and favorable relationship with them and the inclination provided by a launch from Kourou (6 degrees) is very desirable for the proposed satellite.

The company has committed to meet the demands of a changing market by evolving the Ariane 5 launcher to accommodate heavyweight spacecraft, handle the deployment of satellite constellations and serve the growing number of orbits required by satellite operators.

One of their recently developed tools for accomplishing this, is the Ariane Structure for Auxiliary Payloads (ASAP). This structure will be capable of carrying multiple small satellites (per launch) to geostationary transfer orbit. ASAP seems to be a popular concept that continues to evolve and it's important for us to note that they have customers ready to use this new launch service today.

For P3D we had to design and build a special launch adapter at a significant cost to the project. Using the ASAP we would not only save that cost, but also derive additional benefit from a multiple payload launch--a shared ride and shared launch costs.

While that all sounds good, the best part may well be that if this launch concept (ASAP) is well received, there is the increased likelihood of multiple auxiliary payload launch opportunities each year.

It might be feasible to build more than one of these 'Next' generation satellites and have one ready for launch whenever a spot on the launch structure becomes available. A last minute cancellation, for instance, from a paying customer could yield a low cost ride to geostationary transfer orbit for a properly designed and sized amateur satellite!

CHALLENGES AND OPPORTUNITIES

The concept detailed here includes yet to be resolved technical challenges. For instance, designing a smaller space frame to fit the ASAP means fewer square inches for solar panels and less area for high gain antennas.

We don't yet know if Arianespace would react favorably to the propagation of secondary payloads in the range of their geostationary transfer orbit and there is always the issue of negotiating to get a ride at a price we can afford.

And then, there's the matter of raising the funds to finance such an endeavor should we decide to pursue this project.

There are probably at least a dozen other considerations that would challenge the viability of such a project.

But consider the opportunity we have to grow the amateur satellite community.

The launch of P3D and the addition of amateur radio on the International Space Station will further expose this facet of our hobby to the public. With a relatively minor investment in a project such as this, we can ensure that operators have more than one good reason to assemble a groundstation, become active with satellite communications and join AMSAT in the continuing quest to pioneer amateur radio in space.

REFERENCES

Specific technical information for this paper was derived from the Ariane 5 Users Manual (Issue3.Rev0) and from an e-mail discussion list, which includes:

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An APRS Satellite for Mobile/Handheld Communications

Bob Bruninga, WB4APR
115 Old Farm Court
Glen Burnie, MD 21060

MISSION: This paper will describe the design of a low cost easy to build APRS satellite to meet the need for mobile and handheld amateur satellite users. This APRS Satellite Mission is for worldwide real-time message and position/status data exchange between users and is in contrast to the mission and design of all existing amateur PACSATS that concentrate on message store-and-forward. Further, it incorporates the Internet as part of its design instead of trying to compete with it. Although we are working on such a satellite at the Naval Academy, we have been kibitzing a number of other satellite owners and designers over the last 7 years to accommodate these concepts into their designs as well. The SUNSAT team has been especially receptive of such suggestions and has conducted a number of on-orbit experiments to validate this design. The following list of mission objectives form the basis for this design:

1) Handheld/Mobile live digital tracking and QSO's in footprint
2) Worldwide handheld/mobile position/status reporting (via internet)
3) Handheld/Mobile message uplink to satellite (then to Internet)
4) Handheld/Mobile message downlink delivery from Internet
5) Nationwide Bulletin delivery to all users
6) Low Power GPS tracking of buoys, telemetry devices, wildlife, etc
7) Other UI digipeating applications (TBD)
8) Worldwide one-line Emailing

All of these mission objectives can be met with just a simple hardware TNC on orbit acting as a UI digipeater. Also, with the sophistication and added I/O of recent TNC's designed for APRS, the TNC itself can be the command and control system. Thus no additional on-orbit CPU's are required. Not only is the satellite hardware simple, but it can be reproduced by other satellite builders to help form a constellation of these relay satellites, all operating on the same frequency to give mobile users extended access beyond what is possible with one satellite alone. This concept of a Builders Channel for similar-mission spacecraft was presented at last years AMSAT Symposium [1].

BACKGROUND: Ham radio is on the move. Satellite Wireless is the leading edge of technology. In HAM radio, it should be a major driver for future amateur satellite missions. In just the last year we have seen *many* hints at the future of Amateur Mobile and Handheld satellite communications.

1) Continuing high popularity of AO27 for handheld FM voice comms.
2) Growing popularity of UI digipeating via MIR through 1999
3) Activation of UO-14 for FM voice repeater mode in February 2000
4) Experimental UI digipeating via a 9600 Baud Packet Satellite
5) FM VOICE repeating via SUNSAT SO-35 throughout 1999
6) Recent activation of a SUNSAT SO-35 for UI digipeating and APRS
7) Recent Introduction of integrated TNC/Radios (Kenwood & Alinco)
8) Dayton 2000 introduction of the upgraded Kenwood TH-D7 HT!

The potential of two-way satellite handheld text messaging (national paging) was serendipitously demonstrated at the Dayton Hamvention during a parking lot demo of the SUNSAT downlink. Due to a scheduling error, there was no success at the expected time so the HT was placed in a pants pocket and forgotten. But minutes later, the tale-tale beeping of the TH-D7 alerted me to an incoming APRS message and on inspection, it was a Bulletin from SUNSAT. Thus, amateur satellite message delivery to an un-attended obscured Handheld Transceiver was demonstrated.

Photo 1. This is a photo of Chas Richards W4HFZ's mobile APRS Satellite capability (also includes HF). With an APRS Satellite, he can send and receive brief text messages anywhere on the planet a few times a day.

ASTARS: To give this APRS satellite communications system a name, we call it ASTARS, for APRS Satellite Tracking and Reporting System which has evolved through a number of existing and previous satellite communications experiments. First was **1200 Baud PSK ASTARS** which we called TRAKNET [2] at the 1998 and 99 AMSAT conferences using AO-16, LO-19 and IO-26. It is a very viable capability for stations with PSK TNC's or using KA2UPW's sound-card uplink capability[3]. But it never became popular due to the rarity of PSK modems amongst most APRS operators.

Satellite packet experiments using **1200 Baud AFSK ASTARS,** however, which ANY TNC can do, was demonstrated many times during experiments with the Space Station MIR[4] packet system and SAREX[5]. These experiments culminated in the June 1999 week long experiment via MIR which used the new Kenwood TH-D7 with built in 1200 and 9600 baud TNC's to demonstrate two-way self-contained APRS communications via MIR at 1200 baud. During this test[6], over 55 stations conducted 2 way HT-to-HT message communications.

Recently we have been able to experiment with **9600 BAUD ASTARS** using the new Kenwood 1200/9600 baud APRS data mobile radio, the TM-D700A [7]. This dual band data radio with built-in TNC's and front panel APRS displays made it possible to send and receive the very short APRS style communications via any 9600 Baud PACSAT with digipeat enabled. Thus, the TM-D700 radio is an off-the-shelf satellite data terminal ready for ASTARS and it needs NO PC or other accessory. Kenwood also followed suit with 9600 baud upgrades to the TH-D7(G) HT with its internal front panel displays. Alinco also now sells another integrated TNC/Radio called the DR-135 which can also do both 1200 and 9600 baud built-in, though it needs an external Laptop to display the APRS data.

THE INTERNET: Unlike previous Amateur Satellite designs, an APRS satellite can capitalize on the connectivity of the Internet instead of trying to compete with it. The Internet makes possible the linking together of multiple disparate downlink sites which allows a tremendous gain in reliability through space and time diversity reception. Instead of each station requiring their own downlink receiver and then only being able to hear packets within his own footprint, the Internet allows a few stations, called SAT-Gates (Satellite IGATES) to combine all packets heard into the existing worldwide APRS infrastructure (APRServe)[8] for delivery to any APRS operator anywhere.

APRS MESSAGES: For satellite operators unfamiliar with APRS messages, it should be understood that an APRS message is a single LINE of text. Most messages stand alone, but are occasionally strung together if it won't fit on one line. Photo 2 is a photo of a very brief 15 byte message received on the TMD700 radio. Messages from mobiles are usually quite brief as they must be entered on the TouchTone pad. But longer messages up to 64 bytes are routinely displayed.

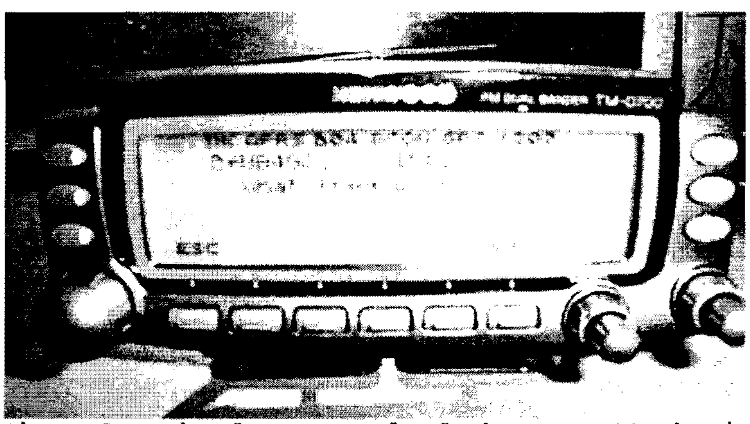


Photo 2. The front panel of the TM-D700 showing an incoming 15 byte message (Messages can be longer up to 64 bytes).

EMAIL: Similarly, the APRS messaging system can send and receive standard EMAIL messages worldwide via the well established worldwide APRServe internet system. This capability is limited, but very useful. The first limitation is that messages are only ONE LINE and the one line *includes* the full email address. This forces BREVITY! Secondly, although EMAIL can be originated under the control of the HAM sending it, EMAIL replies back from the Internet are only allowed via special

Igates with operators that have volunteered to screen such traffic for 3rd party legality prior to being returned to RF. Here is an Email I transmitted from my D700 mobile enroute to work. Notice that the SINGLE packet entered into the D700 was simply:

EMAIL :wb4apr@amsat testing delivery via pacsat from my van enroute to work.

Yet, here is how it was received by my Email system after being SAT-Gated to APRServe and from there, picked up by the EMAIL Engine at WU2Z's and shipped out as regular Email:

```
Date: Mon, 7 Feb 2000 07:58:09 -0500 (EST)
From: WB4APR-9@unknown.net
To: wb4apr@amsat.org
Subject: APRS Message from WB4APR-9
--------------------------------------------------------
 testing delivery via pacsat from my van enroute to work.
--------------------------------------------------------
Message received by MacAPRS IGate station WU2Z
Located in NO BRUNSWICK, NJ
APRS path = WB4APR-9>APK101,SUNSAT*:
```

USER GROUND STATION EQUIPMENT: To design an APRS satellite we must fully understand the capabilities of the users mobile stations. The table below shows the uplink power and receiver antenna gains for all participating stations in the ASTARS system. The column labeled Standby Receive Gain is for the user who is not aware of, nor optimized for satellite reception. For example, someone hiking with an HT in his pocket, or mobile parked under trees.

USER Stations	ERP UHF (W)	ERP VHF (W)	Rcv UHF dBi	Rcv VHF dBi	Rcv STBY dBi	Applications
HANDHELDS	3	5	3	3	-6	Sailboats, Hikers, Wilderness
MOBILES	70	100	5	5	-6	Remote Travelers, Boats
HOME Stations	700	1000	13	13		Not intended for UPLINK
NETWORK Stations						
IGATE Receiver			7	5		Omni Internet receive site
MESSAGE NODE	70	100				Internet to user UPLINK site
COMMAND Station	700	1000	13	13		USNA

Although a wide variety of power and receiver gains are involved, these values are what form the basis of the APRS Satellite design and the architecture of the overall ASTARS System.

REQUIREMENTS/CONSTRAINTS DESIGN DRIVERS: To design a satellite to meet the HT/Mobile communications objective and the internet links as well, there are a number of factors involved in selecting the frequency band, antenna types, and baud rates for each of the mission objectives. First there are a number of boundary conditions or assumptions:

1) Optimum ALOHA channel efficiency is about 20% due to collisions
2) VHF links have a 9 dB advantage over UHF links (omni to omni)
3) 1200 baud AFSK has a 7 dB advantage (measured) over 9600 baud FSK
4) T/R delays render 9600 only twice as fast as 1200 for APRS bursts

5) UHF uplinks require wideband Sat Rcvrs to avoid Doppler (- 4 dB)
6) UHF downlinks require user tuning during pass (not desired)

With these design drivers as a guide, the following are some of the obvious first-order alignments of requirements to hardware. From these, then, we need to determine the optimum trade-offs to arrive at our final design.

7) MSG delivery to HT in Standby requires best possible downlink (1200 baud VHF). Igate uplink is relatively unconstrained.

8) MSG receipt from HT requires best possible uplink (1200 baud VHF).

9) Downlink to internet is relatively unconstrained.

10) Continent wide Bulletin Delivery requires existing 144.39 over USA and 1200 baud. The same for Europe will require a common European frequency too.

11) HT/Mobile real-time messaging requires same up/downlink & baudrates

12) GPS HT/Mobile tracking is relatively unconstrained.

13) Low power GPS tracking devices require best uplink (1200 baud VHF) and the uplink must not be used by any other satellite uplinks to avoid unintentional interference to other systems.

14) Other UI digipeating applications should be crossband full duplex and should use same up/downlink baud rates

15) Spread of uplinks among multiple receivers to minimize collisions is desired.

16) Synchronizing of same-band downlink transmissions is desired to maximize the available half-duplex satellite receive time.

17) Redundancy and Backups are desired.

18) Bundling of packets in bursts amortizes individual TXDelays

19) UHF downlinks are of little value due to poor link budget and Doppler.

20) KISS Principle should reign. (Keep it Simple, Stupid)

HARDWARE ALIGNMENT TO REQUIREMENTS: Using the above criteria, we arrived at a design using two KPC-9612 Dual Port TNC's. These TNC's have all the latest APRS generic digipeating advantages and can even cross route packets between ports. By using standard off-the-shelf TNC hardware and FIMRWARE, we have minimized risk on orbit due to the track record of thousands of identical hardware in use all across the country for terrestrial APRS. Thus, the firmware is proven.

Each dual port KPC-9612 can cross relay from either of its two inputs to its two outputs. Since we only have two transmitters on VHF for best downlink budget, we have to output both the 1200 and 9600 baud channels to the same transmitter, one for each TNC as shown below. With four ports, we need a single VHF half-duplex channel in the ITU Satellite Subband, and one other possible VHF uplink. The UHF uplinks are more readily available and are not expected to be an issue. Notice, that the other VHF downlink over the North American Continent will use 144.39 for downlinking occasional bulletins or directed messages to distant travelers. Thus they can receive urgent messages from the satellite at any time while also monitoring the terrestrial channel when in range of the terrestrial network.

```
                  KPC-9612 #1
                 +-----------+
 VHF-Up1 ------>| 1200 Baud |--*-----> VHF-Down1    (ITU Sat subband)
                |    \ /    |  |
                |    / \    |  |
 UHF-Up1 ------>| 9600 Baud |--*
                 +-----------+

                  KPC-9612 #2
                 +-----------+
 VHF-Up2 ------>| 1200 Baud |--*-----> 144.39    (over USA and AUS)
                |    \ /    |  |      (144.xx)   (over Europe?....)
                |    / \    |  |
 UHF-Up2 ------>| 9600 Baud |--*
                 +-----------+
```

To maximize receive (uplink) time, a cycle timer is used to drive the channel-busy inputs of each of the four TNC channels. By holding off both transmitters for N seconds and then allowing them to both transmit simultaneously, we minimize the VHF transmit time and thus maximize VHF receive time. We also bundle multiple packets into one burst thus, amortizing the TX Delays into only one TXD for further savings.. UHF receive time is unaffected. This channel synchronizing will be done with a two step timing circuit:

HOLDOFF to both 1200 BAUD TNC Channels:

```
    ...----------------*    *-----------------------*    *------- . . .
                       |    |                       |    |
                       *----*   <- xmit time        *----*
```

HOLDOFF to both 9600 BAUD TNC CHANNELS:

```
    ...---------------------*    *-----------------------*    *-- . . .
                            |    |                       |    |
                            *----*   <- xmit time        *----*
```

When each of these signals goes low to allow the transmitter to key, if there are packets pending, they will be transmitted. If there are none pending, then no transmission occurs.

FAILSAFE RESET: Since we are using commercial off-the-shelf Kantronics TNCs as our only on-orbit CPU or command processor, we must have a way to reset the TNC's in case of a lockup condition. First we get special ROMS from Kantronics with all of our default parameters burned in. Second, we integrate each TNC with a failsafe circuit. These circuits monitor the PTT of each TNC and as long as a transition occurs at least once a minute, then the TNC is assumed to be operating correctly and the TNC remains powered up. If there are no transmissions for over 1 minute, then a one-shot timer removes power from the TNC for 1 second to allow for a complete power up reset of the TNC.

The one minute baseline is established as the transmit rate for our telemetry packets. Thus, as long as the TNC is operating normally and transmitting packets, then it will not be reset. There will also be a backdoor unpublished commandable backup reset.

TELEMETRY: Based on the APRS TELEMETRY formats that we established back in 1995, Kantronics has added at least 4 channels of analog telemetry to all of their recent TNC's. To make this usable on our satellite, we have added a 16 channel hardware multiplexer to allow us to read as many as 16 values of telemetry per TNC. These APRS telemetry formats were used on STENSAT and more recently adopted for APRS modes on SUNSAT too.

LINK BUDGET: The primary driver of this APRS Satellite design was to deliver messages to handhelds and mobiles with only whip antennas. To do this, we will have a downlink that is at least 12 dB stronger than most existing digital satellites. We do this by taking advantage of the 9 dB link improvement of 2 meters compared to 70 cm and we also use a 3 watt transmitter. Further, our satellite will operate at a low transmit duty cycle. This is unlike all existing PACSATS which are required to operate with a low power budget so they can keep their transmitters on 100% of the time whether the satellite is in use or not. Since the worldwide HAM Radio population only covers 10% of the earth's surface and with the low duty cycle of the ALOHA style of APRS operations, less than 4% of our average power budget is required for each transmitter.

Similarly, to conserve link budgets and bandwidth, we reserve the 2 meter uplinks for only the low power stations such as users with Handhelds, or stand-alone low power tracking devices or data collection buoys or remote WX stations such as the one built by Ronald Ross, KE6JAB in Antarctica [9]. The mobiles and SATgates which have 35 to 50 watt transmitters will be asked to operate only on the UHF uplink frequencies where they can afford the more difficult link budget. Thus we also have the further advantage of having spread out the user base over 4 uplink channels to minimize collisions.

CHANNEL USAGE AND MISSION SCENARIO: The following table maps the mission objectives into the various uplinks and downlinks on the satellite. It matches strengths and weaknesses of each mission area to the available link budgets and hardware:

MISSION ELEMENT:	UPLINK	TNC PATH	DOWNLINK
HT Uplink of MSGS/POSIT to Internet	VHF1	UIDIGI	VHF1
Live HT-to-HT Footprint QSO's	VHF1	UIDIGI	VHF1
Live HT-to-Mobile crosslinks	VHF1	MYgate	VHF1@9600
Live Mobile-to-HT crosslinks	UHF1@9600	Mygate	VHF1
Mobile uplink of MSGS/POSIT to Internet	UHF1@9600	UIDIGI	VHF1@9600
Live Mobile-to-mobile Footprint comms	UHF1@9600	UIDIGI	VHF1@9600
Voice Relay	UHF1	bypass	VHF1
Command and Control	ALL	MYRemote	VHF1
Other UI Applications	TBD	UIDIGI	VHF1
Low power Trackers	VHF2	UIDIGI	144.39 USA
Nationwide Message delivery	UHF2@9600	MYgate	144.39 USA
Nationwide Bulletin delivery	UHF2@9600	Mygate	144.39 USA

Notice the advantage of incorporating the single North American Continent-wide coordinated APRS frequency into the downlink frequency plan. Although this frequency is in use by over 2000 users fulltime including over 600 wide area digipeaters, it is a well established universal frequency where ALL APRS operators can be found. Normally, mobiles will cruise with their radios tuned to this frequency whether they are in range of the terrestrial network or not. Actually, although 90% of the USA ham population is within range of this terrestrial infrastructure, 80% of the land mass is not.

This downlink on 144.39 will ONLY be used for the special applications of 1) Getting an emergency or priority message to an existing APRS mobile no matter where he is. 2) In frequent Bulletins of National interest. 3) Low power but high profile tracking of special devices, for example, the Olympic Torch. Due to the low duty cycle channel statistics of an ALOHA TDMA channel like APRS, even though the channel is in full use by thousands of users, still more than 50% of the time, the channel is "clear" as heard by any mobile anywhere.

OPERATIONS SCENARIO: To develop a viable satellite communications system that can communicate between mobiles and also to/from the worldwide APRServe system within these limitations, the following operating scenario is recommended.

21) Mobile APRS stations use a -3 SSID so the SATgates know to deliver such traffic via the satellite and not to their home or terrestrial stations.

22) The mobile uplink objective is two posit/status successes per pass. This can be met with a 1 minute rate.

23) Mobile uplink of a few outgoing messages per pass using the built-in Kenwood 1 minute message rate is about right.

24) SAT-Gate will transmit return messages during the central 3 minutes when the satellite is at its closest distance to an intended station.

25) Mobiles with beams can indicate to the SAT-Gate to try longer in the pass by including "QRZ" in their STATUS, or by indicating CUSTOM MSG 3 which is easier to set from the TouchTone pad.

SAT-GATE OPERATIONS: The Mobile-to-mobile and HT-to-HT communication missions work without any special considerations on the satellite or on the ground. But the more useful application is sending and receiving messages to any other APRS station worldwide by having the packets received by the SAT-Gates that are monitoring the satellite downlink and feeding every packet heard into the APRServe system. These SAT-Gates perform the following functions:

26) Monitor both downlinks and feed ALL packets into the Internet
27) Maintain a track on all Calls heard via satellite
28) Monitor the Internet and capture MESSAGES for these Calls
29) Deliver these messages at a "fair" rate under these conditions:
    1) The satellite is within 1400 km (above 30 deg) to mobile
    2) It sees "QRZ" in the Mobile's STATUS text or CUSTOM-3
    3) Deliver these messages until seen in the downlink 3 times

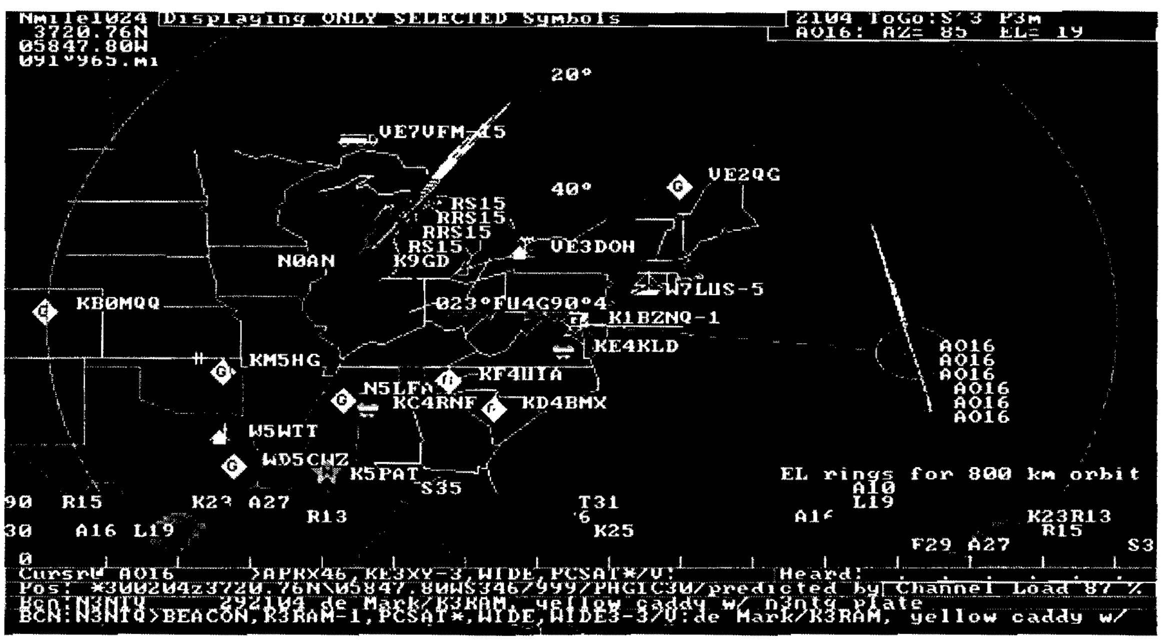
OMNI NO-TRACK SAT-GATES Setting up a SATgate is trivial requiring nothing more than a normal packet station and omni antenna. Any APRS station can do it with existing software which contain the built-in Igate capabilities. Even if the station does not have horizon-to-horizon coverage, they are only contributing their packets to the same stream as all the other Igate receivers, so any station can help. Unlike any previous amateur satellite activity, we use the Internet to combine the outputs from a dozen such stations nationwide and the result is over a 99.96% chance of capturing every packet over the USA! Even if only 4 stations at any one time have the bird in view of their station and even if they only have a 60% chance of decoding each packet, their combined probability is 98%. But if the original packet is replicated TWICE, then this probability becomes 99.96%! A Certainty!

BASE STATION OPERATIONS: Since the APRS Satellites are shared assets with limited bandwidth, we only want to encourage this message system for use by mobiles who have no other means to communicate from distant locations. For this reason, we do not encourage base station operations other than SAT-Gates or for direct contact with a mobile if needed. A Mic-E style packet from the D700 is only 9 bytes long, compared to a typical WinAPRS 80 byte position report.

Base station transmissions are strongly discouraged. Stations using software other than the very short Mic-E radios, should only operate in APRS compressed mode and minimize their STATUS text. Beams on the uplink for this application are also NOT desired. To use this mode, we must keep each stations ERP to 50 watts to an omni... or equivalent to give everyone equal access.

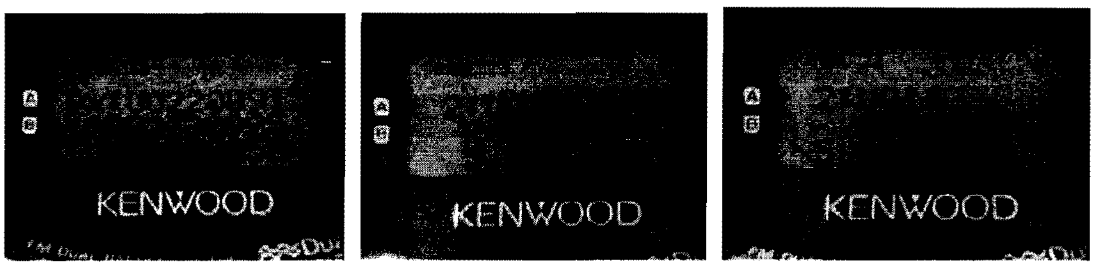
SATELLITE TRACKING AND PASS PREDICTIONS: With dedicated APRS satellites, we will have less of a problem with QRM and congestion on the uplinks than we have had with our experiments on some of the shared access birds. But in any case, it is nice to know when a satellite will be in view to carry your message traffic. To this end, I have added Satellite tracking to APRSdos in the form of APRStk.exe. When run within an existing APRSdos file structure (so you get all the maps and other built-in-data), it presents the satellite predictions on the APRS map and will auto-tune the Kenwood radios including Doppler. It is available zipped up as a complete system for download from:

ftp://tapr.org/aprssig/dosstuff/APRSdos/aprstk.zip



All satellites are shown on the map as moving objects. Across the bottom of the screen the next 2.5 hours of satellite passes are shown in a graphic showing the maximum elevation of the pass.

DISTRIBUTING LIVE SAT TRACKING DATA TO MOBILES: Another version of the same APRSdos derivative is called APRSdata.exe and it has the unique feature that it can distribute via the terrestrial network sufficient pass information so that other travelers are aware of pass times long before they drive out into the wilderness. Fortunately, we have an excellent way to display this special Satellite Pass Info directly on the mobiles' radio. Not only can APRSdata.exe post the Satellites in view as objects to the local 144.39 network so that all mobiles can see where they are in real time, but it can also transmit the schedule to the TH-D7 or TM-D700's DX-LIST for future reference. Thus, our mobile satellite users can get the PASS info they need without lugging along a laptop.



Photos 3. These screen shots show what the TH-D7 HT will capture and display about the satellites while monitoring the terrestrial network if an APRSdata.EXE station is in range. First is the DX-SPOT list showing that there are three satellites UO22, AO27 and UO14 coming up in the next 80 minutes and when.

The next two screens show up when the satellite is in view. They show the Range, Azimuth Frequency, Doppler and distance to the satellite. Just perfect for aiming your handheld antenna. For more details on this resource for non-PC distribution of satellite info, see the WEB site:

http://web.usna.navy.mil/~bruninga/satinfo.html

The power of this on-line, real-time delivery of current satellite pass data to mobiles and handheld users without the need for a laptop is in itself a brand new opportunity for Amateur Radio. Already we have expanded it to hundreds of other data screens that we can push to these radio displays. We call them Tiny Web Pages [10]. Although this application is beyond the scope of this paper, remember that we can deliver these Tiny Web Pages to any HT/Mobile anywhere on the planet with the combined resources of the existing APRS infrastructure and the future APRS Amateur Satellites.

CONCLUSION: The time is ripe for extending our Amateur Satellite digital communications services to mobile and handheld users. Since packet was first introduced on the Space Shuttle mission STS-35, there have been numerous experiments to test and validate the capability for using UI packet digipeating for real-time digital communications between users. Instead, the mainstream use of satellite packet matured into the PACSAT store-and-forward protocol to meet the more immediate need and higher demand for worldwide bulk message communications. But more recently, the Internet also matured as a global resource for exchanging data worldwide which obviated much of the appeal of such an Amateur Constellation of Satellites.

Now, however, we have a unique opportunity to join the advantages of the Internet and Amateur Satellites as a means of tying together ground stations throughout the world where the infrastructure exists to extend worldwide amateur communications to mobiles in areas where it doesn't exist. And, rather than starting such a global system from scratch, the APRS protocol and worldwide internet infrastructure provides a means of packaging and delivering and displaying this type of real time traffic to users both on the satellite downlink and worldwide via the Internet.

Finally, the introduction of the Kenwood and Alinco integrated TNC/Radio combinations give us off-the-shelf solutions for providing mobile and handheld Satellite Communications Terminals to all users. We hope to use UI digipeating APRS satellites to bring all of these pieces together into the most powerful and far reaching Amateur Radio Satellite project to date.

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[1] Satellite Builders Channels, 17th Annual AMSAT Symposium
[2] http://web.usna.navy.mil/~bruninga/traknet.html
[3] http://members.aol.com/dquagliana/upw/index.html
[4] http://web.usna.navy.mil/~bruninga/mirex.html
[5] http://web.usna.navy.mil/~bruninga/sarex.html
[6] http://web.usna.navy.mil/~bruninga/mir-ht.txt
[7] http://web.usna.navy.mil/~bruninga/TM-D700A.gif
[8] http://web.usna.navy.mil/~bruninga/www.aprs.net

The Houston AMSAT Net

I earned my Ham ticket in 1993 and immediately found that I wanted to work the satellites and work them I did. I found the Houston AMSAT Net shortly after and started participating on the net each week. It met on the 147.10 MHz repeater in Houston operated by Craig, WD5BDX. Craig began transmitting the net over Telstar 302 in February of 1994. Our net control at the time was Ed, N5EM and Andy, W5ACM and I were contributors. Towards the end of 1994, Craig decided to take a brake and he passed the controls to me for doing the uplink to the satellite. On February 7, 1995 I started doing the net on Telstar 302 myself.

We also started trying to get repeater operators around the country to carry the net. We had George, W1ME provide the net over the NETARC net in the Northeast and K4LK's repeaters in Florida plus many more repeaters throughout the country. The AA3RG, Pine Grove Repeater Association in Pennsylvania being the newest. The NETARC net has since lost their repeater sites but K1QL has picked up the slack with his repeater network.

We were using the Omega Radio Network and in May of 1995, we moved to the Tech Talk Network. On September 20, 1995, I did a never before feat.... With one radio, I worked Bob, CE0Z on AO-10. I took that audio feed and sent it over Telstar 302. This was the first cross band repeat between an amateur satellite and a commercial satellite. Our listeners got a big kick out of this contact.

Our net had been on Tuesday nights but in November of 1995, we had to move to Sunday nights. This was not the best for us but in February of 1996, we moved once again. We went over to ANIK E2 and returned to Tuesday nights.

Trouble was not too far behind.... We lost the Tech Talk Network and scrambled for a new home which we found on the W0KIE Network and moved to SBS 6. To make things more fun and increase our listening base, in July of 1996, Scott at North American Internet started doing real Audio Encoding for us. This allowed us to bring the net to many more people. This was our 126th net. This lasted until August of 1997 when I started doing the encoding for the real audio. After losing Scott's services for the hosting of the Real Audio streams, we switched to Greg, KB5OAT's server.

This relationship worked great but once again, we had to move and in 1998, we moved our web page to David, KC8BRL's server, where we remain to this date. At the same time, we did not have a Real Audio server so W0KIE started providing a Real Audio Live Stream for us every week. In September, 1999 after getting a cable modem, I found that I could host the Real Audio Live server on my computer and have been doing so ever since.

In January, 2000, the W0KIE network lost their transponder and we once again went on the move to a new uplink provider. Now we are heard over Lamonica's TVRONET on GE-4, Transponder 16, 5.8MHz audio. The to make things worse, a group of buildings in Houston where many repeaters have been located found that they can rent the space for $500-$1000 per month so the repeaters had to go. We moved the net back to a repeater that was used many, many years ago, the 145.45 MHz WB5RDK repeater. Which is operated by the South Texas Emergency Communications Group and located on the roof of Memorial Hospital Southwest in Houston.

Andy, W5ACM started something new this year. He started transmitting Slow Scan images during the last 5-10 minutes of each net. This has allowed people around the world to view some interesting pictures from the MIR and other sources. Since the Real Audio is available in archive format for 3-4 weeks after each net, anyone can listen and decode pictures that they may have missed.

Last year, we provided Real Audio coverage of the 1999 AMSAT Symposium and also provided live 8 hours per day coverage over our satellite feed. This year, we are limiting it to the Real Audio feed only.

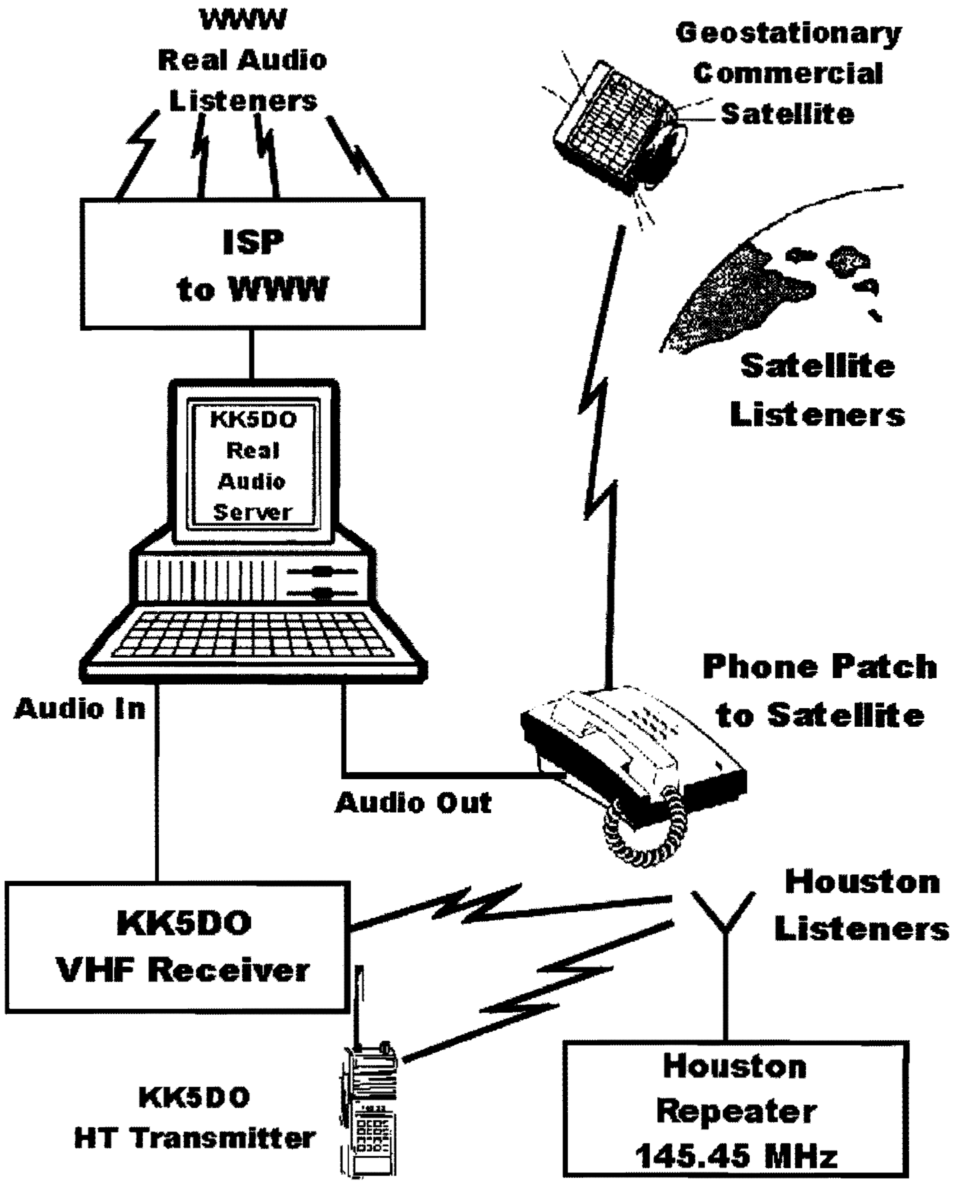
Where do we go from here? Don't have a clue. Something will come up, maybe HDTV, maybe even providing live video with the audio. In any case, it is fun and we enjoy it.

The diagram that is attached indicates how the signal gets from Houston to you either over our local repeater, a commercial satellite, or on the world wide web.

The signal originates on the WB5RDK 145.45 MHz repeater in Houston. It is received on my Icom 821H transceiver and the audio from the radio goes directly into my computer sound card. From the sound card, one output goes to the specialized phone patch designed by George, W1ME. That audio goes to the uplink site for TVRONET and the commercial satellite we are using. Internally to the computer, I use Real Audio Producer to encode the audio for those on the World Wide Web. The Real Audio Producer connects to my Real Audio Server running on my computer which allows 25 live streams (25 listeners at one time). At the same time, on my computer, an archive file is being built. This file is uploaded to my web site after the net is over for those to listen to for the next few weeks. If I need to get into the net, I use an Icom W32A HT and transmit through the repeater thereby never interrupting the audio that is being received on my other radio. Once in awhile, we time out the 10 minute timer on the repeater. When that happens, I am only about 3 miles from Andy, W5ACM (our net control) and I switch over to the input of the repeater so as not to lose anything.

If you have a question, feel free to contact me at kk5do@amsat.org or visit our web page at http://www.amsatnet.com

73... Bruce, KK5DO



How the Houston AMSAT Net gets to you

EasyTrak, A PIC Based Rotor/Radio Controller Interface

by Steven R. Bible, N7HPR (n7hpr@amsat.org)

Abstract

EasyTrak is a rotor/radio controller interface based on the Microchip[1] PIC16F87x series PICmicro® microcontroller. The goal was to design a rotor/radio interface that is compact, low-cost and easy to use. The PIC microcontroller contains many of the peripherals needed to design a rotor/radio controller interface: analog to digital converter (ADC), timers, serial interface (USART), and individually programmable I/O pins. In addition, the PIC contains FLASH ROM for easy programming and upgrades, RAM for system variables, and EEPROM for storage of non-volatile configuration information. With a small amount of interface circuitry around the PIC microcontroller, the goals of compact and low-cost were obtained. Ease of use was obtained by designing EasyTrak to interface to the most popular azimuth/elevation rotors and a serial RS-232 interface to communicate with virtually any computer.

EasyTrak is designed to easily interface to the Yaesu series of azimuth/elevation rotors, model numbers G5400B, G5600, and the newest G5500. These rotors have a computer interface built in with an 8-pin DIN connector on the back of the rotor controller to control left, right, down, up and provide rotor position via a proportional 0-5 VDC analog signal for azimuth and elevation. EasyTrak can be interface to other rotors, for example rotating HF antennas, but will require user modification of the rotor controller. Optional relays can be installed on EasyTrak to provide normally-open (NO) or normally-closed (NC) contacts for azimuth, elevation, and brake.

The computer interface is via a serial RS-232 connection. The rotor controller protocol is based on Chris Jackson's, G7UPN, EasyComm protocol. EasyComm is a simple ASCII character based protocol for controlling rotors and radios. The benefit was that a new protocol did not have to be created, it is easy for programmers to write for and interface to, and several programs already have EasyComm programmed in: WiSP, Nova, MacDoppler, MacAPRS and WinAPRS. The Mac and WinAPRS programs have the unique feature of tracking high and low altitude balloons in azimuth and elevation as well as other objects[2]. Mac and WinAPRS can also point HF beams using the DX Cluster feature or point to a moving object in azimuth only.

Introduction

This project started out several years ago with the goal of designing a low-cost rotor/radio controller interface. EasyTrak was designed primarily with satellite operation in mind. It had to interface easily to the most popular azimuth/elevation rotor system, the Yaesu G5400B/G5600B and G5500 series. The Yaesu rotor controllers have a built in computer interface which supplies a proportional 0-5 V analog signal that corresponds to the rotor position (azimuth and elevation) and four command lines left, right, down, and up (when grounded, command the rotors in the respective direction). EasyTrak also had to control the most popular satellite radios. However, EasyTrak is not limited to satellite operations only. It can easily be configured and interfaced to other rotor controllers but requires the user to modify the rotor controller.

Central to the EasyTrak design is the Microchip PICmicro.® The PIC was a natural choice with the plethora of integrated peripherals in a single integrated circuit package. Integrated peripherals reduce the amount of external circuitry required and help keep costs down. The PICmicro chosen for the EasyTrak project was the PIC16F87x series. The F87x series has a maximum of 8 K FLASH ROM, 368 bytes of RAM, and 256 bytes of EEPROM. The flash ROM provides an easy method to program and upgrade the firmware (verses EPROM) and the EEPROM a means to store configuration values. Onboard peripherals of interest for designing a rotor controller include an eight channel 10-bit Analog to Digital Controller (ADC), one 16-bit and two 8-bit timers, and Universal Synchronous/Asynchronous Receiver Transmitter (USART) for serial communications to a host computer. The PICmicro is the center of the hardware design, but a protocol was needed to control the rotors and radios.

It was important not to create another rotor controller protocol. There already exist several rotor controllers (commercial, kit, and homebrew), each with its own unique protocol. This complicates the software authors' job in keeping up with multiple protocols. What was needed was a protocol that was simple and provided the necessary basic commands.

EasyComm Protocol

The protocol chosen was Chris Jackson's, G7UPN, EasyComm[3] (thus the origin of selecting the name EasyTrak). Chris is the author of the popular digital satellite program WiSP (Windows Satellite Programs) and developed and implemented the EasyComm protocol for those who wish to design their own rotor and radio controllers. Given Chris' experience supporting a variety of rotor interfaces in WiSP, the EasyComm protocol should contain the basic commands necessary to control rotors and radios. As a bonus, EasyComm is already implemented in several popular tracking programs such as WiSP, Nova, MacDoppler, and most recently, Mac and WinAPRS.

During the development of EasyTrak, it became evident that the EasyComm protocol was a good choice. It shielded the software author from knowledge of the rotor or radio. EasyTrak handled the translation from EasyComm command to rotor movement or radio control. For example, to move the azimuth rotor to 270 degrees, the following command is issued:

```
AZ270.0↵
```

Where "↵" can be a space, carriage return, or linefeed (the space allows multiple commands to be placed on one line). It is EasyTrak's responsibility to safely and accurately position the azimuth rotors to the commanded position. An example radio frequency command is:

```
UP145900000↵
```

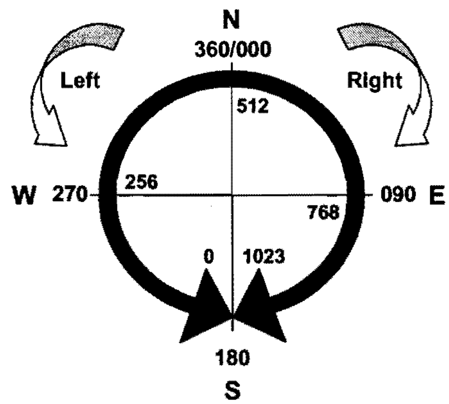
This will command the uplink frequency to 145,900,000 Hz (145.900 MHz). The software author does not need to know what radio model is commanded. EasyTrak handles all of the details. However, it became apparent that configuration commands would be necessary to tell EasyTrak about the rotors and radios interfaced to it. Thus the decision was made to extend the basic EasyComm protocol with configuration commands.

The goal of the extending EasyComm protocol for configuring EasyTrak required that the same basic command structure be followed (two letter command followed by a command value) and that it should not require the software author to implement the extended commands in order to configure EasyTrak. EasyTrak can be configured using a simple terminal program, and once configured, can be interfaced to any tracking program that supports the EasyComm protocol. The goal was to use the fewest commands necessary to configuration EasyTrak. Attachment A summarizes the EasyComm 2 and extended commands supported by EasyTrak.

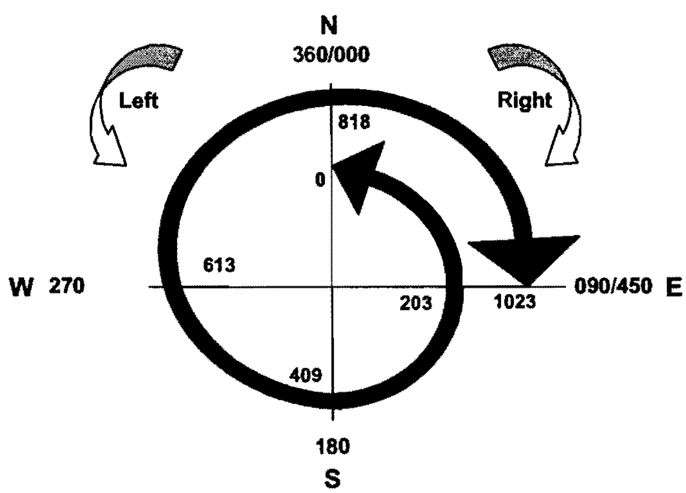
Rotor Configuration

The first rotor configuration command, RO, specifies the type of rotor combination. There are four choices: A = Azimuth only, E = Elevation only, C = AZ/EL Combination, or N = None (no rotor) (default setting). This command allows EasyTrak not to be tied to azimuth/elevation rotors only.

The second rotor configuration command, RS, specifies the physical stop of the rotor. There are two choices: S = South physical stop (such as the Yaesu G5400B/G5600B) or N = North physical stop (such as the Yaesu G5500). This command is necessary for EasyTrak to compute the physical position to the compass direction. The following diagrams explain why this is necessary:



The above diagram illustrates a south physical stop. The inner values represent the 10-bit ADC value that is read from the proportional 0-5 V analog signal supplied by the rotor controller. The outer values represent the compass directions.



In contrast, the above diagram illustrates a north physical stop (with 90 degree overlap) of the Yaesu G5500 rotor. Again the inner value represents the approximate 10-bit ADC value read from the proportional 0-5 V analog position signal supplied by the rotor controller. The outer values are the compass directions. These two types of physical rotor configurations require a different mathematical conversion. Once EasyTrak has been configured with the rotor type and physical stop, the rotors must be calibrated.

Rotor Calibration

First and foremost, the rotors must be assembled and calibrated according to the manufactures instructions. Once this has been done, the rotors can be calibrated to EasyTrak. The first step is to set the maximum 0-5 V analog position signal voltages (azimuth and/or elevation) coming from the rotor controller.

The CA command continuously reads and displays the ADC value for azimuth and elevation. This command precludes the need for a voltmeter. The display looks like:

```
AZ ADC = 127  EL ADC = 64
```

The numbers are the raw binary values (0..1023) read from the azimuth and elevation ADC channels. This number represents the actual physical position of the rotors. The user manually positions the azimuth rotor in the fully clockwise (right) position and adjusts the azimuth output voltage until the ADC value reads between 1020 and 1022. Do not set the voltage for a reading of 1023. That is the maximum value of the ADC and represents 5 V or greater.

To calibrate the elevation rotor, first determine if antenna-flip capability (0 to 180 degrees) or not (0 to 90 degrees) will be used. Manually position the elevation rotor to 180 or 90 degrees. For 180 degrees the above azimuth procedure applies. Manually position the rotor to 180 degrees and set the elevation ADC value between 1020 and 1022. For 90 degrees, manually position the rotor to 90 degrees and set the ADC value to 512 (half the maximum ADC value).

Calibration Limits

The second calibration step is to establish the limits of travel for the azimuth and elevation rotors. There are four calibration limit commands: Calibration limit **L**eft (CL), **R**ight (CR), **D**own (CD), and **U**p (CU). The rotor is manually positioned to the associated limit and the calibration limit command is entered with the rotor position in degrees. EasyTrak will record the ADC binary value associated with the position. If the calibration limit command is queried, the degrees and ADC value are displayed in the format CUd,n where d = degrees and n = ADC binary value. For example, if the calibration limit up is queried, the response is:

CU90,512

This example response displays the calibration limit up position is 90 degrees and the ADC binary value associated with it is 512.

The calibration limit commands provide an elegant method of calculating the linear travel of the rotors. The majority of rotors have 360 degrees of travel. However, the Yaesu G5500 azimuth/elevation rotors present a unique challenge with 450 degrees of travel (an additional 90 degrees of overlap between 0 and 90 degrees). The azimuth rotor is manually positioned to 450 degrees and the command CR450 is entered.

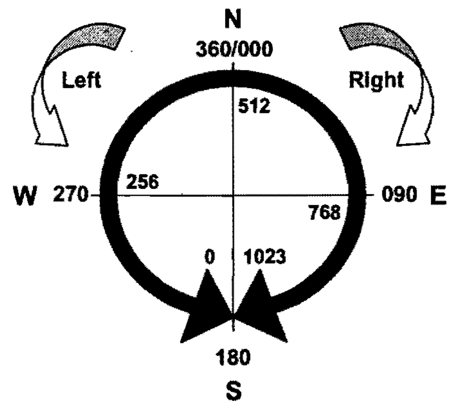
The calibration limit method also provides an elegant method of recording the minimum and maximum travel limits of the rotor. For example, if the rotor model is a Yaesu G5400B (which as a south physical stop) and the rotor installation has a physical obstruction between 180-270 degrees, a left most calibration limit can be entered. First, manually position the azimuth rotor to the desired left most limit, in this example, 270 degrees. Enter the command CL270. EasyTrak will not position the rotor any further left than 270 degrees to the physical stop at 180 degrees (to the left).

Design Implementation

The discussion up to now has been on the operation of EasyTrak. This section explains some of the technical details and design implementation of EasyTrak.

To position the rotors the commanded position is compared to the actual rotor position. If the rotor position is less than the commanded position, command the rotors to move right. If the rotor position is greater than the commanded position, command the rotors to move left. When rotor position is equal to commanded position command the rotors to stop. This is a simplified algorithm that in practice is a little more involved to implement. The rotors are positioned according to a proportional analog voltage that is digitized by the PIC ADC. This value has to be converted to and from degrees to be useful to tracking program.

The rotor indicates position with a proportional DC voltage. The Yaesu azimuth/elevation rotors use a linear 0-5 VDC signal to indicate actual rotor position. 0 VDC indicates the left most position of the rotor and 5 VDC the rightmost. For example, the Yaesu G5400B rotors (which have a south physical stop) use 0 VDC to indicate 180 degrees (to the left) and 5 VDC 180 degrees (to the right). Recall the diagram:



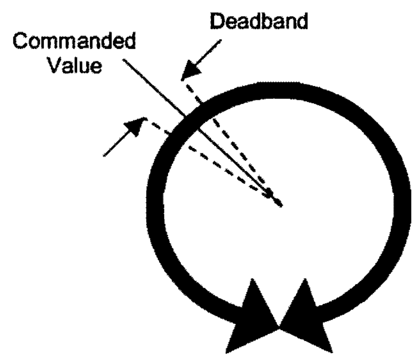
The PIC ADC converts 0-5 VDC into a 10-bit binary value between 0 and 1023 decimal. Effectively the ADC divides 5 volts into 1023 units. The resolution is:

$$\frac{5\,volts}{1023\,units} = 4.9\,millivolts\ per\ unit$$

The range of 0-5 VDC represents 360 degrees of rotation. The calculated volts per degree is:

$$\frac{5\,volts}{360\deg} = 13.8\,millivolts\ per\deg$$

The 13.8 millivolts per deg of rotation is a relatively small value. The rotor position voltage can be upset by noise (EMI on the sensing line and in the ADC). Plus there are mechanical limitations (gear slop) of the rotor and when the rotors stop moving there is a coast down period. Therefore, a boundary value must be specified to avoid the controller from continuously commanding the rotors left and right (chatter). This boundary value is called the deadband and it is a value (in degrees) specified by the user when configuring EasyTrak. The following diagram illustrates:



For example, if the commanded rotor position is 315 degrees and the deadband value is 5 degrees, the actual rotor position can be in the range of 310 to 320 degrees. This range appears to be a large value, but in practice, the rotors fall close to the commanded value. The deadband value should be set to a value that reduces the amount of rotor movement. This is an important property that deadband provides.

In satellite tracking applications, the tracking software is continuously sending azimuth and elevation position commands. The deadband specifies how often the rotor position will change. If the value is too small, the rotors will move often causing increased wear and tear on the rotor motors. If the value is too large, antenna pointing will not be optimal. The largest factor affecting the choice of deadband value is the antenna beamwidth. The positioning error budget is a combination of factors that can add or cancel each other out. These factors include:

- Antenna Beamwidth
- Rotor Gearlash
- Nonlinearities in the position potentiometer
- ADC Error
- Electrical Noise

PIC Programming

Now that the operational and technical aspects have been determined, the next step is to write the firmware routines for the PIC. The C programming language was chosen for the size and complexity of the EasyTrak project. The basic program structure uses an interrupt service routine to buffer the serial data from the host computer and an infinite main loop comparing the commanded to actual rotor position and issuing the appropriate move and stop commands.

The interrupt service routine (ISR) buffers the serial data from the host computer. The ISR allows the main loop to continuous check command to actual several times per second. When a complete command has been received, it is placed in a buffer and a received command flag is set.

The infinite main loop checks if the received command flag is set for a new antenna position. If one has been received, the ASCII command value is converted to binary and compared to see if it falls between the calibration limits. Then the command value (in degrees) is converted to the corresponding ADC binary. All comparisons are done in ADC binary values.

The antenna position routine first determines the low and highband ADC values from the command ADC and deadband values. The following code segment illustrates:

```
lowband = cmdAZadc - AzDeadbandAdc;

if (bit_test(lowband, 15)         // lowband less than zero?
   lowband = 0;                   // correct

highband = cmdAZadc + AzDeadbandAdc;

if (highband > 1023)              // greater than max?
   highband = 1023                // correct
```

Once the low and highband values are determined, the rotor position is read:

```
antAZadc = readADC(AzChan);       // read antenna AZ ADC value
```

It is compared to the low and highband values to determine if the rotors should be commanded to move: Notice that the actual rotor position is compared to the deadband limits. If the actual rotor position falls inside the deadband limits, the rotors do not move. It is only when the actual rotor value fall outside the deadband limits that the rotors are commanded to move:

```
if (antAZadc < lowBand) {         // if antenna < lowband
   output_high(cmdRight);         // command right

} else if (antAZadc > highBand) { // else if antenna > highband
   output_high(cmdLeft);          // command left
}
```

Once the rotor is moving, it is desired that they stop in the center of the deadband. Therefore, the actual rotor position is compared to the command value:

```
if (antAZadc >= cmdAZadc) {       // if antenna >= cmd
   output_low(cmdRight);          // command stop
}

if (antAZadc <= cmdAZadc) {       // if antenna <= cmd
   output_low(cmdLeft);           // command stop
}
```

The above routine works for small antenna arrays and rotors that stop in a short amount of time. In practice, the Yaesu azimuth/elevation rotors stop very quickly. The above routine would have to be modified for larger antenna arrays and rotors that take a finite amount of time to coast to a stop.

The only difference between the azimuth and elevation routines is that azimuth needs to be corrected for north or south physical stop.

Radio Control

Radio control is not as complicated as rotor control. A frequency or mode command is received and sent according to the computer interface protocol of the radio. EasyTrak cannot change frequency bands on dual band radios. Very few (if any) have change band commands. Therefore, it is up to the operator to manually configure the radio prior to operation. Otherwise the radio will ignore the frequency command.

EasyTrak is configured by telling it the model radio used for the up and downlink. EasyTrak has two radio ports. This allows radio separates to be controlled for the up and downlink and it allows the control of dissimilar radio models. For example, a Kenwood TS711 can be configured to port 0 as the Mode J uplink radio (URTS711,0) and an ICOM IC475 can be configured to port 1 as the downlink radio (DRIC475,1). If a port is not specified in the radio configuration commands, it defaults to 0.

If the radio is a dual band model, the port value is the same for the Up and Downlink. For example, to configure an ICOM IC-821 dual band radio to port 0, the following commands would be entered:

URIC821,0
DRIC821,0

Conclusion

Design and development continues on the EasyTrak rotor/radio controller. Presently there are 8 beta units in test. Once testing is completed and finally design decisions are made, it is hoped to provide EasyTrak as a TAPR kit. Be cautioned, the information presented in this paper is subject to change as the design continues to develop. To follow EasyTrak developments see http://www.tapr.org/~n7hpr/easytrak/.

Acknowledgements

Many thanks to the EasyTrak development team who have contributed immensely to the EasyTrak design (in alphabetical order):

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John Koster, W9DDD
Lou McFadin, W5DID
Doug McKinney, KC3RL
Stacey Mill, W4SM
Keith Sproul, WU2Z
Paul Williamson, KB5MU

References

[1] Microchip Technology, Inc. http://www.microchip.com

[2] Keith Sproul, WU2Z, and Mark Sproul, KB2ICI, *WinAPRS/MacAPRS and Automatic Rotor Tracking of Moving Objects*, in this proceedings.

[3] The EasyComm 1 and 2 standard is documented in a text file "easycomm.txt" accompanying the WiSP satellite program available from http://www.amsat.org/amsat/ftpsoft.html#win-wisp

Easy Comm 2 and Extended Commands Supported by EasyTrak

The host computer issues a 2-character command identifier followed by a command value (if required). Commands are separated (terminated) by a space, carriage return, or linefeed. All commands are echoed back to the host computer.

Rotor Commands

Position Commands

Command	Meaning	Command Value	Example
AZn	**AZ**imuth	0.0..450.0	AZ10.2
ELn	**EL**evation	0.0..180.0	EL45.1
SA	**S**top **A**zimuth	none	SA
SE	**S**top **E**levation	none	SE
ML	**M**ove **L**eft	none – move rotor left 1-sec	ML
MR	**M**ove **R**ight	none – move rotor right 1-sec	MR
MD	**M**ove **D**own	none – move rotor down 1-sec	MD
MU	**M**ove **U**p	none – move rotor up 1-sec	MU

The AZ or EL command can be queried (AZ or EL command issued with no command value). The query will respond with the actual position of the rotors. For example, the query

AZ↵ (where ↵ is a space, carriage return, or linefeed)

will return

AZ270.0↵ (where ↵ is a carriage return/linefeed)

Deadband Value

Command	Meaning	Command Value	Example
DAn	**D**eadband **A**zimuth	0..9 (default = 5)	DA5
DEn	**D**eadband **E**levation	0..9 (default = 3)	DE3

Configure Rotor

Command	Meaning	Command Value	Example
ROa	**RO**tor selection	A = **A**zimuth only E = **E**levation only C = AZ/EL **C**ombination N = **N**one (no rotor) (default)	ROC
RSa	**R**otor physical **S**top	N = **N**orth physical stop S = **S**outh physical stop (default)	RSS

Calibration

Command	Meaning	Command Value	Example
CAn	**CA**libration	None	CA

The CA command is used to set the maximum output voltage from the rotor controller to an ADC binary value of 1020 to 1022. Entering the CA command returns a continuous reading and display of the ADC value for azimuth and elevation. Example display:

AZ ADC = 127 EL ADC = 64

Calibration Limits

Command	Meaning	Command Value	Example
CLn	Calibration limit **L**eft	0..450 (default = 180)	CL0
CRn	Calibration limit **R**ight	0..450 (default = 180)	CR360
CDn	Calibration limit **D**own	0..180 (default = 0)	CD0
CUn	Calibration limit **U**p	0..180 (default = 90)	CU90

The calibration limit commands are entered when the rotor is manually positioned to full left (CLn), full right (CRn), full down (CDn) or full up (CUn) positions. When the limit commands are entered, EasyTrak records the associated ADC value with the degrees n entered.

When the calibration limit command is queried, the degrees and ADC binary value are display in the format CUd,n where d = degrees and n = ADC binary value. For example:

CU90,512

displays the calibration limit up position is 90 degrees and the ADC binary value associated with it is 512.

The limit commands also record the minimum and maximum limits of the rotor. For example, if the rotor model is a Yaesu G5400B and the rotor installation has a physical obstruction between 180-270 degrees, the calibration command CL270 can be entered while the rotors are manually positioned to 270 degrees. EasyTrak will not position the rotor further left than 270 degrees to the physical stop at 180 degrees (to the left).

If the rotor configuration command RS (rotor physical stop selection) is changed, the CL and CR default values change as follows:

RSS – North to South physical stop:
CL180,0
CR180,1022

RSN – South to North physical stop:
CL0,0
CR360,1022

Radio Commands

Radio Frequency and Mode Commands

Command	Meaning	Command Value	Example
UPn	**UP**link Freq	in Hertz Note 1	UP145000000
DNn	**D**ow**N**link Freq	in Hertz Note 1	DN435000000
UMa	**U**plink **M**ode	CW, USB, LSB, FM-N, FM-W, NONE (default)	UMFM-W
DMa	**D**ownlink **M**ode	CW, USB, LSB, FM-N, FM-W, NONE (default)	DMFM-W

Note 1: Frequency band must be manually selected and the frequency value within the range of the band selected or the frequency command will be ignored.

Configure Radio Make and Model Selection

Command	Meaning	Command Value	Example
URr,p	**U**plink **R**adio	r = radio model (see below) p = port (0, 1)	URTS711,0
DRr,p	**D**ownlink **R**adio	r = radio model (see below) p = port (0, 1)	DRTS811,1

Current radio makes and models supported by EasyTrak are:

Yaesu: FT736, FT847
Kenwood: TS711, TS811, TS790
Icom: IC275, IC475, IC820, IC821, IC970
NONE (default)

If a port is not specified in the UR or DR command, it defaults to 0.

If the radio is a dual band model, the port value is the same for the Up and Downlink. For example, to configure an ICOM IC-821 dual band radio to port 0, the following commands would be entered:

URIC821,0
DRIC821,0

EasyTrak cannot change frequency bands. Very few (if any) computer controlled radios have change frequency band commands. Therefore, it is up to the operator to manually configure the radio prior to operation. Otherwise the radio will ignore the frequency command.

The benefit of having two radio ports is that EasyTrak can control dissimilar model radios. For example, a Kenwood TS711 can be configured to port 0 as the Mode J uplink radio (URTS711,0) and an ICOM IC475 can be configured to port 1 as the downlink radio (DRIC475,1).

Miscellaneous

EasyTrak Version Information

Command	Meaning	Command Value	Example
VE	**VE**rsion Request	none – returns version info	VE

Alarms

EasyTrak will alarm if the checksum of the configuration values held in EEPROM is invalid.

ALInvalid EEPROM Checksum

APRS®
and the
TAPR EasyTrak™
Az/El Rotor Control System

Keith Sproul, WU2Z
698 Magnolia Road
North Brunswick, NJ 08902
wu2z@amsat.org

Abstract

APRS, Automatic Position Reporting System, has been used to track many things. It has been used with DX Cluster for showing where the DX stations are located. It has been used to track cars, boats, bicycles, motorcycles, weather balloons, and hot air balloons. It has even been flown on the Energizer Bunny® Hot Air Balloon many times.

When tracking balloons, especially the high-altitude weather balloons, normal antennas work fine for the Packet/APRS/GPS signals. But when you are trying to receive ATV (Amateur Television) signals from the balloon, you need much better antennas. Usually, you need to have a high-gain antenna of some type pointed directly at the balloon.

APRS already knows where you are, and it knows where the other stations are. From this information, it is easy to calculate the angle(s) needed to point a directional antenna at the other station, when needed.

Uses of Rotor Control within APRS

Usually when people think of Rotor Control, they only think of either satellite tracking, or rotor control for DX Chasing. Although these are the primary uses, there are other situations where rotor control could be useful. The following table shows some possible uses of rotor control within the APRS system.

Satellite Tracking	Azimuth / Elevation
Balloon Tracking	Azimuth / Elevation
DX / HF operation	Azimuth only
Ground based vehicle tracking	Azimuth only

Background

APRS has been used for tracking high-altitude balloon projects for many years. MacAPRS/WinAPRS has features for predicting where the balloon will land even before the balloon is launched. This software also has display features for showing altitude. [i]

For normal APRS/GPS tracking operation with balloons, standard, omni-directional antennas do fine. The data is 1200 baud packet, and 1 – 5 watts on 2meters or 440Mhz is adequate. However, when you try to transmit Amateur Television, (ATV) signals, it is much harder to receive at great distances. Since the antenna on the balloon cannot be directional, you have to make up for it with good antennas on the ground. In the past, some groups have simply had a person manually pointing the antenna at the balloon. As long as the balloon is in view, this works fine. After that, it is just guessing. Also, this gets tiring very fast.

Computer controllable Rotor Controllers used to be complex and require special interfaces. They were also quite expensive. With the introduction of the TAPR **EasyTrak Rotor Controller,** [ii] this difficulty has been greatly reduced. This unit is also significantly less expensive than some of the other rotor controllers on the market. See the paper elsewhere in these proceedings about the details of this controller.

Software Design

If the world was flat, the calculations for tracking an object would be simple trigonometry. But since we have to deal with a round world, the math becomes more involved. In addition to having to do three-dimensional trig, we have to take into consideration the fact that the altitude reported by the GPS is the altitude above sea level at the current location of the balloon. The curvature of the earth has to be taken into consideration and subtracted out, otherwise, the antenna would be pointed too high.

The rotor itself has to be considered. Most rotors are north-centered. Depending on what you are doing, you may want a north-centered or south-centered rotor. When tracking balloons from a temporary location, you need to consider where you locate your ground station. If the rotor has to go through a 'FLIP', moving from one end of the rotation limit all the way around to the other, you will loose valuable time. During that time, the signal will be totally unusable because the antenna won't be pointing in the direction you need it to point.

Another thing to be concerned about is the fact that you don't want to constantly move the rotor, this could shorten the life of the rotor considerably. Therefore, you want to know the beam width of the antenna array, and move the antenna only when needed. Some rotor controllers already take this into account. The EasyTrack rotor controller has a setting to tell it the 'DEAD ZONE'. This is the number of degrees that the antenna has to be told to move before it will actually rotate the antenna.

Not all devices that you will want to track will be configured to send altitude. In this situation, the software realizes that the tracked device does not have altitude and does not tell the rotor controller to set the elevation angle. This allows the operator to manually adjust the elevation with the switches on the rotor controller, or manually from the software on the computer. The software will not try to point the antenna below the horizon.

The TAPR EasyTrak rotor controller uses a protocol called EasyComm. This is a simple ASCII text protocol for controlling all of the features of the rotor. This protocol is easier to use than the others and has more flexibility. It has also allowed the software to have a few more features.

Rotor Control and Status Window

WinAPRS/MacAPRS/X-APRS has a Rotor Control Window that allows you manually control the rotor and to display the current status of the rotor. This window can also be used for making sure the antenna system is working properly. The following commands are supported:

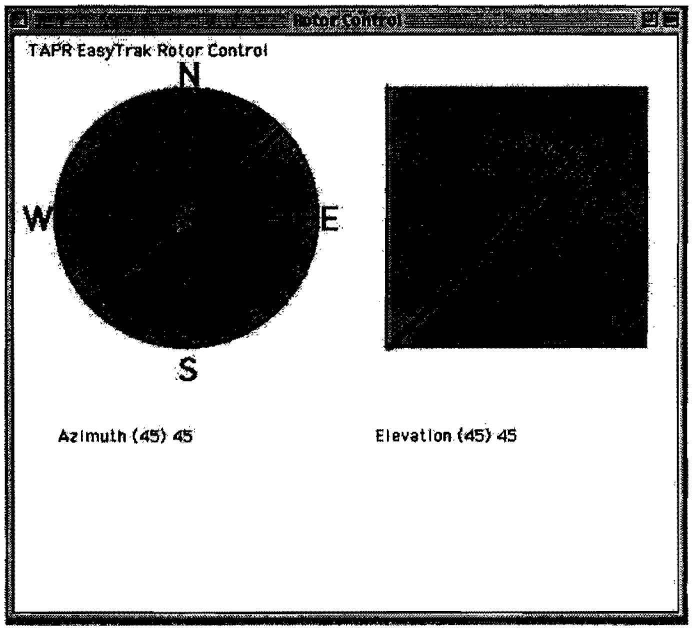
N	Set the Azimuth rotor to point North.
S	Set the Azimuth rotor to point South.
E	Set the Azimuth rotor to point East.
W	Set the Azimuth rotor to point West.
L	Rotate Azimuth rotor Left 5 degrees.
R	Rotate Azimuth rotor Right 5 degrees.
V	Set the Elevation rotor to point straight Vertical.
H	Set the Elevation rotor to point at the Horizon.
U or +	Raise Elevation Up 5 degrees.
D or -	Lower Elevation Down 5 degrees.
X or ^C	Sends a CANCEL command to the rotor.
? or /	Query the rotor controller and update the display.

The arrow keys do the same things as the 'L', 'R', 'U', and 'D' keys.

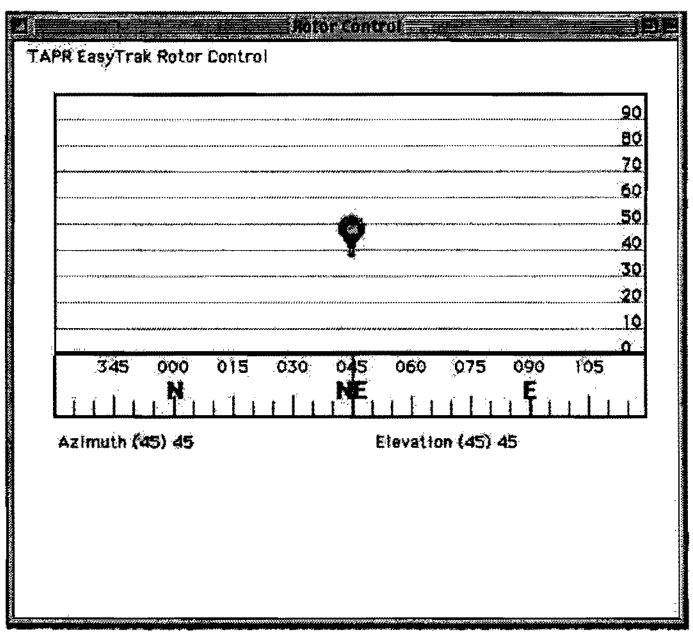
Numeric Keypad	The numeric keypad works as a control also.
5	Home (Azimuth 0, Elevation 0)
1-4, 6-9	Move the antenna in the appropriate direction, 1 degree at a time. In the direction as they appear on the numeric keypad.

There are two different configurations for the Rotor Control Window. The default window shows separate displays for azimuth and elevation. This is the used for normal manual control and display, this is also used when used for DX Cluster type applications. The other configuration shows an icon and elevation indicator. Below this display is a compass display showing which way the antenna is currently pointing. The above commands work in both configurations.

Rotor Control Window 1 (Normal Mode)



Rotor Control Window 2 (Balloon Track Mode)



DX Cluster Station Antenna Pointing

APRS has had the ability to understand DX Cluster data for a long time. Some people have used this feature, but it has not been a major aspect of APRS. Once rotor control ability was added to WinAPRS/MacAPRS/X-APRS, the ability to point to any station was extremely simple to add.

You can also go to any of the Station List windows, select a station there, and hit 'P', it will then POINT the rotor to that station. If the station you select does not have a valid position report, it will ignore the command. If the station has a position and altitude, it will rotate both the azimuth and elevation rotors. If the station does not have an altitude, it will simply rotate the azimuth rotor.

Note: You can make it point to any station or object in APRS, it does not have to be a DX station.

Automatic Weather Balloon Tracking

To use the Balloon Tracking feature of WinAPRS/MacAPRS/X-APRS, you need to perform the following steps:

(1) Select the station you want to track by opening up any of the Station Lists, then hi-light the station you want to track. (The TRACKED STATIONS LIST is recommended for this).

(2) Type the letter 'B' for BALLOON TRACK.

(3) Watch the rotor follow the 'balloon'

Note: The station you want to track does not have to be a balloon.

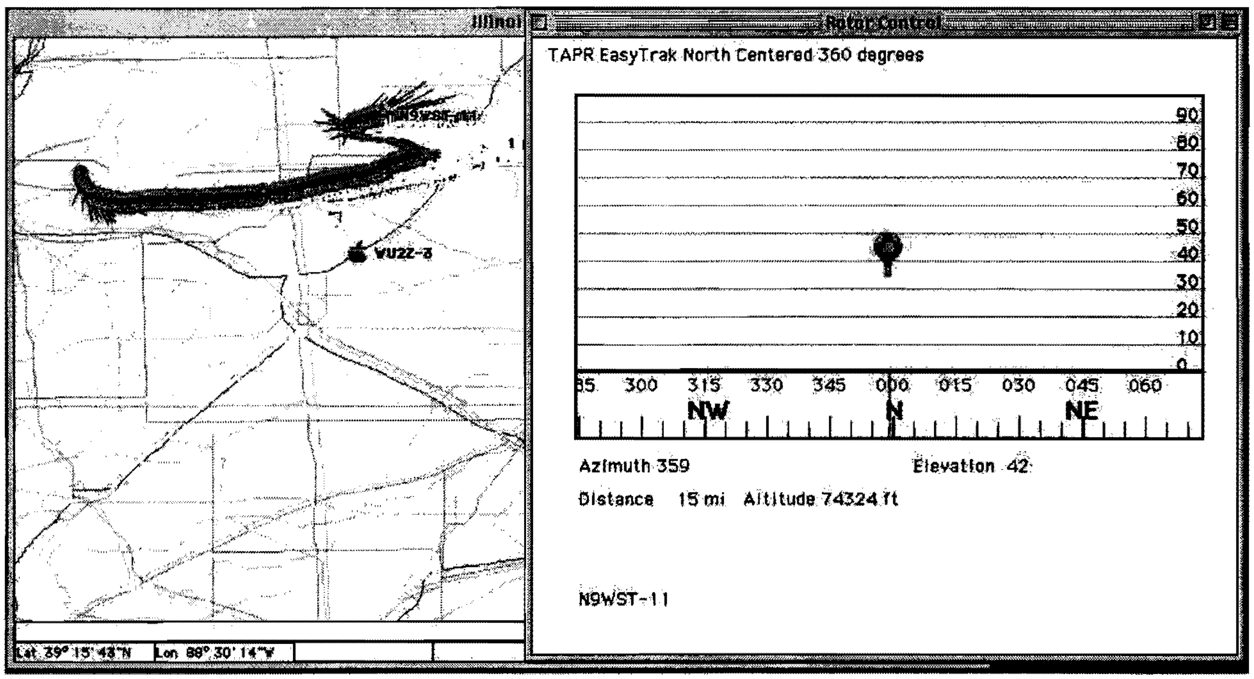
If the station is sending altitude, it will track azimuth and elevation. If the station is not sending altitude, the software will only track azimuth. If this is the case, you can manually control the elevation using the rotor control window described above.

Each time a valid position report or elevation report is received, the program will calculate the azimuth and elevation angles needed to keep the antenna pointed at the balloon, it will then send commands to the rotor controller to tell it where to point the antenna.

Automatic Weather Balloon Tracking Example

The map and rotor control windows below show a balloon in central Illinois. The track on the map shows the balloon track soon after its maximum altitude. The antenna is located at WU2Z-3 on the map. The rotor control window shows the azimuth and elevation angles that the antenna was pointed at the time the last packet was received.

Balloon Tracking Map



Ground Based Station Tracking

In most cases, if you are tracking a moving station, it is either close enough to be heard direct, or there are digipeaters so that you are able to receive the data even when the station is far away. If you are in an area that has few digipeaters, but want to be able to track a car or other moving station, for further distances, it would be nice if you could have a directional antenna automatically point at the moving station.

To make this work, for normal APRS type operation, you would need a vertically polarized 2 meter yaggi on a rotor. Then, you select the station that you want to track, just like you would if it were a balloon. WinAPRS/MacAPRS/X-APRS will then point the antenna at the last known position of that station. Since the yagi has more gain than the normal vertical antenna, you should be able to copy the signal at much greater distances than you could if you were just using an omni-directional antenna.

Unfortunately, this cannot counter the affects of terrain. For example, this cannot compensate for a car that disappears on the other side of a hill. This feature would be most useful in areas that are flat, or when tracking boats. Since there are very few digipeaters in the water, the tracking of boats is where this could be of greatest use.

If it were desirable to track many boats, or other moving stations, at one time using this mechanism, the capabilities could be easily expanded. It would be easy to develop the software where the system would point the antenna at one station, leave it there for a couple of minutes, or until it received a position report, then rotate the antenna to the next station, wait for a position report from that station, etc. The order in which it looked at the stations would be optimized based on the least amount of antenna movement and which station had the oldest position report. The logic and code for this feature has been developed, but it is not currently in the released versions because it is doubtful if anyone would truly use it. This feature has much more probability for use in the commercial market. If anyone really wants this feature in the Ham version of WinAPRS/MacAPRS/X-APRS, please contact the authors.

Ground Based Station Tracking Example

To show how Ground Based tracking works, we conducted an experiment. We set up two stationary receive stations and one mobile station. The mobile station was configured to not use any digipeaters, i.e. the path was not set.

Receive Station 1: Omni directional antenna, about 30 ' elevation.

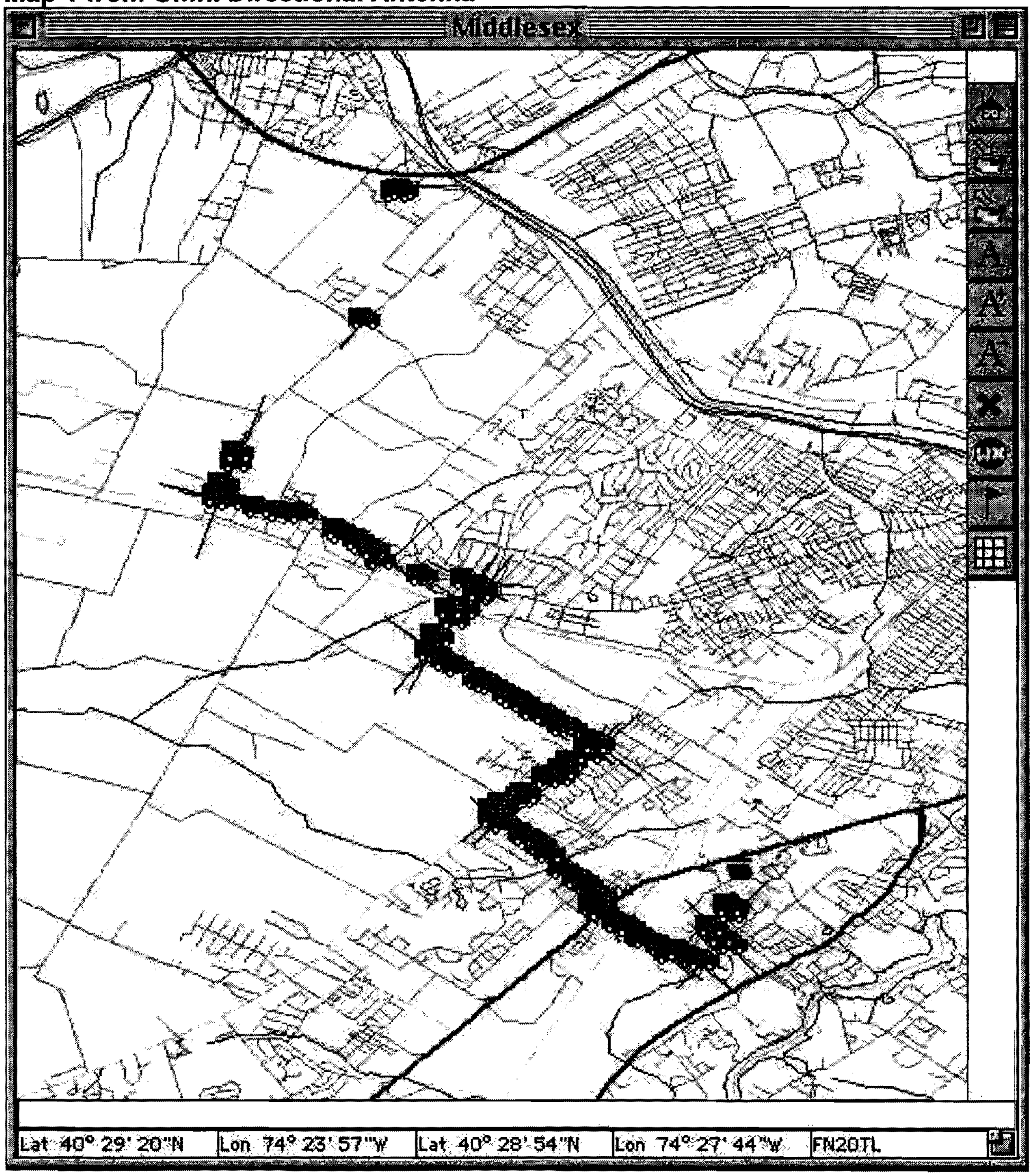
Receive Station 2: 5 element yagi, with rotor control, about 30' elevation..

Mobile Station: Omni directional antenna on my van with a Kenwood TM-D700 configured to transmit every 12 seconds, with medium power (25 watts).

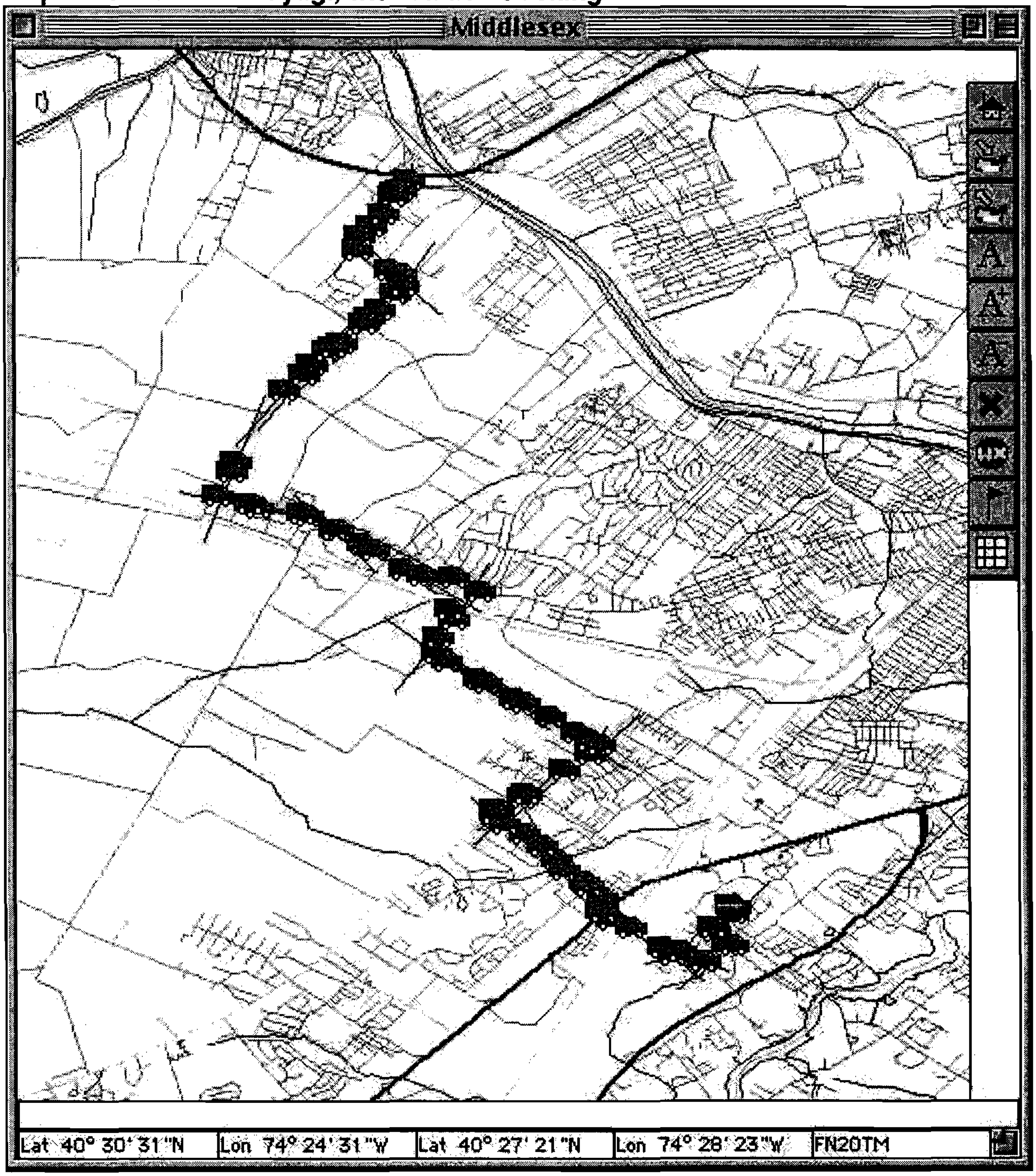
This experiment was not done on 144.390 to avoid collisions with other APRS packets. This also eliminated any possibility of digipeaters. The receive site is at the Apple Icon at the bottom right of the map. The track is from my house to a hotel about 7 miles away and back.

Below are the two maps showing the difference in received signals from the mobile station. Map 1 shows the position reports received on the Omni directional antenna and Map 2 shows the position reports received on the Yagi with station tracking.

Map 1 from Omni Directional Antenna



Map 2 from 5 element yagi, with station tracking



Camera Tracking

Recent events have made using this system accurate enough to keep a camera pointed at a moving object. Selective Availability has been turned off. This gives GPS an accuracy of about 30 feet. The altitude has also greatly improved.

If you have a GPS and a D7 radio and have it set to transmit your position at least once a minute or more, WinAPRS/MacAPRS/X-APRS could keep a camera pointed at you as you walk around in the area within the view camera. To make this work, the camera needs to be up high, and you have to have a fairly wide viewing angle since GPS still is not exact. When doing this, you need to get an extremely accurate position and altitude set for the camera location.

For this application, the accuracy of the Mic Encoder format is not good enough if you want to have the camera track you real close to the camera. The Mic Encoder format transmits accuracy of 1/100 of a minute. If you use a GPS data transmitter, i.e. a TNC set up to transmit the $GPGGA NMEA data, you can get much better accuracy. The Garmin III+ sends data to 1/1000 of a minute, or 10 times better than the Mic Encoder format.

The good news is that the Kenwood D7 will do this also, but you have to configure it from a computer and it doesn't remember these settings if you turn the radio off or change the TNC mode. The Palm Pilot works very good for configuring the D7 while out walking around.

The settings in the D7 needed to do this are:

GPSTEXT $GPGGA	GPGGA includes lat, lon and altitude all in one line
LOC E 3	Send the location every 30 seconds

The accuracy transmitted will now be the same as the accuracy that your GPS reports. All GPS units transmit at least 2 digits, the Garmin GPS III+ transmits 3 and I have seen a couple GPS units that actually transmit 4 digits of accuracy.

Comments

In all of the different uses of this system, it is extremely important to have the rotor system calibrated accurately, and to make sure that it is pointed at TRUE NORTH, and not Magnetic North. In New Jersey, the difference between true north and magnetic north is about 12 degrees. This can make a big difference in the accuracy of the system.

The original implementation uses the TAPR EasyTrak Rotor Controller, but the capability is being expanded to include other rotor controllers as needed.

Currently, we support:

TAPR EasyTrak	
Endeaver AutoTrack	
Heathkit Intellirotor	Azimuth rotor only

We are working on supporting the following:

EA4TX Automatic Rotor System (ARS), From Europe (Windows Only)	
Yaesu GS-232	
Hygain/MFJ DCU	
Kachina 505AR	Azimuth rotor only

The Heathkit Intellirotor works fine for DX type operations, but due to the nature of how it operates, it is not well suited to track moving objects in real time.

Future

We are working on a rotatable antenna system on a car. The software could use the GPS data to know where you are and which way your car is headed. It would then adjust the antenna accordingly while driving. This would be most useful for chasing balloons. This is being worked on, but we need to get a useable antenna system designed before testing can start.

Garmin's eTrax Summit GPS is a GPS with pressure based altitude sensor and a flux gate compass built-in. Garmin just introduced an upgrade to this unit that includes compass headings in the NMEA data stream. This gives us an easy way to get HEADING information instead of BEARING information. This is important because the

BEARING is only accurate if you are moving. This makes the tracking from a car much easier, especially if you want to go to someplace and park, then do your tracking while stopped in the car.

For things like the camera tracker and tracking while moving in a car, it would be nice to have a much faster rotor, but currently, there are none available commercially.

Now that WinAPRS/MacAPRS/X-APRS can point an antenna, satellite tracking would be a next logical step.

Conclusion

This new addition to WinAPRS/MacAPRS/X-APRS has a lot of potential, for both the balloon chaser, and the DX person. In addition, the simple tracking of a ground base station can greatly improve the communications with stations at greater distances, especially in areas with little or no digipeaters.

As APRS continues to develop, people will find more and more interesting things to do with it.

Web Sites of Interest

http://aprs.rutgers.edu/

http://www.tapr.org/

http://www.kenwoodusa.com/

http://www.yaesu.com/

http://www.garmin.com/

http://dorm.rutgers.edu/balloons/

http://dorm.rutgers.edu/~ksproul/pantilt.html

ftp://ftp.amsat.org/amsat/software/win32/wisp/easycomm.txt

[i] ***Graphical Information Systems and Ham Radio,*** Keith Sproul, WU2Z, ARRL 14th Digital Communications Conference, Arlington, Texas, September 8-10th, 1995, pp 108-118.

[ii] ***EasyTrak, A PIC Based Rotor Control Inerface,*** Steven Bible, N7HPR, ARRL 19th Digital Communications Conference, Orlando, Florida, September 22-24th, 2000.

Applications of PIC Microcontrollers to Digital Amateur Satellite Communications

By John A. Hansen, W2FS

Abstract: This paper discusses a on-going work toward the development of inexpensive hardware that can be used for accessing digital satellites at speeds of 9600 bps and up.

Keywords: PIC Microcontroller, WiSP, KISS, Digital Satellite

Introduction

Consider for a moment the near term needs of those who wish to utilize amateur satellites for digital communications. The dominant mode in digital satellite work today is 9600 bps FM. It is utilized on a daily basis by several satellites (including KO-25 and TO-31) and is also a standard mode for a number of new satellites (including P3D). The typical groundstation active on this mode consists of a 9600 bps commercially made TNC, a multimode, multiband radio, and a set of directional antennas with the associated rotators. Most often the station will be equipped with a PC running Chris Jackson's WiSP groundstation program. In the near term, assuming the successful launch of P3D, digital satellite communication at 9600 bps is likely to become even more popular. In addition, higher speeds (notably 38,400 bps with UO-36) are coming on line. Yet the cost of higher speed packet radio equipment has remained relatively high.

Two different paths are available to bring down the cost of digital satellite communications. First, as Phil Karn noted at least as early as 1996, there is plenty of horsepower in today's PC's to handle this sort of processing.[1] However, we are currently not using soundcards and PC's to work the digital satellites because of a protocol conflict. Virtually every digital groundstation program (from PB/PG to WiSP) assumes that a KISS mode TNC will be connected to one of the computer's serial ports. In the context of the history of the development of these programs there was a good reason for this. KISS is a protocol developed by Mike Chepponis and Phil Karn in the 1980s. It is fairly easy to write software for this protocol because some of the more difficult functions (such as bit-stuffing and CRC checking) continue to be performed in the TNC, while the rest of the intelligence is moved to the host computer. KISS mode has been implemented in virtually every modern commercial TNC. Furthermore, once you get a TNC into KISS mode, all TNCs perform exactly the same way, and there are few settings to worry about. Finally, in KISS mode, a binary data steam is as easy to deal with as text.

However, the only 9600 bps TNC software that utilizes a PC soundcard on a Windows platform that is available at this writing is Flexnet. Flexnet specifically eschews the KISS protocol in favor of an alternative scheme called "6Pack". While 6Pack may well be a step above KISS, we are nevertheless left with a situation where the sound card software doesn't support KISS or WiSP and the satellite groundstation programs don't support anything except a KISS TNC connected to a serial port. I assume that this problem will eventually be solved, either by the development of alternative

[1] see http://www.tapr.org/tapr/html/conff.html go to the 1996 TAPR Hamvention Forum and select "A High-Performance Satellite Modem for the PC"

groundstation software specifically written for PC soundcards or by the revision of WiSP to support Flexnet. However it is worth noting that this protocol conflict has existed for at least a couple of years, and no one has yet promulgated a good solution to it.

Even given the existence of cheap sound cards there may be reasons to consider alternative hardware solutions to the problem of developing higher speed FSK modems. Dedicated hardware TNC's offer the flexibility of being independent of the computer platform or operating system used by the groundstation. They put minimal demands on the groundstation's computer. And, most significantly, it will soon be possible to create a suitable KISS TNC for use with programs like WiSP or PB/PG for *very* little money.

Small, cheap, microcontrollers from companies like Microchip, Atmel, and Scenix are in the process of revolutionizing amateur radio. It is virtually impossible to pick up any amateur radio or electronics magazine these days without finding at least one construction project that features the use of these microcontrollers. It is time for the amateur satellite community to begin to think about how microcontrollers can reduce the size and cost of satellite groundstations, and perhaps satellites themselves.[2]

A 1200 BPS KISS TNC

For the past year I've been taking a somewhat leisurely stroll down the road toward creating a cheap 9600 bps KISS TNC. I've not arrived at end of this path, but this paper describes the progress to date. My point here is to explain what I have learned in hopes that others who wish to pursue the same objective might be able to do so at an expedited pace.

I began with an intermediate goal of creating a KISS TNC that would operate at 1200 bps. I started with 1200 bps because it was something that I understood a good deal better than I did 9600 bps and I had previously had some experience in working with 1200 bps modem chips. This project is described in detail in a recent issue of *QST*.[3] The most significant thing about this project is that it is cheap. Requiring only four ICs that cost a total of about $20, it's a pretty simple project by TNC standards. The simplicity is achieved because most of the real work is done by a single PIC 16F877 microcontroller chip.

I selected this chip for a number of reasons. First, I had previously had a fair amount of experience with Microchip's "flash" PIC chips, which can be erased and reprogrammed without the use of a time-consuming UV eraser. Second, I wanted to use a chip that had an on board USART.[4] The biggest problem to be confronted in designing a PIC TNC is not getting the chip to send and receive AX.25 frames. Rather, the most difficult part is getting the chip to do several things more or less at the same time. A

[2] An introduction to the use of PIC Microcontrollers in amateur radio applications can be found in Hansen, John A. Hansen, "Using PIC Microcontrollers in Amateur Radio Projects." *QST*, October, 1998.
[3] Hansen, John A., "An Inexpensive KISS Mode TNC." *QST*. November, 2000.
[4] Universal Synchronous Asynchronous Receiver Transmitter

TNC must simultaneously be in communication both with a radio and with a computer or terminal. It watches the radio link to look for incoming data at the same time that it must watch the computer link to see if there is any data that it has to transmit. Thus, the TNC may have to simultaneously 1) receive data on the radio link, 2) forward received data over the serial link to the PC, and 3) accumulate outgoing data over the serial link from the PC that it later needs to transmit.

There are two ways for a microcontroller chip to handle the serial communication with the PC. On the one hand, the higher end PIC chips have a USART. A USART is simply a device that handles the timing of the serial communication. If you have a USART and you wish to transmit a byte of data over the serial link, you can simply write the byte that needs to be transmitted to a register in the microcontroller and then not worry about how the bits are actually sent. If the microcontroller you are using lacks a USART, of course, you could use a dedicated USART that is external to the microcontroller, but this defeats the goal of keeping down the number of chips (and hence the size, complexity and cost of the project). As a result, usually when designers require that serial communications be done with the lower end microcontrollers (as for example, with the ubiquitous PIC16F84), they have the microcontroller itself time the bits that are sent or received (a process known as bit-banging). It was my view that it would be very difficult to design a KISS TNC that had so many things going on at once if the PIC chip was responsible for all of these timing functions. Thus I wanted to make sure I selected a PIC that had a USART.

In addition, there was the issue of data storage. While PIC microcontrollers have some on board data storage, none of them have enough to create a KISS TNC. The PIC16F877, for example, has 368 bytes of storage. The reason that storage is an issue is that in order to receive a packet frame, you must accumulate the entire frame in memory, and then perform an error checking calculation to determine whether the data have been received properly before the data are sent on to the PC. While you are transmitting this frame to the PC, you need to have enough storage so that you can be accumulating the next received frame from the radio and at the same time be accumulating any data from the PC that needs to be transmitted. Some terrestrial packet applications (notably TCP/IP) use packet frames that are as long as 1K bytes. Thus, some sort of off chip storage will be required.

However, the transmitting function storage requirements may be even greater. My 1200 bps KISS TNC is a half duplex device. The reason that I designed it this way is that most end users of terrestrial packet (for, say, APRS) are only interested in half duplex communication and the modem chip that I selected (an MX-COM MX614) is a half duplex chip. Making the device into a full duplex TNC would require a second modem chip. However, having a half duplex device required even more storage capacity. KISS mode provides no means of flow control. That is, you have to expect that data will be streaming in continuously from the PC over the serial link and there is no way to tell it to stop. However, since the radio channel can only be used to transmit data when the channel is not busy, it is possible that there might be a significant backlog of data to be transmitted over the radio channel which will have to be stored in the TNC.

This led to my decision to use a 32K static RAM in the 1200 bps KISS TNC. However, static RAM chips require separate lines for each data bit that is stored and for each address bit that is used to tell the RAM where to store the data. That added a great deal to the complexity of the project and required that I use a PIC with a lot of input/output lines.

Additional Considerations for 9600 BPS TNC Design

Designing a full duplex 9600 bps TNC dedicated to digital satellite use, however, will present a somewhat different set of challenges. Considerably less data storage space will be required. It will still be necessary to receive an entire frame before performing the error checking to see whether it should be sent on to the PC, but it will probably no longer be necessary to worry about frames that are longer than 256 bytes, because longer frames are not used on the PacSats. Most importantly, the need for transmit data buffering will be significantly reduced because in a full duplex system the transmit channel should never be busy. Thus, you may be able to get by with as little as 2k to 8k of storage space. Assuming this to be the case, it may be useful to abandon the static RAM approach in favor of a FRAM device from the Ramtron company.[5] Ramtron makes nonvolatile RAM devices that can be accessed via synchronous serial communication using only three I/O lines. These devices are much smaller than a static RAM yet still quite cheap (less than $3). They have significantly larger capacities than serial SRAMs and don't have a significant restriction on the number of read/write cycles as do EEPROMs. In addition to being physically smaller than static RAMs, they also will make it feasible to use a smaller PIC because it will be possible to dispense with the large number of I/O lines needed to access the static RAM.

This is a good thing too, because it appears to me as if two PIC's will be required for this project, one for transmit and one for receive. Having a full duplex TNC complicates the problem of there being many activities going on at once, since it will now be necessary to transmit data over the radio link at the same time that data is being received over the radio link. At the same time data may well also be flowing in both directions over the serial link to the PC. Handling full duplex communication over the serial link to the PC isn't all that difficult if a USART is available. You just have to make sure that every now and then a byte is read from or written to the USART. But the data that comes and goes over the serial link must be bit-banged, since a USART is not available that will perform the timing functions necessary to the NRZI (non return to zero inverted) encoding scheme used by packet radio. Thus to do a full duplex TNC in one PIC would require that you time incoming bits from the radio while simultaneously timing outgoing bits to the radio while at the same time servicing the USART for incoming and outgoing bytes over the serial link. It may be possible to do this in a single PIC, but I'm not at all confident of my ability to figure it out, so I'm inclined to use a pair of PICs, one for transmit and one for receive.

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[5] www.ramtron.com

This leads to the selection of a modem chip. A couple of years ago I was looking for a modem chip to use in an APRS tracker (which later became the TAPR PIC-E) and I stumbled upon the MX-COM MX614. It worked well in a number of applications and was relatively inexpensive. It's only drawback was that it was not readily available in small quantities from any supplier.[6] MX-COM also makes a higher speed modem chip called the MX589. This chip appears to have been used in the GMSK Vfast28.8 modem and I have heard (though not personally confirmed) that it is also used in the Kantronics KPC 9612. The chip is actually capable of significantly higher speeds than 9600 bps and a single clock frequency of 4.9152 MHz could produce data rates of both 9600 and 38,400 bps using somewhat different resistor and capacitor values. I have obtained a sample of this chip, but as yet have not had time to play with it.

Development of the PIC firmware for this TNC is a fairly straightforward extension of the 1200 bps firmware. Fortunately, the fact that one only needs to implement KISS mode in order to work with any of the extant groundstation programs makes the task much easier. Much of the complexity of the AX.25 protocol can be ignored because it is handled in the groundstation software itself, not in the TNC. The TNC itself will have to take care of bit-stuffing, the frame check sequence (FCS) calculation[7], and the KISS byte substitution of FEND and FESC characters, however.

Additional References for Developers

A fair amount has been written that will assist developers in writing AX.25 code for PIC chips. It is no longer necessary to begin with the ARRL's AX.25 protocol document itself and then attempt to apply it to programming the microcontroller. The easiest way to begin is probably to rely on the transmit and receive functions that have been published for AX.25 UI frames and then proceed from there to learning to do KISS encoding. For a discussion of how to transmit AX.25 frames using a PIC chip see:

> Hansen, John A., "PIC-et Radio: How to Send AX.25 UI Frames Using Inexpensive PIC Microprocessors" in *17th ARRL and TAPR Digital Communications Conference* (Newington, CT: ARRL, 1998) p. 29. Also available as DCC.ZIP at ftp.tapr.org/pub/wa0ptv.

For the details of the receiving side see:

> Hansen, John A., "PIC-et Radio II: How to Receive AX.25 UI Frames Using Inexpensive PIC Microcontrollers" in *19th ARRL and TAPR Digital Communications Conference* (Newington, CT: ARRL, 2000). Also available as DCC2.ZIP at ftp.tapr.org/pub/wa0ptv.

For information on the technical details of the implementation of the KISS protocol see:

[6] This problem has since been solved as TAPR now sells the devices in single quantities for $6.
[7] This calculation is very similar to one that is better know as a "cyclic redundancy check" (CRC). For details see: Morse, Greg "Calculating CRCs by Bits and Bytes" (*Byte*, Sept 1986, pp. 115-124).

Chepponis, Mike and Karn, Phil, "The KISS TNC: A Simple Host-to-TNC Communications Protocol." ftp://ftp.tapr.org/general/kiss.txt

A key distinction between the 1200 bps encoding and higher speed encoding is that the higher speeds require the addition of a "data scrambler", which is designed to ensure frequent transitions between 1's and 0's to allow the timing information to be recovered more easily.[8] This does not require the addition of any more ICs, but can be relatively easily implemented in the PIC code itself. For details on how scrambling is done see:

Heatherington D.A. "A 56 Kilobaud RF Modem", *Proceedings of the Sixth ARRL Amateur Radio Computer Networking Conference*,(Newington, CT: ARRL, 1987) pp. 65-75.

Conclusion

Following along the path outlined above, it should be possible to create a full duplex 9600 bps TNC for satellite applications for under $50. With relatively minimal changes, it may be possible to get it to run at 38,400 bps as well. Remember that we are not discussing a modem here, but a complete TNC (though one that operates in KISS mode only).

[8] The theory behind this can be found in McDermott, Tom, *Wireless Digital Communications: Design and Theory* (Tucson: TAPR, 1996)

Distributed system for LEO satellite control station

Eduardo Jacob Taquet (EA2BAJ), Álvaro Gago Mayoral
ea2baj@amsat.org, jtagamaa@bipt106.bi.ehu.es
Dpto. de Electrónica y Telecomunicaciones. E.T.S.I.I.T
Phone: (34)946014214;Fax: (34)946014259
Alda Urquijo s/n
48013-Bilbao (SPAIN)

Objectives

The projects aims at the development and implementation of a distributed satellite control station system using Internet so that the different stations are provided with a simple and powerful communication method which improves the management of LEO satellites. Among the different functionalities of the system one of its main features will be the reception of any important information from a satellite and the capability of forwarding it to the rest of the stations if needed.

The system has been designed to be flexible enough to allow member stations to dynamically leave or enter it whenever it is required without causing any damage in the integrity or modification in the service for the rest of the control stations, i.e., the mechanisms for joining or abandoning the system will be accomplished in a transparent way.

A ground station network can offer several advantages:

Redundancy: In a single station system when something fails, the entire system goes off the air, but when multiple stations are involved, the consequence of any error in an station could be reduced with the help of the rest of the stations.

Link Efficiency improvement: There are a lot of LEO satellites that include an store and forward system and, in many cases, users from geographically distant stations could download the same data. By distributing the pieces of information through a different media, the Internet, the requests for the same data from the spacecraft will not be made over and over again.

Multiple access When there are several ground stations available with various satellites of interest in view, it is possible to access to multiple satellite at the same time by using the dissemination of received data in each single satellite control station.

Design

As you may know, Linux is an operating system that has experienced a great development during the last years, not only in professional or commercial environments but also in domestic ones. This growing popularity has been due partly to some features derived from its close relationship with UNIX systems, examples of these are its unbeatable conditions in protocol implementation and its reliability in running processes, but also as a result of the development of certain tools aimed at making the system more "friendly", namely KDE and GNOME desktop environments, helping this way to its expansion in the domestic market. Besides, we can observe that there are an increasing number of applications designed to operate in this operating system, moreover some of them closely related with the development of radio-amateur space programmes, such as microsat, predict, sattrack, pb-pg.... So bearing all these characteristics on mind we found quite easy to choose the most suitable operating system for the development and implementation of the project. Our election was undoubtedly Linux.

The architecture required to implement the project forced us to use a distributed system in which none of the stations could be considered as the master or leading one. All the stations in the system must possess the same priority and in any moment could change its behavior from that of a client, receiving packets and information sent by another satellite control station, to act as a server, sending information to the rest of the active stations.

The use of a typical unicast communication between all the stations was considered as the first possibility to intercommunicate all the members in the system but was found too inefficient and too complicated. This solution implies that the server that wants to communicate with the system must send the information to each one of the members individually, consequently this task becomes very tedious and lacks speed. We thought that the real solution to the problem could arrive from using a more efficient protocol: IP multicasting in which sending the information once to the network would be enough to achieve our goals of intercommunication.

IP multicasting network topology is mostly based on IP tunnels over IP joining different networks that are part of Mbone network. So, as we can see, one of the requirements of the system will be that the LEO satellite control stations must be part of the Mbone, that is to say, the local network or the ISP, depending on which type of Internet access the station enjoys, must offer connectivity to this multicasting network.

Another of the problems we had to face came as a result of the heterogeneous and different connectivity access that the satellite control stations have (via local network, via ISDN, via satellite..) and their different locations. The information must cross a number of different networks each with different conditions and packet losses could become frequent using a non-reliable protocol as UDP, something that is totally unacceptable. The use of this transport layer protocol comes as a consequence of the use of IP multicasting and, thus, it is not an election but an imposition.

To avoid these packet losses and solve the problem mentioned above, it is necessary to rely on the implementation of yet another protocol, this protocol will operate over the transport layer being in charge of the reliable transmission and receipt of packets. The protocol will be part of the family of RMP (Reliable Multicast protocols) protocols which are used to develop a totally trustworthy end-to-end communication among all of the members in the network trying to overcome the lack of efficiency UDP shows in transmission through WANs.

Some of the requirements that the chosen protocol must fulfill to make it suitable are listed below: good characteristics in file transmission across a different range of network architecture and heterogeneous conditions, efficiency in communication among a sender and a lot of receivers, possibility of using control messages, totally configurable transmission parameters. Of course, a software toolkit supporting Linux is good addition indeed. MDP (Multicast Dissemination Protocol) can fit these features and is proposed as the protocol to be implemented over the transport layer.

This architecture can face severe security problems for any machine with the proper configuration could introduce some hostile or ill-intentioned data causing several problems in the system. To avoid this type of behavior, a very simplistic system using authentication of the server at the moment any information is sent has been developed. This authentication is based on possessing a key word or password that any "authorized" station must know. To implement this, we use the VTUN package that can create secure tunnels between two machines, the server and any client that asks for an authentication in our case.

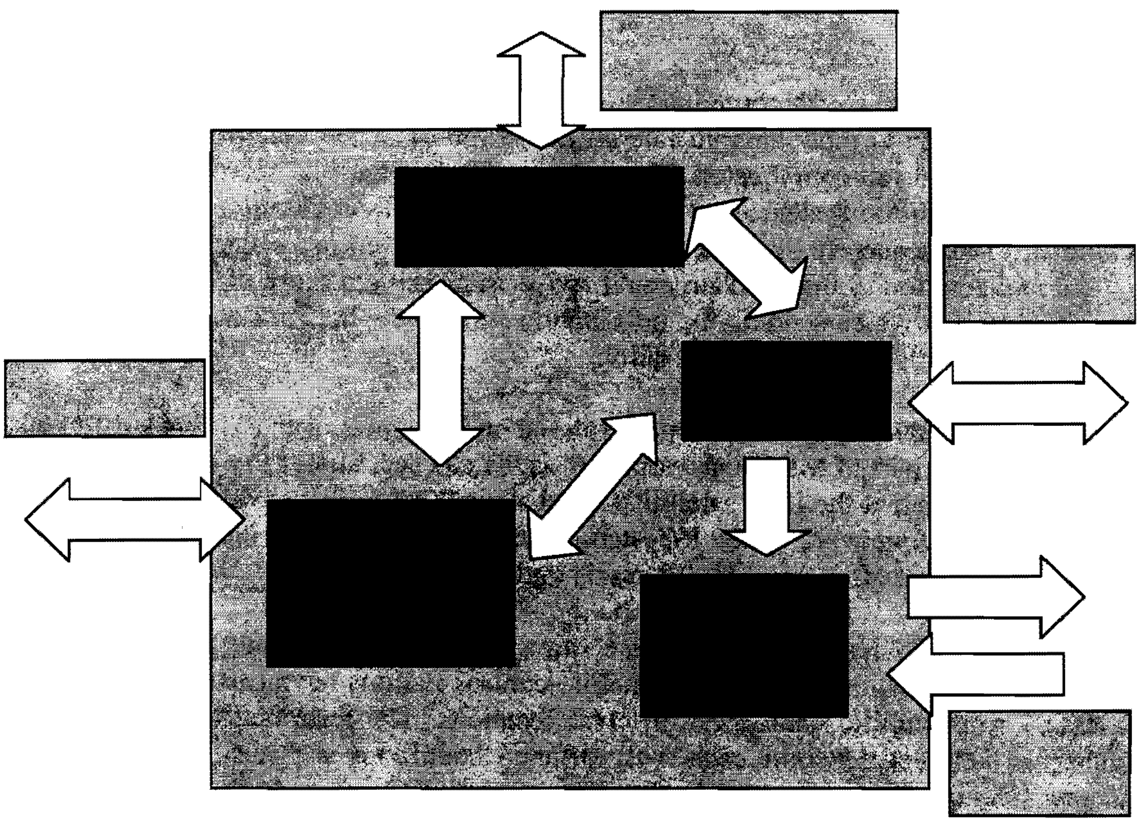

Figure 1. Different functional modules developed for the project

Implementation

Our implementation has taken the microsat suite as starting point. This set of programs manages the satellite link, both the uplink and the downlink, offering a group of extra functionalities such as presentation of telemetry data and downloaded messages.

The source code of the microsat suite is implemented in C, so it seemed reasonable to write the rest of the modules of the project with this language in order to reduce the possible incompatibilities that could arise if mixed with other language. But, as we will be able to realize later, and as file processing is also be very important in the project, we have written several parts of the code helped by shell scripts.

The main application will be, as in the case of microsat suite, the xpb which manages and controls the downlink. This application can handle one communication link at a time, so the first thing to do was to provide the application with the capabilities to manage several communication links.

We think that it is possible to suit all the proposed requirements for the project with just three processes. The first one would be the one who manages the satellite link and controls the graphical user interface, the original xpb application. The second process is responsible for receiving and sending files from the Internet link, that is, it will receive IP multicast packets in case the satellite control station takes the "role" of client and it will send this type of packets if working as a server. This process also implements all the capabilities MDP offers like reliability in the communication, management of control and state messages etc.

The third and last process treats all the received and sent files depending on whether it is behaving as a client or server. If acting as a server, this process creates an extra information file containing some data about the features and characteristics of the file to be disseminated. For example, the IP address of the server, the time when the file has been downloaded from the satellite, which satellite the information comes from... This file could contain any information available in the satellite control station and could be appended with any information which may be considered important for the management of the system. When acting as a client, this process tries to process all the information received from the server, especially the file which contains these "extra" features.

As we can see, this last process will handle a lot of information contained in a single file, either for the server or for the client. At this point, and owing to improvements in execution time and easiness of programming it has been decided to use shell scripts to implement parts of this process.

The communication between these three processes has been made by means of the typical IPCs, used so much in UNIX environments. Mainly, it has been done with signals (determining and defining some user routines for SIGUSR1 and SIGUSR2) and with pipes to communicate the main process which controls the satellite link and the process which handles the files received from the Mbone and the ones that are going to be sent.

The security features have been introduced in the code of this third process due to the fact that we can know exactly how and when to connect to the server in order to authenticate it processing the proper information.

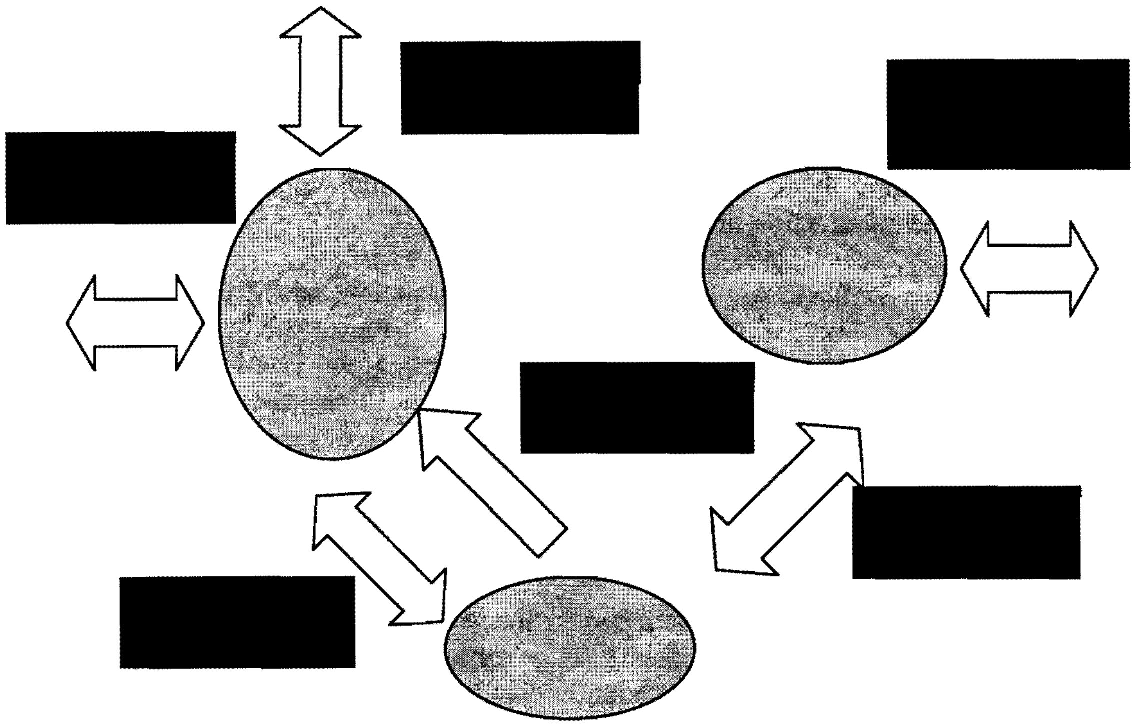

Figure 2. Processes in the main application and type of communication between them.

Finally we can show the original xpb and the modified xpb

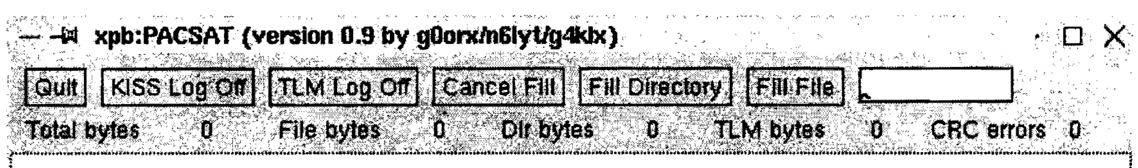

Figure 3. Original xpb.

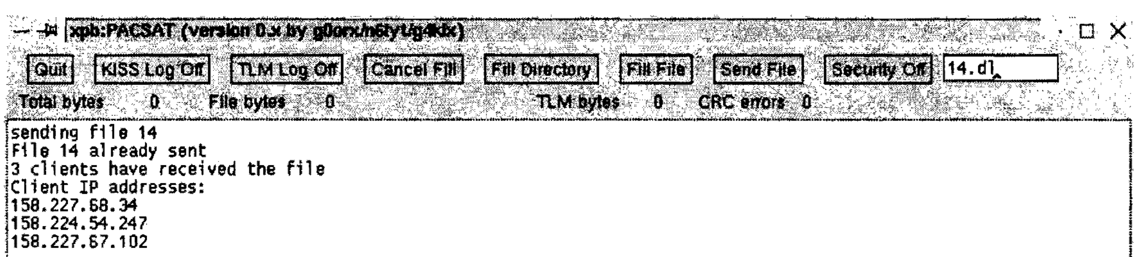

Figure 4. Modified xpb acting as server

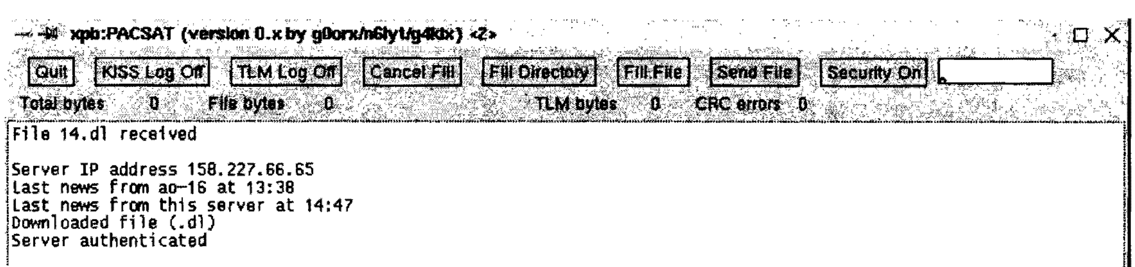

Figure 5. Modified xpb acting as client

At this moment, we only offer two additional buttons, one for manually diffusing a file (thus becoming the server) and another one to activate the security features. The modified xpb, also gives some information about it's activity in the main window. We expect to have some statistical information in an additional window.

Work in progress

This project is obviously an unfinished work. There are several things we would like to investigate, i.e. diffusing smaller than files information pieces (AX.25 frames?). We also would like to broaden the usability of system for transmitting for uploading. We would like to get a system in which every client in the system could send a request to the satellite and the system itself should be able to route the request to the current or next station to be under the footprint. The security model needs to be redesigned in order to improve the process of authentication and to be able to extend its architecture to new applications that happen to be developed in the near future. Sadly this work is not on the top of priorities of our team, so we don't know which will be it's future. We intend at some point to put the result of the work freely available in the ETSII e IT's radioclub (Ingeniaritza Irratizaleen Elkartea) Website at http://iie.bi.ehu.es.

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MDP information: http://manimac.itd.nrl.navy.mil/MDP/
Amsat Microsat Protocols: http://www.amsat.org/amsat/sats/nk6k/msatpro.html

The new G3RUH software modem for the DSP56002EVM

Borja Etxebarria, Itziar Martínez, Txema Rúa, Inma Hernáez
Escuela Técnica Superior de Ingenieros Industriales y de Telecomunicaciones de Bilbao (Spain)
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Abstract

This paper presents the new design of the G3RUH software modem. This is a two level PAM modem that works at range of bit rates from 9600bps to 38400bps and admits different rates at transmission and reception. The major improvement of this new version is the synchronism algorithm and the structure of the reception filter. It provides a better performance of the modem. The software is aimed for the DSP56002EVM from Motorola as this is one of the most extended platforms in the ham radio.

1. Introduction

In 1999 our research group developed a software G3RUH modem for the DSP56002EVM compatible with the hardware G3RUH [1] at the rates of 9600, 19200, 28800 or 38400bps based on the software version of the 9600bps modem developed by Jarkko Vuori [2]. Our version permitted the selection of different rates in transmission and reception, but presented some problems when running at 38400bps mainly due to lost of synchronism.

The new version presented in this paper gets a better performance by consequence of the new synchronism algorithm and the polyphase structure of the reception filter.

2. Functional structure

The structure of this modem, which is shown in Figure 1, matches with the general one of a base-band modem.

The modulator consists of the first two blocks: the scrambler and the transmission filter. The next block represents the channel, which is supposed to be flat and noise additive. The rest of the blocks develop demodulation, by means of the reception filter, the AGC, the threshold detector, the synchronism recovery subsystem, the unscrambler and the DCD.

In the following sections the implementation of each block is described, with emphasis on the transmission and reception filters and the synchronism details.

3. Scrambler - Unscrambler

The scrambler aleatorizes the data to be sent providing a flatter spectrum in transmission. It also makes the synchronism process easier and reduces the DC component. The unscrambler restores the original data from the received data.

Scrambler and unscrambler are self-synchronizing and employ the same polynomial as the hardware version to provide compatibility [1].

4. AGC

The Automatic Gain Control attempts to maintain a constant signal level before decision. As the codec gain of the DSP56002EVM cannot be changed while running, this block acts on the sampled signal.

The algorithm searches for the biggest value of the signal within a group of samples and adjusts the gain value in accordance.

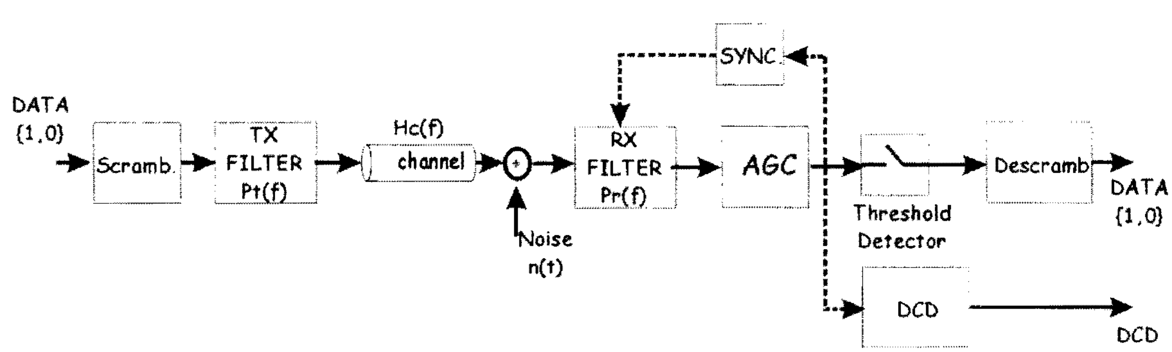

Figure 1. Functional structure of the G3RUH modem

5. DCD

The Data Carrier Detect block validates the received data. It uses the Eye's Aperture to decide if there is any incoming data. When the Eye's Aperture is bigger than a certain threshold, the received data is valid [2].

6. Tx and Rx Filters

The filters were designed considering the Nyquist criterion to minimize the effect of ISI and the matched filter criterion to maximize the received SNR. The result is a set of two square root raised cosine filters, one for transmission and another one for reception. The selected roll-off factor is the same as the first software version of [2].

The bandwidth of the raised cosine filters depends on the selected bit rate and the roll-off factor. Table 1 shows the necessary bandwidth at each rate.

BIT RATE	ROLL-OFF FACTOR	SIGNAL BANDWIDTH
9K6	0.3	6,440 Hz
19K2	0.3	12,480 Hz
28K8	0.3	18,720 Hz
38K4	0.3	24,960 Hz
38K4	0.2	23,040 Hz

Table 1. Necessary bandwidth as a function of the bit rate and roll-off factor.

The codec of the DSP56002EVM has a maximum sample rate of 48,000 samples/s, so the maximum bandwidth of the analog input signal is 24,000 Hz. Table 1 shows that at a bit rate of 38,400bps, with a roll-off factor of 0.3, the necessary bandwidth (24,960Hz) is greater than the available bandwidth (24,000Hz). To solve this problem, the roll-off factor is reduced to 0.2.

This change of the roll-off value will produce a reduction on the performance of the modem when working against a hardware version.

6.1. Transmission filter

The transmission filter is designed using a polyphase structure due to its multirate character.

The codec will be working at 48,000 samples per second, so the output of the filter should provide that rate of samples to the codec at all the modem rates. To achieve this, the structure shown in Figure 2 is used.

The system performs zero padding, filtering and decimation. The zero padding process, increases the working rate of the filter, leading to the figures shown in Table 2. The decimator converts the filter sample rate to the 48,000 samples per second required by the codec. Some samples will be thus ignored, and will not be calculated. This process is known as multirate filtering [3] [4].

BIT RATE	FILTER SAMPLE RATE	DECIMATION FACTOR	POLYPHASE SEQUENCE
9K6	48,000	1	0 1 2 3 4
19K2	96,000	2	0 2 4 1 3
28K8	144,000	3	0 3 1 4 2
38K4	192,000	4	0 4 3 2 1

Table 2. Characteristics of the transmission filter.

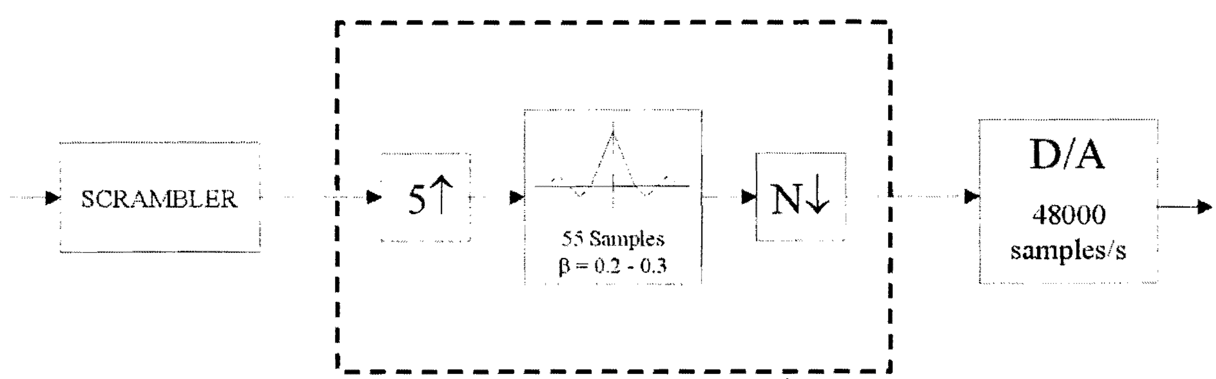

Figure 2. Structure of the transmission filter.

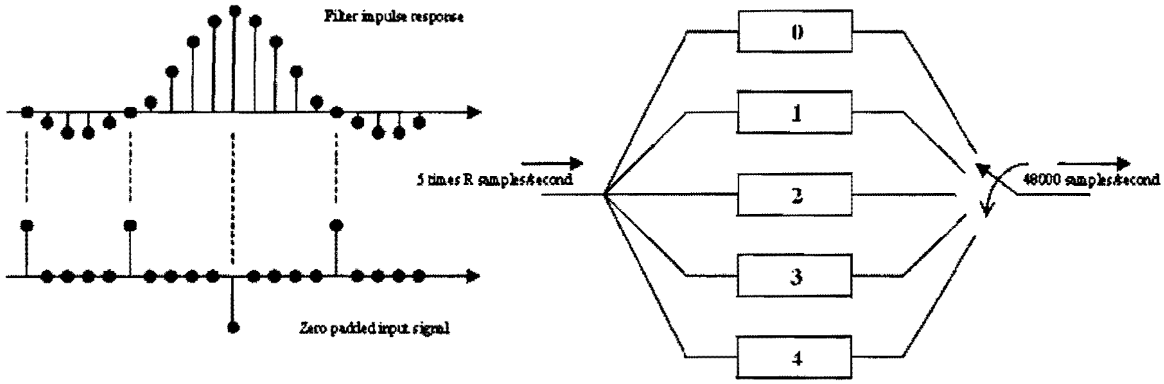

Figure 3. Multirate processing

Figure 3 shows the multirate processing system. The filter length would be 55 samples. At the input of the filter we will find four zeros between the two data bits. If we used this zero padded sequence in the filtering process, a high number of multiplications by zero would take place. To avoid this, the filter is divided into five subfilters, called *polyphase* filters, numbered from 0 to 4 in Figure 3. Each *polyphase* includes the 11 coefficients of the filter that would not be multiplicated by a padded zero input sample.

As only the samples required by the codec are calculated, a different sequence of polyphases is used at every rate and the step in the sequence is given by the decimation factor. In this way, at the rate of 9600bps 5 samples/bit are necessary, so we must use one output sample from each polyphase filter. At the 19200bps rate we need five samples every two bits, so we will use the output of the 0, 2, and 4 polyphases for the first bit and 1, 3 for a second bit. The sequence of polyphases used for every rate is shown in Table 2.

6.2. Reception filter

In order to perform detection the optimum decision time instant must be calculated, and the more time resolution is available, the better. Thus, a high number of samples per bit should be available. In our design the demodulator can calculate up to 80 samples per bit period. However, we only need two samples to perform synchronism recovery and the detection, so just two out of 80 will actually be calculated, avoiding computing overhead.

To perform this sample rate conversion we use the same multirate filtering structure for the reception filter as the one used in transmission, now with a constant decimation factor of 40 to downsample from 80 to two. The reception filter architecture is shown in Figure 4. The filter used with a roll-off factor of 0.3 is 768 samples long, and 576 for 0.2.

The interpolation factor depends on the bit rate and sets the number of coefficients of each polyphase filter. Table 4 shows the figures. At every bit rate, the interpolation factor is such that it converts from 48000 samples per second to 80 times the bit rate.

BIT RATE	INTERPOLATION FACTOR	COEFFS PER POLYPHASE
9K6	16	36
19K2	32	18
28K8	48	12
38K4	64	12

Table 4. Parameters of the reception filter.

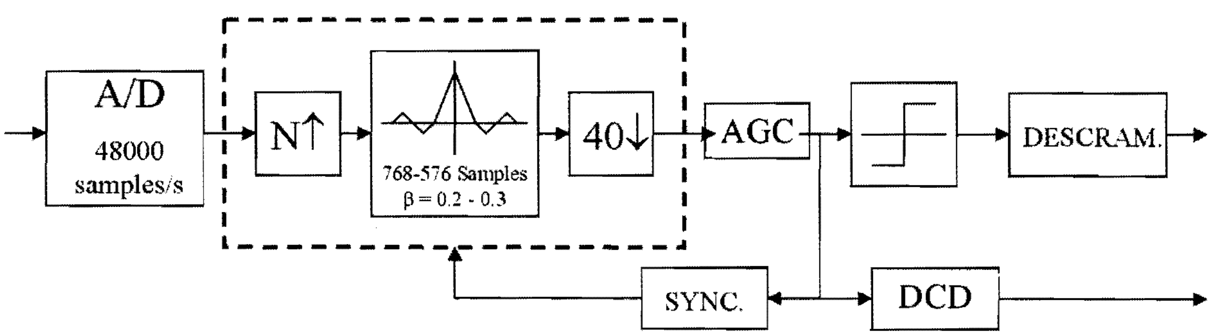

Figure 4. Structure of the reception filter.

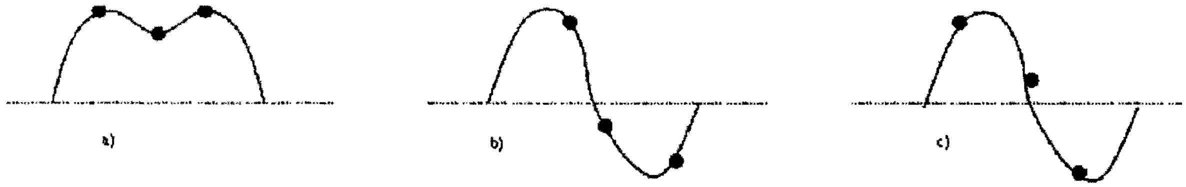

Figure 5. Possible locations of the samples in the synchronism recovery.

7. Synchronism recovery

The synchronism recovery algorithm uses the two samples corresponding to the center and the beginning of the bit symbol, and performs a comparison between their values. The three possible situations are shown in Figure 5. If a transition between bits has no zero crossing, the synchronism cannot operate (Figure 5a).

In case a transition occurs, we observed the value of the border sample. If it is located before the zero crossing, a variable is increased (Figure 5c). In the opposite situation, the same variable is decreased (Figure 5b).

For every received symbol, the synchronism algorithm tests the value of the variable to decide whether an adjustment in synchronism has to be done. When the variable's value is greater than a positive threshold or smaller than a negative one, an adjustment is perform by going up or down in the polyphase structure, selecting a new set of filters for the two samples to be calculated.

The up/down stepping is done with acceleration, with step values varying from one to eight. If the present necessary correction is in the same direction as the previous one, the step in the correction is duplicated, so as to reach more quickly the optimum state. If the present necessary correction is in the opposite direction or no correction has been performed during a certain number of consecutive symbols, the step value is divided by two, so as to refine the search of the optimum state.

8. Conclusions

A new software modem running variable bit rates has been described here. This modem has proved a very good performance, even when it is used with a hardware version of the G3RUH modem at the highest bit rates.

Acknowledgments

We would like to thank the URE (Union de Radioaficionados de España) and AMSAT-EA for the financial help given to this work.

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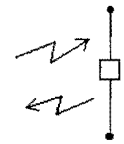
MODE-V/I EASY-SATS FOR EVERYONE



Bob Bruninga, WB4APR
115 Old Farm Ct
Glen Burnie, MD 21060

EASY-SATS: The great popularity of the FM satellites, AO-27, UO-14 and SO-35 shows how much interest and excitement can be generated amongst the Amateur community if satellites are made easier to access using simple equipment. Of course, single-channel FM while popular and simple, is very difficult to use reliably due to the heavy congestion and FM capture effect that only allows one user at a time to gain access to the bird and always at the expense of others.

Although we have had linear Amateur Satellite Transponders for more than 30 years that can support numerous simultaneous conversations, their popularity has fallen quite low recently probably because of the significantly higher cost of all-mode radios, antennas and tracking required compared to the FM "easy-sats". What we need is an "easy-sat" that is designed from the ground up to optimize the functionality of the satellite to many users while also addressing the needs of low cost user equipment. Also, it should allow operation from stations with only omni-directional whip antennas for ease of use.

BACKGROUND: Frequently, experienced satellite operators remember the first satellites operating in MODE-A and offer this mode as the best solution to get more low tech operators on the satellites using the linear modes. But the problem with MODE-A is the requirement for the user to transmit an SSB signal on the 2 meter uplink and use a separate HF receiver for reception on 10 meter downlink. This typically takes a $700 all mode transceiver or a do-it-yourself transverter as well as an HF rig. In my mind, these are high cost and not readily available items and not suitable for an entry level *easy-sat* satellite mission. Also, the current satellites have insufficient link budget to be worked reliably from the mobile or omni antenna environment.

MODE V: But if we analyze the overall requirements and availability of low cost off-the-shelf equipment, and simply invert the frequency bands of MODE-A to what I will call MODE-V there accrues a lot of advantages:

- 10 meters UPLINK can use low cost 25 W Radio Shack $149 transceivers
- 10 meters UPLINK has very low Doppler compared to all other bands
- 10 meters has plenty of bandwidth
- 2 meters DOWN has a 9 dB link budget advantage over 70cm for mobiles
- 2 meters DOWN has significantly less Doppler than 70 cm
- 2 meters DOWN can be received by the same $149 radio and a $49 converter

Of these advantages, the LOW COST user station is the main factor involved from the user requirements standpoint while the 9dB lower power budget is the most significant factor involved in the satellite design. This 9 dB link advantage is what makes this satellite design possible in the currently popular small microsat design package. Conserving power in the link budget by wavelength selection allows for adding enough power in the transmitter to close the link to a user with only an omnidirectional receive capability. No need for beams, tracking, or tracking computers. Thus newcomers would find it trivial to get onto the bird.

Another way to conserve satellite power and the precious 2 meter satellite spectrum is to keep the total width of the satellite transponder relatively narrow compared to previous linear transponders. By limiting bandwidth to only 30 KHz, it takes up not much more bandwidth than a single FM channel yet it can support over 10 simultaneous 3 Khz voice QSO's. This is actually a lot, considering the amount of existing linear satellite usage which has fallen to only one or two QSO's per satellite per pass during non-prime hours.

COMMON USER GROUNDSTATION: By designing for a low cost 10 meter transceiver as the common uplink investment and for a link budget that will work to an omni directional antenna, this design will strongly encourage a relatively consistent baseline for all user ground stations. By having a common baseline, then the performance of a linear transponder is much more consistent across all users and is far more predictable in performance. There are several factors that would tend to standardize on this common consistent baseline.

- The availability of the $149 SSB transceivers all with 25 watt power
- The lack of availability of high power amplifiers for 10 meters
- The ease and success of using an OMNI vertical will make little sense for users to develop large high gain tracking antennas on the uplink.

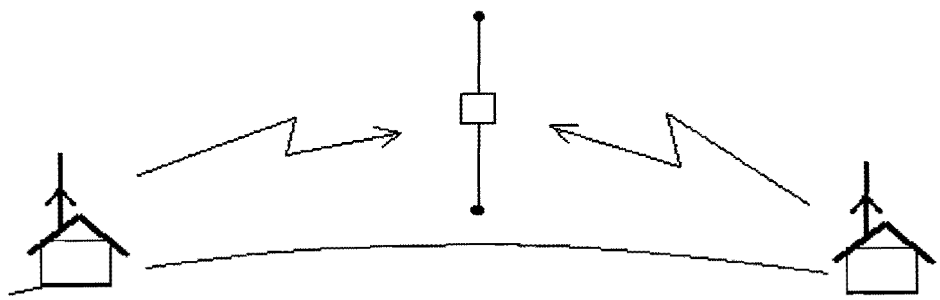
By having this common consistent baseline ground station that only uses 25W into an omni directional antenna as a standard uplink configuration would drastically level the playing field. Not only are the transmitted powers quite consistent, but the combination of the consistent transmit power and the antenna elevation pattern of an omni-directional vertical combine to give an almost constant level at the satellite receiver from all users. This solves one of the main disadvantages of linear transponders when some individuals greatly overpower the uplink at everyone else's expense.

Although there is a 10 dB variance between the satellite on the horizon compared to the satellite overhead due to range between each user and the bird, this "range gain" is almost perfectly offset by the vertical elevation pattern of a vertical whip antenna which is 10 dB or more down in the same area where the satellite is 10 dB closer. This self regulating configuration is a great advantage as long as everyone uses their 25 watt transmitters and vertical whip antennas.

SATELLITE DESIGN: One of the most critical factors in satellite design is the transmitter power budget. Especially when you have a broadband transponder which must support up to 10 simultaneous QSO's. This need to conserve satellite transmit power is what drives the downlink to use 2 meters. This downlink has a 9 dB advantage over 70cm, thus requiring only 11% of the power (to users with omni receive antennas). One other advantage of the linear transponder over an FM satellite is that the transmitter uses little power when it has no users in the footprint. This can give a savings of almost 90% since only 10% of the world's surface has any appreciable HAM population.

Fortunately, we think this MODE-V transponder can be built into an 8 inch or smaller type satellite. Such a satellite can have an average DC power budget of about 5 watts in low earth orbit and this is more than adequate to provide usable downlinks across a 30 Khz bandwidth containing as many as 10 simultaneous QSO's during the 10% of the earths area where it would see use.

Finally, the need for a 10 meter dipole antenna on the small satellite suggests that the satellite will inherently align itself to a gravity gradient attitude (if small masses are placed at the ends) and thus will provide a worldwide vertical polarization that is ideally matched with all the users who are also using vertical whip antennas. There will be a null beneath the satellite, but as noted before, this will help balance all uplinks to a consistent level that is ideal for linear transponders. Further the satellite will never be in the null of any one station for more than a few seconds per day.



Using Gravity Gradient stabalized microsat with small masses on the end of the 10m dipole, will give optimum coverage to all users.

It is these subtle but significant differences between the existing MODE-A and this MODE-V relative to satellite power and getting more people and newcomers involved in satellites that makes this such a viable design opportunity.

1) SSB uplink on 10m needs only a Radio Shack 10m transceiver ($149). Mode A needs an all mode 2m rig ($700?).

2) Using 2m as the SSB downlink requires only a 2m to 10m converter ($49). Mode A requires both the 2m SSB transmitter and 10m HF receiver ($139).

3) 2m down is quieter and requires less satellite power. Mode A's weak downlink must compete with higher atmospheric and man made noise.

DOPPLER: Another argument can be made for MODE-V that minimizes the problems encountered by newcomers in tuning for Doppler. Unless the current convention (which for mode-A is to tune the 2m UPLINK) is used, then QSO's tend to wander up and down the band by as much as 3 Khz during a pass and this wandering can be in either direction for each different QSO geometry. The result is that some QSO's slide into each other and cause unnecessary QRM.

In contrast, MODE-V places the uplink on 10 meters where the Doppler is 5 times less. This establishes QSO's to remain relatively fixed in the passband relative to each other and allows a much closer spacing between QSO's without encouraging QRM. Thus we can get more users in the same bandwidth on MODE-V compared to MODE-A in the situation where not everyone is properly following the MODE-A convention.

Although the MODE-V user still has to tune an overall Doppler that is the same as the MODE-A user, he is tuning it on his receiver where it affects only his reception, and does not affect the spacing of QSO's in the passband. This has clear advantages on a satellite designed for newcomers and minimizing bandwidth.

HALF-DUPLEX OPERATIONS: Usually for the MODE-A linear birds, users operate full duplex so that they can find themselves on the downlink and so that they can tune their uplink on MODE-A to balance out the Doppler effect on their signal. This Full-Duplex significantly adds to the cost of the new-user station requirement. But with the minimum Doppler of MODE-V on the uplink, half-duplex operations are quite possible. Thus the minimal newuser only needs a single cheap 10m transceiver and a down converter instead of two radios.

The minimum uplink Doppler, and the adjustment for Doppler on the downlink and the tendency to tune into a station by tuning one's own receiver leads to almost chanelized uplink operations. Users simply set their transmitters to one of the 10 uplink channels and then all they need to do is tune their receiver to the QSO in progress. There can still be up to 600 Hz between different users in a roundtable discussion, but at least half-duplex single-radio operation with a 2-station QSO is quite possible.

AUTOMATIC TRANSMIT/RECEIVE DOPPLER CORRECTION AND TUNING: Because of the relatively low UPLINK Doppler and therefore operation in sort of a fixed channelization on the uplink, it is very easy to implement automatic Transmit/Receive tracking when tuning among the 10 or so simultaneous QSO's on the downlink. By adding a pot to the oscillator crystal in the downconverter, the tracking relationship between your transmit and receive signal can be adjusted in real time. Since the major component of the Doppler by a factor of 5 to one is your own receiver, at any instant, your adjustment of this pot for zero-beating a QSO will be the same for all QSO's in the passband (+/- their minimal 10m uplink Doppler).

So, you tune your 10m rig from fixed channel to channel on the uplink, and the downconverter offset tracks beautifully with you through the channels. You only need to adjust the donwconverter offset to correct your receive signal for Doppler as it varies through the pass. But still you can return to any of the other uplink channels and your tuning offsets will still be correct within the 600 Hz variability of the other QSO's uplinks.

Thus you never have to search for your donwlink, it is always the same fixed offset from your transmit signal as the XTAL in your donwconverter. For any instantaneous Doppler observed at your station, ALL channels are affected the same way, so you can QSY among all the QSO's on the bird with the same relative setting, only making minor adjustments to the pot during the pass, no matter what "channel" you are on.

With the 1 KHz step size of most cheap 10 meter radios, this "channelized" operation with automatic transmit/receive tracking of the fixed offset downconverter is actually a significant advantage. Using this method, you will never be more than 600 Hz away from any QSO you tune in. This is far simpler than trying to use two separate rigs full duplex which would have to be separately retuned by as much as 20 KHz every time you jumped from channel to channel.

DISATVANTAGES: Although this new MODE-V has many advantages and benefits as a newcomer's satellite that is easy to work with simple equipment requiring no antenna tracking and useable while mobile, it does have two minor disadvantages:

- First is the requirement for a General Class license to transmit on 10m
- Second is the unknown worldwide nature of interlopers and unintended stations operating on 10 meters in the satellite segment of the band.

Actually, the first problem is really no problem at all, but can be considered as an incentive to upgrade. The second problem is also not considered significant, since we are only talking about a single 30 KHz portion of the 10 m band and these days, the problem is just as bad on 2 meters as on 10 meters.

COMPARISON TO FM EASY-SATS: Although most of the excitement about the FM Easy-sats is their direct accessibility from a Handheld HT transceiver, under favorable conditions, most operators prefer a relatively large handheld beam antenna to pick up many dB on both the up and downlinks. Thus, the weak downlink signals are not considered that much of a disadvantage since the user's radio easily fits into one hand and the antenna in the other. Thus, using a handheld ARROW antenna with an FM HT is a very easy form of operating FM.

But, this ease of operation and workability with a weak downlink using handheld **beam antennas with significant gain, does not carry over well to linear** operation using SSB with new users on 10m for several reasons.

- Doppler demands constant hands-on tuning of the receiver
- Radios are not handheld, but large and separate for transmit and receive
- Uplink power requires bulky power supplies.

But conversely, the MODE-V permits mobile operation with only a vertical whip antenna, which in many cases is far more comfortable, just sitting in the car, out of the weather.

MODE-I: By taking the search for the cheapest off-the-shelf USER Satellite station to the extreme at the expense of satellite complexity, a 10 meter **INBAND** transponder would provide the ultimate in simplicity for operation with the $149 low-cost SSB transceiver. The advantages are:

1) One radio and it is cheap.
2) With an inverting transponder, you get NO DOPPLER
3) With no Doppler you get instant QSY all over the passband
4) On 10m you get maximum link budget for minimum satellite power

BUT, there are two problems to consider:

1) It would need to be a split-tethered dual satellite to get a few hundred feet separation between the XMTR and the RCVR. But this can be done and it provides gravity gradient stabilization for an easy vertical polarity to mobiles.

2) You go up LSB and come down USB. Lets assume that someone will figure out a single-wire mod to hook the PTT to the SIDEBAND switch to make it change between USB and LSB on transmit.

But imagine the popularity of this Satellite. Anyone with $149 and a CB whip antenna can work it a few times a day. Now that is an EASY-SAT. And a good satellite design challenge. Although operating in-band on 10m will have to use shared spectrum, it is possible within the ITU regulations and this mission would be an ideal use of the 10m band during the several year long solar minimums.

CONCLUSION: Searching for an optimum new-user easy-sat design has been a fun exercise. There are so many variables to balance both on the satellite, on the ground in the choice of user equipment, modes, antennas and operating options, that even if no one builds one, it is still a good design project for students looking for a satellite mission. Although my usual interests are in looking for low-cost access to satellites for digital applications (see other paper in these proceedings), a strong case can be made that the ANALOG modes of future amateur satellites might be more popular than the digital ones. With today's worldwide internet connectivity and the ability to send bits and megabytes anywhere on the planet almost, the appeal for digital Amateur Satellites might actually decline. In competition with the Internet, maybe the only niche for HAM radio will remain the thrill of a live voice QSO using just your simple radio wherever you may be…

Doing it with a $149 radio instead of a $2000 computer is still fun to me…

Thayer School of Engineering
at Dartmouth College

Modular Nanosatellites as Amateur Radio Communication Platforms

Amish Parashar, KE6EZM*; Todd E. Kerner, KB2BCT

Thayer School of Engineering, Dartmouth College

ABSTRACT

Amateur radio communication satellites have been long established and technological proven. Miniaturization and reduction of design and production costs of electronics is at the forefront of today's technological efforts. Ground based applications have been the forerunner of this trend. It is proposed that a space analog be created. A modular architectural approach to the construction of an extremely small satellite may provide a standard for future space-based research, educational, and communication platforms. Dartsat is to meet such specifications while providing the footing for ongoing research on space operations at Dartmouth College. The first iteration of Dartsat is to serve as a model for future missions. Dartsat has dimensions of ten centimeters cubed; the maximum allowable mass is one kilogram. Of this volume, roughly 75 cm^3 is occupied by mechanical superstructure. The remainder of the volume, approximately 925 cm^3, is divided into modular bays. The control, power, and radio communication (CPR) of the satellite occupies one of these bays. The other two bays are to be outfitted with standardized interfaces allowing the "snap-in" of interchangeable, independently engineered payloads. The unique design of Dartsat is to provide a benchmark for future space flight orbital operations.

Keywords: Nanosatellite, Picosatellite, small satellite, modular satellite design, amateur satellite

1. INTRODUCTION

Satellites are often large, expensive, and built with a very specific application in mind. A modular approach to the creation of a versatile orbiting platform may spark a revolution in space borne technologies. An initial nanosatellite must be created as a model which future satellite generations may be based. Subdivisions of satellite development include mechanical design, power, microprocessor control, communications, and onboard experimentation modules.

*Correspondence: Email: Amish.Parashar@dartmouth.EDU; WWW: http://engineering.dartmouth.edu/~dartsat

2. MECHANICAL DESIGN

Mechanical fabrication of a small satellite should be viewed as a multi-tiered system. First, structural integrity must be considered. The satellite space frame must be able to withstand the rigors of launch and orbit. After this is accomplished, the mass of the structure must be minimized in order to allow for greater payload mass. As this is considered thermal and radio frequency factors must be accounted for. The drastic thermal oscillation that will occur each orbital cycle is amplified by a low thermal mass. This must be carefully balanced with reducing the overall mass of the structure. The final stage of mechanical design should be integration, ensuring an acceptable structure is the final result. Such a final product houses three main factors of design: size, mass, and modularity.

Size constraints are dictated chiefly by the specifications set forth by the launching apparatus development team. The California Polytechnic State University, in a program to develop a multi-nanosatellite launching devise, has set forth standards around which many developers are working[1]. Such a launching platform seems simple and effective; the development of the Dartmouth College small satellite, Dartsat, will adhere to the standards set forth by the designers of the launching system.

The pre-deployment dimensions are not to exceed ten centimeters on each side. The adopted plan of design calls for a satellite that meets but does not exceed this limit. A total of eight seven-millimeter standoffs are to be placed upon the top and bottom faces of the cube; one per corner of each of the two faces. These are to be oriented so as to provide adequate separation between adjacent satellites in the launcher.

The mass of the satellite, in launch ready mode, is not to exceed one kilogram. This is a standard governed by the California Polytechnic State University Pico Orbital Deployer program. Mass characteristics, such as center of mass, will be modified upon further completion of engineering models of Dartsat.

The first iteration of Dartsat is to be a model by which many small satellites may be built. Expandability and versatility are fundamental design considerations in the development of this first generation satellite. Future satellite, based on the Dartsat model, will be able to house a variety of payloads. Every level of satellite development, from the microprocessor bus to the division of space, will occur with modularity in mind.

The interior volume of the satellite will be divided into two areas. The first section will house system boards. Each board will be approximately eight centimeters by eight centimeters. The microprocessor and associated circuitry, along with power system circuitry, will be housed on one such board. A second board will accommodate all radio circuitry, the transmitter and receiver. A final board will house data collection circuitry as well as data packaging circuitry – the packet radio system. Slide-in slots are to be created on the upper section of the inside volume of the satellite. One such slot is to be left vacant along with the lower section of the interior volume. This combined space is to be used jointly by one of a multitude of possible payloads as well as the battery subsection of the power system. Differentiated system boards as well as a relatively large expanse of interior volume are the result of modular system level design.

Many of the materials used to create the space frame have been long established as standards in space flight. Many revolutionarily new materials were presented as ultra-light and ultra-strong. Due to potential problems of out-gassing in the high vacuum environment of space, plastics and epoxies are not viable options for the satellite. More traditional materials must be employed. Aluminum (7075) will be used to create the frame of the satellite. The outside faces of the shell will accommodate solar cells, including required under and over coatings, and sensing instrumentation. The inside faces host sculpted mechanical support as well as the slide-in slots for the system boards. Deployables, chiefly the antenna subsystem, shall be addressed in detail in the "Communications" section.

Upon ejection from the launching apparatus, the satellite will orbit in an unstable, and perhaps more significantly, orbit in an unpredictable manner; much of the exact launch characteristics are, and will remain, unknown. In order to alleviate such problems, and add stability to the orbiter, one of two options may be implemented. Active stabilization, the use of thrusters to achieve desired satellite orientation, is costly in terms of space and power consumption. The more reasonable option seems to be the use of passive control. A permanent magnet will be housed onboard the satellite. This will control for one axis of spin. The magnet will align itself to the magnetic field of the earth, forcing the satellite to do the same. This first degree of stabilization is enough to allow optimal placement of deployed antennas and the heat dissipation face of the satellite.

The satellite will reside in a low-earth orbit (LEO), between 500 and 1500 kilometers in elevation. When combined with the high inclination, north to south to north, orbits, and the drag forces present at the given elevation of the flight path, the satellite is expected to undergo atmospheric degradation between one and two years from launch. Active thrusting capability and/or MEMs technologies may be potential solutions to this seemingly early demise; however, the cost in power and space is great.

3. POWER

Flexibility in power options is highly desirable in the creation of an experimental orbiting platform. In order to accept the widest possible array of payloads, battery size, mass, quantity, and placement must accommodate other aspects of satellite design. Solar cells must be resilient to potential environmental stresses while accommodating deployable structure and satellite-surface instrumentation. As a result of these factors, a spectrum of power options emerges. The high and low ends of the spectrum are significant.

Photovoltaic cells will serve as the primary source of power for the satellite. Five of the six faces of the orbiter will be covered by solar cells. Ideally, each cell would be constructed of the highest available efficiency. Gallium-arsenide cells lie on the upper end of photovoltaic options. Silicon cells, one of the lowest in terms of efficiency, posses unique benefits. An amorphous silicon (a-Si) cell is thin, ultra light, and extremely resilient to external stresses. These cells allow for a balance between efficiency and desirable mechanical properties. The sixth face of the satellite will serve as a thermal dissipation face. Through passive control, this face will be aligned so as to rarely be oriented towards the primary heat source, the Sun. This design allows for greater thermal stability of the satellite as a whole.

Power storage will occur in the form a battery pack. Lithium-ion cells, the upper end of available batteries, are not acceptable for use in space due to out gassing hazards that may endanger the satellite and the launch vehicle. Nickel metal-hydride cells are on the upper end of battery options. However, these light, highly efficient batteries posses a unique set of challenges related to charging and long-term stability. A trusted standard will most likely be adopted for the first iteration of the nanosatellite. Nickel-cadmium batteries, although lower than Nickel metal-hydride in terms of efficiency and size to power ratio, are able to handle the power cycles the satellite may likely undergo. Estimated battery pack power characteristics are 3.6 volts at 3.0 amps.

The satellite will likely pass over North America a total of six times per day. Given the characteristics of LEO, the satellite will be in radio view for a fifteen-minute window during each pass. During this time the transmitter will transmit at 0.5 Watts RF. A total of 90 minutes of high power draw, transmission, is expected each day. It will be ensured that the transmitter does not stay activated once out of range.

The cells, when combined with the charging attributes of the photovoltaic array, provide enough sustained power to maintain a viable satellite. An IC controlled charging circuit will govern charging of the cells, monitor power levels, and provide insight into satellite power input and output.

Power is unequivocally vital to the operation of the satellite. System level design must be overtly redundant and fail-safe. For these reasons a hierarchy of satellite functions was created. If power levels decrease, a graceful degradation of functions will occur. The greater the power consumed by a function, the higher it is placed on the list, save the transmitter. The receiver, then the microprocessor control unit, then the experiment, and ultimately the transmitter will be placed offline until power levels exceed the threshold value.

4. MICROPROCESSOR CONTROL

The microprocessor control unit (MCU) will oversee core satellite functions. This "brain" of the satellite, will monitor power status, collect and store data, prepare the data for transmission, and send out a periodic identification signal. The first iteration MCU will be simplified so as to reduce potential sources of error. A specification goal of the initial MCU design is ease of expandability. Future models of the MCU will have added memory and greater functionality. Components used to assemble the MCU, and all other electronics, must be able to withstand the radiation rich environment of space. Military specification and space rated parts were selected in order to protect against radiation and shock damage to electrical circuitry.

The MCU is to be based on an Intel® 8051 microprocessor. The low power version of this chip is to be used in order to comply with the power budget of the satellite. This chip will be used in conjunction with 20 kilobytes of Flash RAM. The RAM will be the primary memory bank, housing the basic onboard programs. Dual control methods will be employed. Touch-tone codes will serve as primary control of the MCU. The dial tone mixed frequency (DTFM) standard was selected because of the number and wide variety of base stations that are able to comply with and thereby communicate with the satellite. Each DTMF tone received by the satellite will be converted to a corresponding four-bit number. Based on this number, or sequence of numbers (which is dependent on a sequence of tones), the MCU will be interrupted of its operating functions and implement a series of routines.

Power management of the satellite will, in part, be handled by the MCU. DTMF codes will be assigned to vary the transmission power of the satellite. Through this system a base station will have the ability to control the signal strength as governed by satellite transmission. The MCU and associated circuitry is to draw no more than one watt of power. In the event of MCU failure, satellite functionality, albeit limited, must be maintained. The default mode of the MCU circuitry will allow the repeater portion of the satellite is activated and operating at minimal power.

The MCU will be designed to handle the collection and storage of data. The first iteration of Dartsat will collect information regarding the conditions of the Low Earth Orbit (LEO) it is placed in. Sensors onboard the satellite will capture and send analog data to the MCU where it will be digitized and stored in the external Flash RAM. Valuable information regarding the sun exposure, thermodynamic characteristics, and solar cell performance may be obtained as a result of the sensor data stream. Periodically, possibly once a day, a serial transmission of this data will occur (see communications section). The receiving base station will collect and analyze this data.

In tandem with data acquisition and transmission, the satellite must be able to perform a set of other functions. As per Federal Communication Commission rules, the satellite must send out an identification signal, a beacon mode, at given intervals when the satellite is operational. In order to limit the use of memory and simplify circuitry, thereby reducing power consumption and potential sources of error, a Morse code message will be transmitted in lieu of voice identification. The timer portion of the MCU will govern the transmission of the beacon signal. Morse code signaling is in compliance with, and commonly practiced, in the FCC governed amateur radio community. Such beaconing has been used on many generations of amateur communications satellites.

Adaptability and expandability are key design goals of the first iteration MCU. The proposed design should allow efficient, reliable, and consistent operation of basic satellite tasks. This should serve as a platform upon which more complex MCUs may be based.

5. COMMUNICATIONS

The ability to effectively communicate is pivotal to measure satellite success. "Effective communications" was divided into three categories. First, and foremost, satellite communications must strictly adhere to FCC regulations. Second, accessibility was considered. In order to present a test of possible future commercial viability, the satellite must be universally accessible to many people using an established standard of communications, the amateur radio. Finally, the communications method adopted must be able to sufficiently penetrate the Earth's atmosphere under many weather, solar, and atmospheric conditions.

Cross band repeater operation was chosen for the satellite in order to reduce unwanted harmonic desensitization of the receiver. This traditionally occurs above the frequency of transmission. For this reason the range of possible transmitter frequencies was set above that of the onboard receiver. UHF and VHF band signals possess the somewhat unique ability to permeate the ionosphere under a wide variety of conditions. Short-wave (HF) frequencies bounce within the ionosphere and are dependent on solar and atmospheric conditions.

Radio interference can occur on many levels; mechanical design must give special consideration to such factors. This may be exhibited in the radio related circuitry. The radio receiver may be remarkably susceptible to the signal caused by the transmitter circuitry. As a result, structural design of the satellite will incorporate metal grounding cages. These thin copper assemblies will completely surround around the transmitter and receiver circuits. This preventative measure will provide electrical isolation for these sensitive circuits.

Dartsat transmission frequency was chosen to be in the 440 MHz amateur radio band, the receiver frequency was chosen to be in the 144 MHz amateur radio band. The wide separation of these bands will minimize interference onboard. The spread also allows for the potential to duplex the two bands through a single antenna and a space saving filtration circuit. An FM mode of communication will be adopted. This was chosen over the narrower Single Side Band (SSB) for multiple reasons. When compared to the narrower SSB frequencies, the wide FM signals will be influenced less by the Doppler shift phenomenon. Second, FM transceivers, both mobile and handheld, are widely available; SSB transceivers are less common. The 144 MHz/440 MHz combination of bands are commonly available in transceivers – base station, mobile, and handheld – commercially produced by manufacturers such as Icom, Kenwood, and Yaesu. Any licensed amateur radio operator with such equipment will be able to access the satellite.

Aside from voice communication modes, the satellite must be able to send as well as receive data. Onboard data reception will be in the form of DTMF codes sent up to Dartsat from ground stations. Transmission of onboard data will be fundamentally different. The "packet radio" standard is to be adopted. Such a method of data exchange is a standard in the amateur radio community and is a communications option in many ground stations worldwide. The packet system ensures accurate transfer of information. Data streams are broken up into small segments, "packets." These are transmitted to the receiving station. The packet system requires checks on the data transmission. At regular intervals a check set is sent to the packet circuitry confirm that a variable amount of the data stream has been received. If for some reason a portion of the data is not received, it is resent until a reception receipt is transmitted. This method ensures that communication is complete and accurate. Data speeds will most likely occur at 1200 bps. The highest allowed by FCC regulations is 9600 bps. Due to atmospheric, Doppler, and other phenomenon, it is unlikely that such a baud rate will ensure accurate data exchange. Transmitting and receiving circuitry has been built and tested along with MCU interfacing.

The viability of the radio systems is largely dependent on antenna design and implementation. The first major consideration is that the satellite is not actively stabilized. One axis of the satellite will be fixed, through passive magnetic stabilization; antenna design can take advantage of this fact. Second, the number and complexity of deployables exponentially increase the probability for error. Antenna construction, especially with respect to deployment method, must be overly redundant, robust, and virtually failsafe. A set of dipole antennas is to be adopted. These will provide the most omni directional signal possible thus reducing the problems caused by the lack of stability in satellite motion. Omni directional antennas provide a distinct propagation pattern that may be tailored to provide an electrical advantage. The number of deployables is kept at a minimum, four. Two ¼ wavelength rods will serve as the receiving antenna. Another pair of ¼ wavelength rods will function as the transmitting antenna. This is superior in many respects to the commonly used ¼ wavelength antenna design. Such a design calls for a ¼ wavelength driven element and four additional ¼ wavelength rods to serve as a pseudo ground plane[2]. This design is inferior to the dipole design with respect to the two criterion – omni directionality and few, simple deployables.

Shape memory alloys are to be used to construct the antennas. These will easily be fitted into the satellite in the launch configuration, and, at the appropriate time, be deployed to the desired shape. The material is 0.025-inch diameter Nickel-Titanium alloy. Such an alloy, after being treated at specified temperature constraints, posses the ability to reassume an induced shape after being subjected to a constraining form.

Integration of onboard communication systems must take into account space, power, RF, and thermal factors. In order to maximize space available for non-essential satellite systems, payloads, core satellite components must be miniaturized. Radio systems, both transmission and reception, will likely fit onto two sides of an eight centimeter square board. Isolation (in terms of RF) of sensitive components is to be accounted for in analog circuit layout. A select group of radio components are thermally sensitive – crystals for example. These must have the greatest possible thermal mass in order to reduce the upper and lower end temperature fluctuations.

Satellite transmissions will occur at relatively low power, about 0.5 W RF. Extra measures must take place on the ground in order to ensure the satellite is heard. Two high gain antennas connected to a 144 MHz/440MHz all-mode, 100 W radio. This will serve as the backbone of ground communications. A computer, through a three-axis rotator, will control the antennas. The ground station is to be located at the Thayer School of Engineering, Dartmouth College in Hanover, New Hampshire.

By using many standards adopted by amateur radio operators worldwide, Dartsat, and future nanosatellites, should provide a valuable communications link while presenting unique scientific research opportunities. Modularity by design allows for a myriad of possible payloads. Nanosatellites may, in the near future, possess the ability to talk to not only the ground, but also each other. Communications networks in space, whether using amateur or other (i.e. internet) protocols, maybe the next step in the development of extremely small payloads in space.

6. EXPERIMENTATION

The modular design of this nanosatellite makes it an ideal candidate to host a variety of payloads. The first generation satellite will house instrumentation to give the development team a greater understanding of the conditions the satellite undergoes in a LEO. Temperature and light sensors will be key to this. The analog data acquired by these sensors will be digitized onboard and sent to earth for analysis. Future iterations of the satellite will present a unique research opportunity. Strict specifications concerning power, external space, interior volume, and available memory will be presented to the scientific and radio amateur communities. The hope is for researchers to approach to satellite team with drop-in modules that may be inserted into the satellite. Seamless integration of an experimental module is a goal of Dartsat development. Aurora Borealis and plasma ion density measurements have been suggested as well as a test bed for zero gravity micro-machines and space-borne networks. Future models may house GPS reception equipment in order to provide time and location stamps for each collected datum.

7. TESTING

Testing will start at the system level. After each section of the satellite is function as per specifications, the entire unit will undergo rigorous testing. It must be ensured that the satellite will function properly, but also not endanger the launch vehicle, other satellites aboard it, and other orbiting craft. Thermal vacuum testing will subject the satellite to temperatures of -40° C to 65° C. Vibration testing will make certain the satellite can withstand the 15G's of force, and associated vibrations, that may be encountered during launch. Electromagnetic testing will make sure that radio systems and other circuitry does not interfere with or is not interfered by other orbiters. Finally, integration with the launch apparatus will occur. Most testing will take place at Saunders Labs in Nashua, New Hampshire.

8. CONCLUSION

Due to modularity of design and the ability to "snap-in" interchangeable payloads, the Dartmouth College Nanosatellite, Dartsat, may have a virtually limitless future. Since conception and presentation of design, many proposals, concerning the use of such an orbital platform, have emerged.

It is believed that the satellite will prove to be a cost effective, mass-producible space vehicle. Its small size and versatility may prove it to be a valuable research tool for the scientific community and a viable communications platform for the amateur radio community. Applications in space borne sensing, orbital data acquisition, and micro gravity testing may be ideal for this satellite. As the technology is refined and developed a plurality of satellites may be launched. Such a constellation may be a viable communications solution in an era of global handheld communications. A space-borne network of nanosatellites may provide amateur radio operators with large area coverage on low power on VHF/UHF. The possibilities are endless thanks to modularity in design and adhesion to proven, commonly used standards.

ACKNOWLEDGEMENTS

The Dartsat development team would like to acknowledge the guidance of Professors Lotko and Cooley of Dartmouth College as well as funding received from Dartmouth College and various space grants.

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2. *The ARRL Handbook for Radio Amateurs*, Chapter 33, The American Radio Relay League, Newington, CT, 1992.

AMSAT SYMPOSIUM PRESENTATION

PHASE 5(V) SATELLITES

While we enjoy the results of the last century's successes from the Amateur Radio Satellite community, we have to entrap our younger people with goals that will put their reach higher than current projects dictate. It was not long ago that we began to send electronic *balls of radios* into orbit and fascinate us with the communications of today. Tomorrow's projects will become increasingly difficult to sell to the public as communications worldwide is commonplace. *Telstar* is a miracle word from yesteryear. The exploration of other heavenly bodies, like our Moon, Mars & the Moons of other planets will become the targets of NASA. These will be our younger generation of *"HAM'S"* dreams. Thus. . .

- PHASE 5(V) Satellites (ARPP) *Amateur Radio Planetary Package*
  Communications/Data Satellites on the surface of another Moon or Planet.
- BEAM ME UP!
  What size slingshot to use.
  Who to keep in touch with.
- PROPOSAL
  Satellite community's future adventure.
  Together – NASA(and other Space oriented groups) – Collegiate Community & AMSAT spacecraft experience(Worlwide) collaborate to include ARPP in a future exploratory adventure.

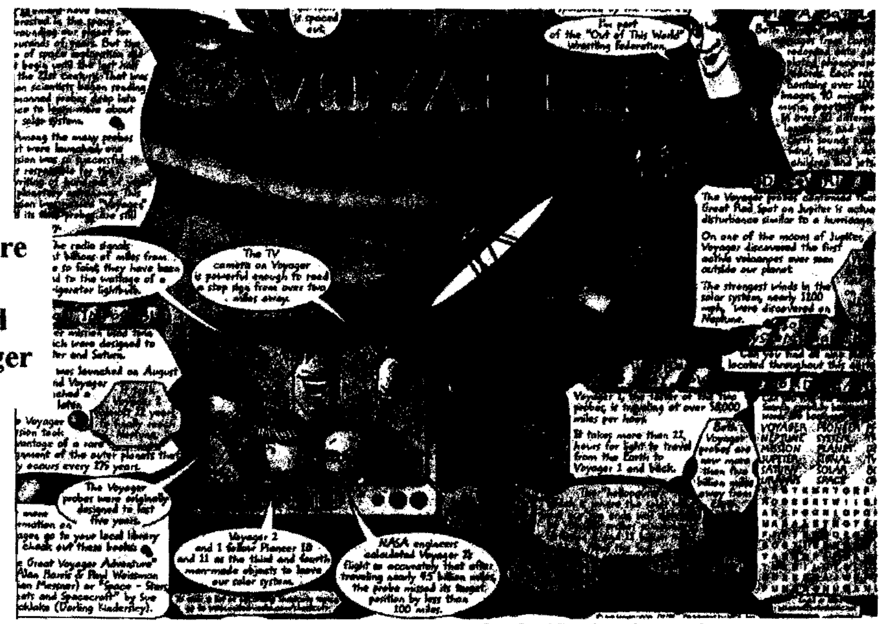
Phase[1] V and Beyond. . .

By Dominick "Dee" Interdonato, NB2F

Now and Then and When

Our sites are re-aiming now that phase III D is up and running (hopefully by symposium time). In Amateur Radio circles, a push for another satellite project is gathering steam. Discussions and pointed suggestions give a direction for the movement. Some point towards a "Phase[1] IV" type of a satellite (geosynchronous). We've had discussions on this before and the drawbacks of position location and limited use pour water on the fire. Some of the same reasons dictated the type of orbit Phase III D took. Others are satisfied to give another Molniya orbiting satellite funding, although scaled down to allow Amateur Radio coffers to rebuild themselves.

Pix to right-- A rare example of space related fun pointed towards our younger generation

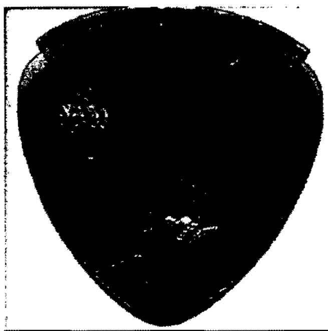


(From *Bergen Record of NJ* 7/23/2000)

ECHO

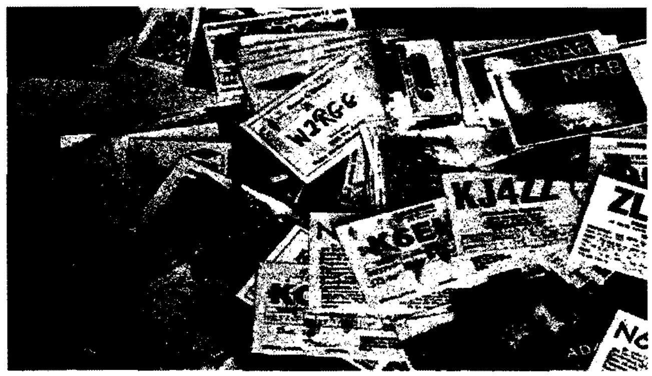
In today's high tech world, we all take our communications technology for granted. If you ask the *under* 20 crowd what it takes to get a TV signal from Europe to the U.S.A. they immediately say the word *satellite* but actually have no idea what is involved. It is all taken for granted and *matter of factly* state that it just happens and they expect it was always this way. Instant INTERNET has everyone mystified but even this mode has some satellite links seamlessly merging the flow of information. While most of us *over* 20 crowd still recall the early space adventures, younger people need to have this excitement rekindled and passions for new explorations ignited again. I can

[1] Phase represents the different plateau's of satellite activity. I = early simple sats w/beacons only. II = more advanced low orbiting self contained sats. III = same as II but into an elliptical orbit. IV = same as II & III but in a geosynchronous orbit. V = a hamsat orbiting or fixed on another planet, moon or stellar object.



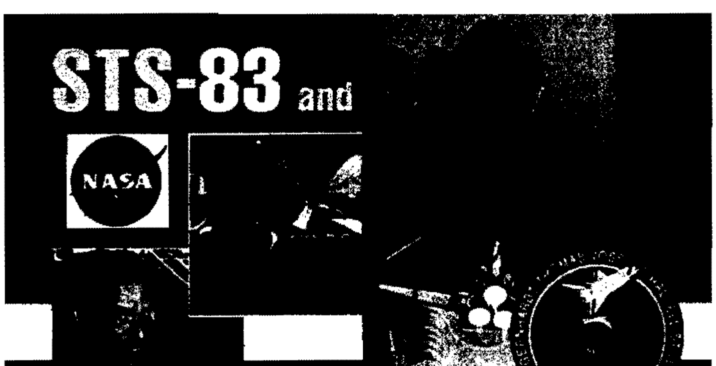
SAREX PATCH

remember awaiting the sun to go down during my summer vacation from school to watch the "Satellites" go by overhead and dream about those mysterious signals being bounced off of them. Satellite operation is an everyday occurrence in this age. Our Space program has become so commonplace that the actual exciting happenings are rendered to a few seconds mention on the nightly news. When the ISS modules docked in July, I timed the report and it lasted 33 seconds on the channel I was watching.



A portion of the QSL's Rcvd for contacts with the STS-83/94 Shuttle mission.

NASA funding is always on the budget cutting hit list. Their belt tightening efforts have not gone without downsizing projects to encompass minimum efforts with exploration. The Space Shuttle SAREX missions have given a glimpse of what the future could be like with Amateur Radio. SAREX, ***Shuttle Amateur Radio Experiment,*** has been the single most attractive element to this hobby for youngster's to come along since OSCAR's were first proposed. Second to the no code event. Although we have an Amateur Station on the upcoming ISS which will add to the satellite repertoire, our goals should be with a more distant target-another orbiting body of our Sun!



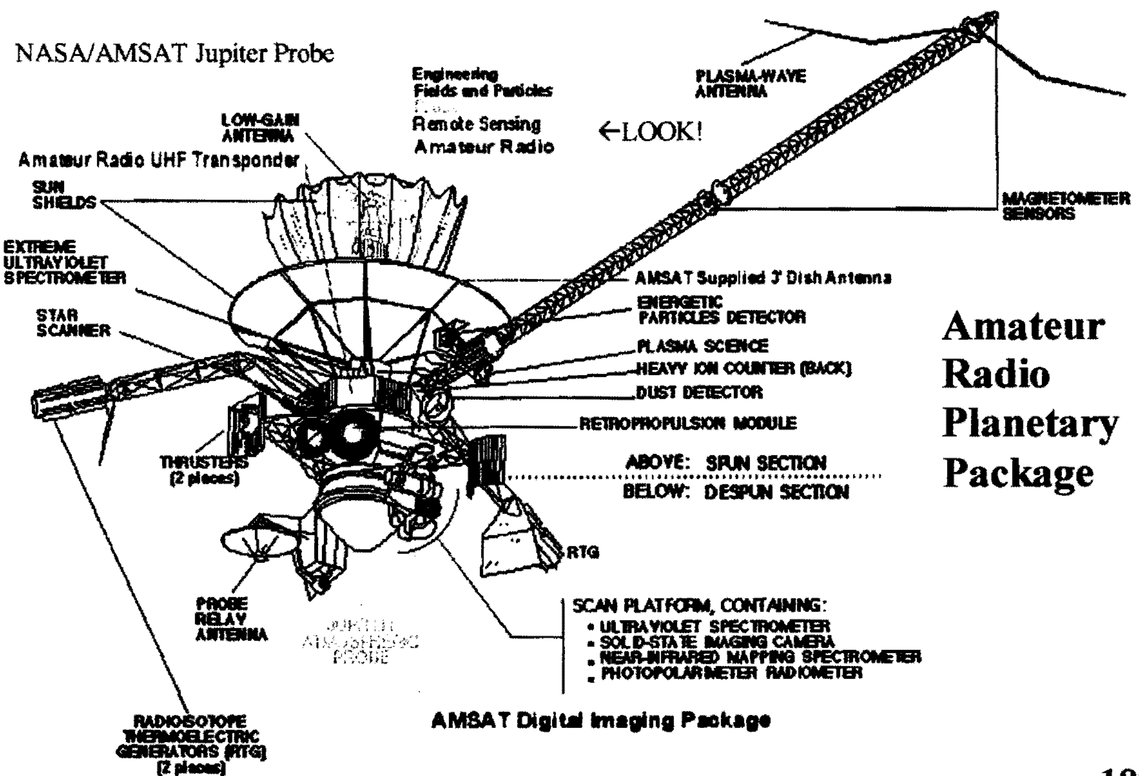
Actual Shuttle QSL

With AMSAT's expertise in building and assisting in the designs of experimental satellites for various scholastic endeavors, we have a wealth of proven experience adding communications techniques to projects. The new smaller & smarter packages that the space exploratory community is now being forced to assemble are the perfect platform to add "our" projects to. We are approached by many learning institutions to provide them with ideas and ways to get information from their experimental space probes back to ground stations and they have Amateur Radio frequencies being touted as the easiest way to do this. With all the great proven designs at our disposal, we could easily integrate our packages with their experiments. Just think of the advertisement opportunities and news exposure of projects that thousands of "Hams" (and Non hams) are listening to could encourage. NASA and Space explorers alike are scrambling for Congress's money and offering our enthusiasm to any newly proposed agenda could be worth as much as Dan Goldin's (NASA DIRECTOR).

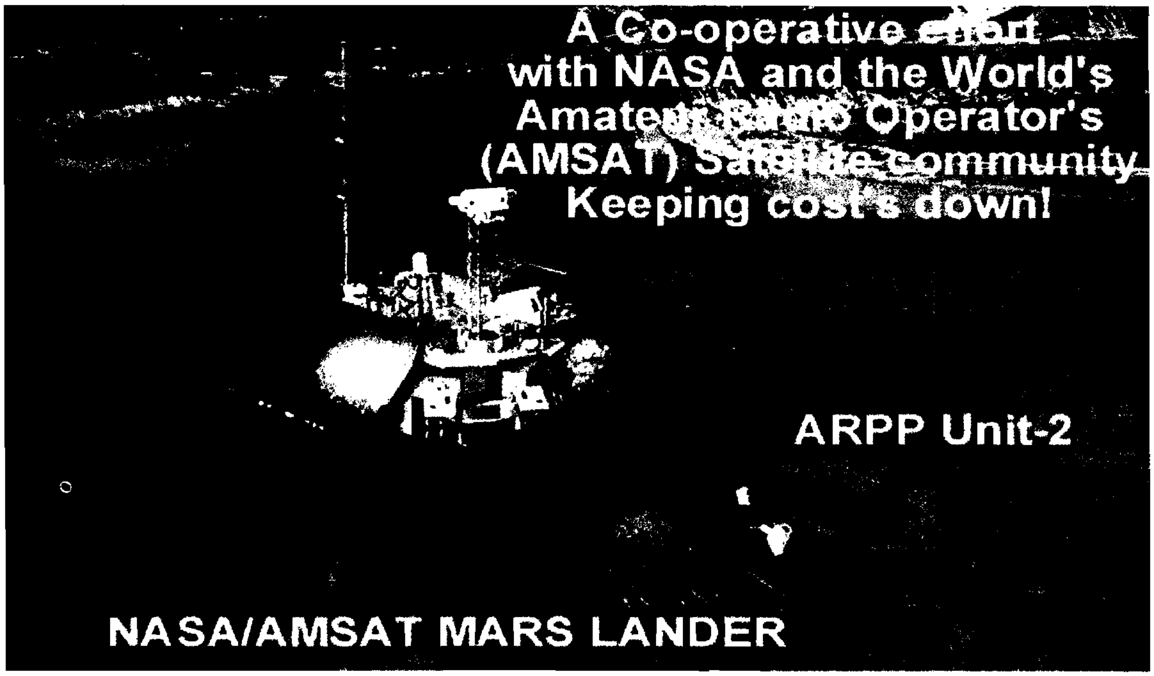
Piggyback to Mars

It's Saturday evening and I think I'll check the WX on Mars. I fire up my computer and find that Mars is about 30 degrees elevation and 235 degrees azimuth. My modified satellite dish is ready to be pointed and is now set up. The 2.4 ghz downconverter is energized and I pick up the signal of the Mars ARPP8 attached to the latest NASA Mars surveyor scouting the polar region. *AMSAT's design team sure came up with a clever idea to add that additional feed to the high gain antenna that they manufactured for NASA costing them next to nothing for this previously costly part of the experiment.* Our equipment supplied to them with our ability to "piggyback" our ham package was a great association for both of us. *Wow, it seems a dust storm is making visibility poor at this time. I think I'll ask through ARPP 4 comm link near moonport I if this is expected to last awhile.* Sound far-fetched? Well the next steps for AMSAT needs to be in a direction that can generate our younger ham's interest. These scenarios can be that catalyst.

While OSCAR has been a household word in the Amateur Radio Community, ARPP, ***A**mateur **R**adio **P**lanetary **P**ackage*, can also become an acronym in the future. The prices involved with putting together an exploratory package can be quite high and we can become a willing partner in these types of voyages. Most of our equipment is powered similarly to most equipment in these spacecraft or landers. Since our goal is



communications, this will open up a whole new level of DX for everyone wishing to equip their stations to do so. We must start a major effort to protect our higher frequencies and this can be accomplished by using them onboard spacecraft. Higher frequencies mean smaller antenna assemblies and add a bonus of less cost for Joe ham.



As projects come to fruition, manufacturers and construction enthusiasts will have a whole new area for experimentation. School systems will have additional ham radio related projects to keep the interests of students high. Advertised products use pictures to entice. Imagine seeing the latest picture of the Earth on CNN taken from the Mars orbiter via a "Ham Cam."

Speaking of school awareness, tracking programs themselves would be an interesting avenue for introduction into our hobby. After all, if you can't find the ARPP in the sky, communications would be impossible due to the distances, doppler, or what side of the Earth you're located on, all come into play. Thus, involving the computer whiz with position locating could teach more than any Kung-Fu scenario. Our abilities to assemble space qualified packages begins to open possibilities that will give the Space Exploration community an opportunity to meet with the people who find antennas at "K-Mart" and space hardware in surplus warehouses. We design flight worthy power sources and communications equipment to their envy.

Our "Techies" come up with ways to integrate on a regular basis. Some of the commercial satellites up presently use ideas fabricated by Hams. Common power supplies or even use of our RF or video designs for the spacecraft (landingcraft) could lead to many other avenues for our integration. The World listening in on our downlink of information or communications dangles a carrot the size of which the Ham Community has NEVER seen in front of these "Techies."

RECON

Now I don't propose that the *Amateur Satellite Community* open up a SATS "R" US company because we are still "Amateurs!" However, we have the expertise to give us even more exciting satellite projects with a reach only dreamed of before.

Look through the list of proposed projects* Space pioneers have on their plate. We can come up with a few we could possibly add some of our equipment to. Then give suggestions to the proper ears.

Approach the scholastic community that is craving for projects* that can be constructive teaching material to their aerospace students. Discuss possibilities with people in the know and ask what can and can't be done. When an avenue is seen and determined to be fruitful don't stop or give the info to someone who might be in a position to address this better. Explain our goals (again) and find our integration niche.

I can see with all the monies being spent to launch commercial space adventures becoming more commonplace, that the "New Frontier" is about to boom. The technology is at hand to add our systems into the mix. Younger "hams" must be convinced that the hobby is not just a bunch of "Older" gentlemen & women giving newcomers a verbal thrashing for forgetting to use "over" correctly. Projects for these types of adventures will sweep up imaginations and carry the rest of us along with the excitement. Introduction to the hobby by the nightly news or an Internet headline giving details of how hams have jointly made efforts with NASA (or some other aerospace entity) on the "Io" probe could be the catalyst to rope them in. Our future existence, Ham Radio, is in jeopardy. Frequencies must be used to anchor our present ham bands. ARPP should become an everyday word to add our voices, packets, sstv, etc. to the galactic adventures.

*(http://accesstospace.gsfc.nasa.gov/)

About the Author...

Dominick "Dee" Interdonato, NB2F. First involved with Amateur Radio in 1964. Have been licensed ever since. (EXTRA CLASS) Involved with ARMY MARS in the 60's and assisted in MARS programs while in the ARMY. (Avionics trained.) Struggled like everyone else arriving home from Vietnam. Worked in Avionics and two way communications and worked with Satellite Communications and Navigation in the commercial shipping industry. Presently enjoying working as a Communications Equipment Specialist for the Port Authority of NY & NJ.

AMSAT Membership # 9441. I have for the past many years been representing AMSAT at local hamfests in the New Jersey area answering questions and fundraising by offering my "I work for Donations!" attitude at local Ham clubs. After having done this for so long, I can assure you, I've heard pro's and cons in all areas of satellite activity. My booth at hamfests has become a popular hangout for satellite enthusiasts. (lately for "when's PH 3D going up?") Grass roots for AMSAT starts on the "GRASS!"