$12.00

AMSAT

RADIO AMATEUR SATELLITE CORPORATION

PROCEEDINGS OF THE AMSAT-NA

14th Space Symposium, and AMSAT Annual Meeting

November 8-10

1996

Tucson, Arizona

Cliff Buttschardt K7RR
950 Pacific Street
Morro Bay CA 93442

PROCEEDINGS OF THE

AMSAT-NA

14th Space Symposium, and **AMSAT** Annual Meeting

November 8-10, 1996
Tucson, Arizona

Papers courtesy
AMSAT
PO Box 27
Washington, DC 20044

Published by the
American Radio Relay League
225 Main Street
Newington, CT 06111

Printed in USA

$12.00 in USA

ISBN: 0-87259-584-6

ARRL Order Number: 5846

First Edition

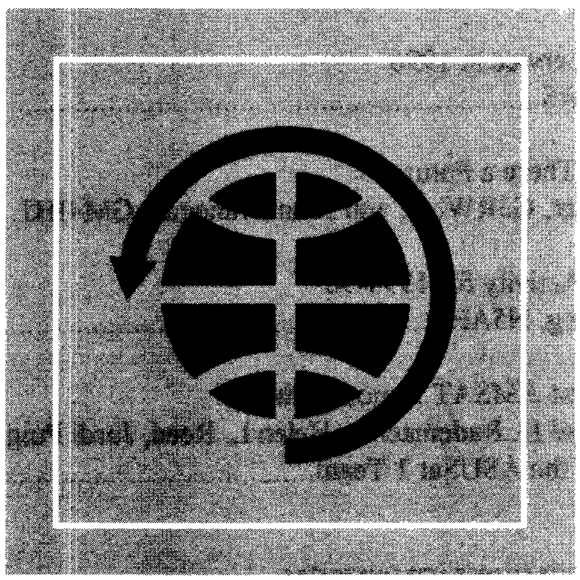


Table of Contents

WELCOME

I am glad that so many amateur satellite enthusiasts are able to attend the 1996 AMSAT Annual Meeting and Space Symposium. It is especially gratifying to see so many people from overseas. Many new faces, not previously seen at AMSAT Space Symposiums (or is it "Symposia" are in evidence. Some were able to come because the meeting is closer to home this year. That's why we hold our gatherings in different parts of the Country. It gives everyone, who wishes, the opportunity to attend one eventually. For example, next year, we will even be going out of the Country, to Toronto, Canada to be exact. But, this year we are happy to be here in Tucson in America's great Southwest.

Although attendance is substantial, a look around reveals the absence of some of AMSAT's key people. There is a very good reason for their truancy. Many of those, who we have grown to expect to see at AMSAT Annual Meetings, are hard at work in Orlando and elsewhere putting the finishing touches on the Phase 3D satellite. For example, Dick Jansson WD4FAB is in France where, in a few days, the European Space Agency (ESA) will begin testing our Specific Bearing Structure (SBS). They will load it up with weights to simulate the force that will be imposed on it as it sits on the Ariane 5 launcher supporting a large communications satellite, as all of them roar into orbit. Lou McFadin W5DID, Stan Wood WA4NFY and others are toiling at the Phase 3D Integration Laboratory in Orlando, getting the spacecraft ready to receive the modules, some of which are already there, and others which will be arriving shortly from overseas. Karl Meinzer DJ4AC, Peter Guelzow DB2OS, Werner Hass DJ5KQ and many others in Europe are finishing up and testing the many RF modules which will give Phase 3D its voice.

Of course, all of us thought that our new satellite would be up and working by this year's meeting. But, as is often the case in the space business, there have been delays on the launcher side as well as on ours. Everyone is aware of the failure of Ariane 501 last June. That event caused a major reappraisal of the Ariane 5 Project by ESA and other organizations associated with it. This, in tern, has caused a significant delay in the flight of Ariane 502, the mission we are on. Latest information puts the launch of 502, with Phase 3D aboard, sometime next April. To meet that schedule, we must have our satellite completed and tested by sometime in February. Every effort is focused on meeting that schedule. But, if another launch slip should occur, we will do everything we can to take maximum advantage of the extra time, to further hone our spacecraft - just as we have been doing over the past year. But, for now, we are focused on the current ESA schedule for an April launch.

Phase 3D could not be where it is today without the help of many people and organizations. This includes those actually working on hardware and software, those looking after the management and business end of the Project and those who have so generously donated the money needed to make this most ambitious and capable Amateur Radio satellite, to date, a reality. Despite the fact that AMSAT members have come up with about $700,000 and the ARRL, and its members, have put in another approximately $530,000, the monetary situation is not a rosy one. Expenditures have also been significant. To date about $1.2 Million has had to be expended by AMSAT-NA alone. The delay in the launch has caused a significant increase in our anticipated total outlay. So, there is still a need for additional contributions. There remain several avenues for participating in Phase 3D fundraising efforts. One, announced last year is a campaign sponsored by AMSAT-UK. Those giving 150 Pounds Sterling or more directly to AMSAT-UK will have their names and call signs inscribed in the spacecraft and sent off into space with it. To facilitate contributions from this part of the world, Eric Rosenberg WD3Q has agreed to act as AMSAT-UK's agent for this fundraising effort. Those interested in being aboard Phase 3D next April, may send Eric a check for $250 for individuals ($400 for clubs). In addition, AMSAT-NA continues to ask it members for assistance. Letters will go to our members in a few weeks making the case for additional contributions in the light of the launch delay. There is also the new AMSAT-NA "Major Donor" campaign which is now underway. This effort is aimed at securing large individual, foundation and corporate donations. Those contributing increments of $2,500 will receive a large plaque depicting Phase 3D, complete with all of its solar cells. Each individual plaque will carry a plate acknowledging the name of the contributor and the specific solar cell, or cells, or other component dedicated to that contributor. In order to encourage those who have already contributed to Phase 3D through regular AMSAT-NA campaign to increase their contribution to necessary to qualify as a "Major Donor", credit will be given for previous contributions toward the $2,500 needed. Naturally, those who have already contributed $2,500 have already qualified, and will receive their plaques soon. A few will be awarded during this meeting, one to ARRL for the over $500,000 it, and its members, contributed in two Phase 3D campaigns.

On behalf of all of Amateur Radio, I want to extend thanks to every individual and organization contributing to the Phase 3D project. I believe that this new spacecraft is destined to bring substantial benefit to our hobby for years to come. The help of all of those who have contributed to Phase 3D, no matter how much, has been crucial in assuring its success.

Although most of AMSAT-NA's energies have been devoted to Phase 3D, we have also been active in SAREX, as well as devoting attention to planning for amateur participation on the International Space Station. We have also spent a little time thinking about other kinds of projects our organization might undertake after completion of Phase 3D. Some of the papers to be presented at this symposium suggest a few possibilities. Please, take advantage of the opportunity afforded by this gathering to discuss, any ideas you have with the authors of these papers as well as AMSAT Board members and officers. It is also a fine time to give your kudos and criticisms to any of the AMSAT-NA officials you encounter. This meeting is yours. You are urged to use it to get your ideas across as well as absorb ideas of others.

I hope you enjoy this 1996 AMSAT-NA Annual Meeting and Space Symposium, and that your attendance will prove to be productive to you, and to the amateur space community.

73 and thanks for coming,

Bill Tynan W3XO

Phase 3D Update

by

The Phase 3D Design Team

Compiled and edited by Dick Daniels W4PUJ

INTRODUCTION

A new era of amateur radio space communications will be launched in the first half of 1997 from Kourou, French Guiana with the Phase 3D spacecraft on the Ariane 502 flight. This satellite, more than six years in the making, will provide a wider range of communications capabilities to amateurs around the world than any amateur radio satellite before. Phase 3D will not only introduce frequencies not previously available in radio amateur space communications, its attitude control capability, coupled with higher gain antennas and higher output transmitters, will make more reliable space communications available to virtually every licensed amateur in the world.

The Phase 3D project is truly international in scope. It is being designed, financed and constructed by an international team representing over a dozen countries. Much of the early conceptual work was done by AMSAT-DL group in Germany. Two of the transmitters which will be aboard are being built in that country along with key receive systems. A 10 meter bulletin transmitter is the product of the Southern Africa AMSAT group. The 2 meter transmitter is being designed and built in the U.K. A group in Finland is supplying the 10 GHz transmitter and its associated antenna. The 24 Ghz transmitter is coming from Belgium. Receivers are also being supplied by groups in Belgium, Slovenia and the Czech Republic. The propellant tanks came from Russia. Spacecraft integration and checkout is taking place in a facility in Orlando, Florida. A block diagram of the Phase 3D spacecraft is shown in Figure 1.

For its flight into space, the Phase 3D spacecraft is now firmly manifested on the Ariane 502 development mission. Following the failure of the Ariane 501, the European Space Agency (ESA) convened a review board to investigate the cause and recommend changes. That board has now reported, targeting software design and testing as the principal culprit. An extensive review and retesting process is being undertaken with launch of Ariane 502 expected during the first half of 1997.

While much of the material included in this report has been made previously available in one form or another, the framework serves as an excellent summary of the project and a good check list for updated technical information and status reporting. Although an effort has been made to provide some progress reporting at the system and subsystem level, it must be recognized that with the accelerating pace of activity much of this information will be obsolete by the time the Proceedings are published.

SPACECRAFT, SPACEFRAME & LAUNCH ADAPTOR

Spaceframe

The Phase 3D spaceframe is a hexagonal structure largely made up of thin-gauge sheet aluminum. Its design evolved through close collaboration between AMSAT-NA and AMSAT-DL after the originally planned Phase 3D structure was made obsolete by an ESA decision not to implement a planned payload interface. It's basically a sheet metal structure designed for strength and light weight. Its fabrication, to rather unusually close tolerances for sheet metal structures, caused more than passing concerns by all who were involved in the effort. Typically these tolerances are in the range of 0.2mm (0.008in.). The secret to this type of very lightweight construction is to place all of the load stresses into the shear plane of the sheet metal, where it is notably strong for its weight. Examples of this are the six Divider Panels connecting to each corner of the spaceframe. The only machined parts in the spaceframe are six Corner Posts at the outer ends of the Divider Panels. These must be robust enough to carry all of the launch thrust loads into the spaceframe, translating these forces into the plane of the 0.8mm thick sheet metal Divider Panels as sheer forces. The three Corner Posts anchored to attach points in the launch adaptor will be heavily loaded in all directions during launch.

Two flight structures were fabricated by students and their advisors at Weber State University in Utah. The primary structure has been in the clean room at the Orlando, Florida Integration Facility for some time now where installation of flight systems is well underway.

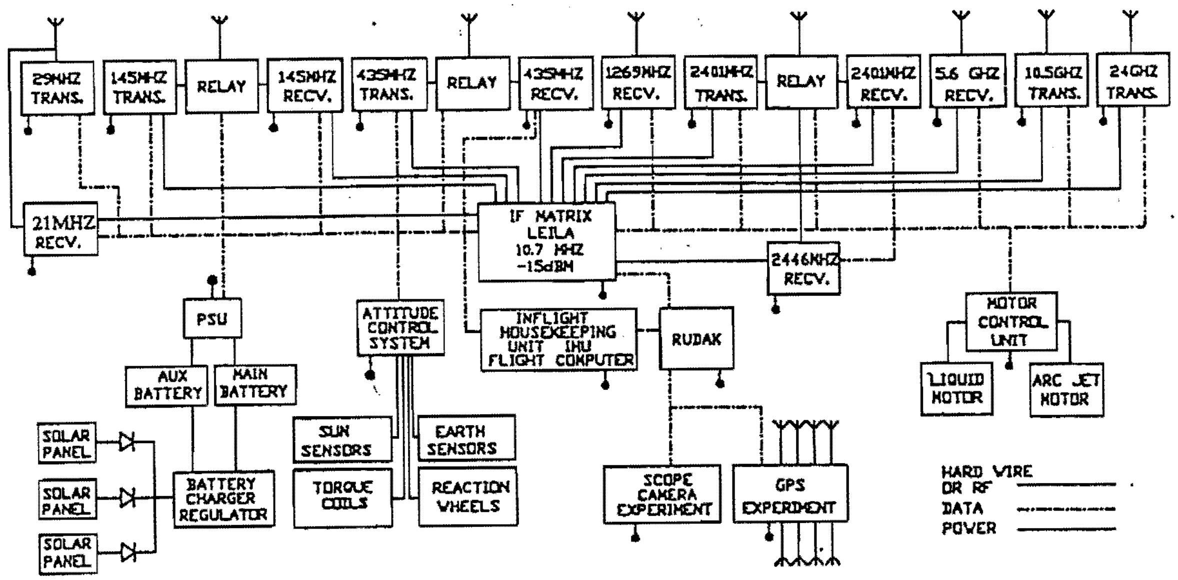


Figure 1
Phase 3D Block Diagram

SBS

Since Phase 3D was designed to fly as a secondary payload on the Ariane 5 launch vehicle, it had to conform to the volume The European Space Agency (ESA) was willing to make available for it. After the ESA decision to not implement the 1920 mm payload interface, the only available alternative was use of a conical adaptor which interfaces between the 2624 mm diameter bolt circle on the Ariane upper stage to a 1194 mm diameter clamp-band used for major payloads was already available. Although hollow, the conical adaptor did not provide sufficient volume to house Phase 3D, or any other reasonably sized payload. Accordingly, the AMSAT group offered, and ESA agreed, that AMSAT could provide a cylindrical "spacer" to mount between the 2624 mm diameter bolt circles on the bottom and the conical section on the top. This provided the necessary space to mount the Phase 3D spacecraft inside the cylinder. Since it is a part of the payload stack, this spacer had be able to accommodate another major payload satellite sitting on top of the conical adaptor. Thus, AMSAT provided 2624 mm diameter spacer, or "Specific Bearing Structure" (SBS), as it has been named, had to be able to not only support the 400 kg weight of Phase 3D but also withstand the load forces imposed by a 4.7 metric ton (10,350 lb.) mass. Providing assurance that the design is capable of handling such a load required extensive computer structural analyses to be performed (on the same home computer used to accomplish the thermal analysis).

As with the space frame, the fabrication of the SBS was carried out at Weber State University . A second unit was later built off campus by a number of the same individuals that had been involved in the student project. One unit has been shipped to France where static tests of the payload stack are being conducted by ESA to confirm the structural analyses.

POWER SYSTEM

Solar Arrays

Phase 3D incorporates transmitters of considerably higher power than used on previous amateur satellites, some capable of several hundred Watts output. Generating the power needed to support these transmitters requires substantial power, and hence quite large solar panels. The design which evolved calls for a total solar panel area of 4.46 m2 (48 ft2) and solar cells of 14.3% efficiency. At optimum sun angle, this array will produce about 620 Watts of power at beginning-of-life (BOL). Like almost anything else, solar arrays deteriorate with age. After 10 years in orbit, it is expected that panel output will still be about 350 Watts even at a 45 degree sun angle. This is sufficient to operate at least two transmitters and the other necessary spacecraft systems. After investigating a number of sources and configuration of solar cells, AMSAT was fortunate to obtain the needed cells through a very attractive agreement with DASA, the German Space Agency which also undertook to fabricate the arrays on carbon composite substrates provided as a donation by a U.S. firm.

Phase 3D will employ four deployable solar panels in addition to the two mounted on the spaceframe. This will be the first time deployable panels are used on an amateur satellite, requiring mechanisms to initiate their unfolding plus appropriate hinges and latches to achieve and maintain the desired final configuration. One of the German members of the design team suggested the solution to the hinge design. The type found at the entrance to German bistros, the same kind seen in old-style North American western saloons - the cabaret hinge. This hinge is able to swing both ways but always return to the desired center position. A sample was actually obtained at a local hardware store to demonstrate the utility of the principle. As there is not a lot of excess space around the Phase 3D spacecraft when installed in the SBS, this hinge design had to go through several gestations in order to achieve the desired configuration that could be accommodated in the space available. This effort included finding a spring wire material able to withstand the rigors of operation at temperatures as low as -100 degrees C.

The fabrication of the solar arrays in Germany has been completed. They have been shipped to Orlando and are currently stored at the Integration Facility.

Batteries

While solar panels are satisfactory as a primary source of power, some form of energy storage is necessary, not only to power the spacecraft during times that the sun is eclipsed by the earth, but also to operate the arc-jet thruster, described later, whose power requirements exceed the capability of the solar arrays, even under the best of sun angle conditions.

The Phase 3D satellite will carry two batteries, a "main" and an "auxiliary" to provide redundancy in case of failure of the main battery. The Phase 3D design team evaluated several sources and types of batteries. Options ranged from nickel-cadmium cells to use of an assembly of nickel-metal hydride cells for the main battery and a more conventional nickel-hydrogen stack for the auxiliary. The final decision was to select the more or less conventional nickel-cadmium cell for both batteries, albeit with a new plate design, proposed by a German firm. As in the case of the solar cells, cost, and the fact that they can be expected to perform reliably and satisfactorily, was the deciding factor in selecting the German nickel cadmium cells.

The main battery is complete and in storage at Marburg, Germany. Due to its nature, shipping it to Florida has proven a little more difficult than envisioned. The auxiliary battery is complete and at the Orlando Integration Facility.

Battery Charge Regulator

Three Battery Charge Regulators (BCR's) control the flow of current from the solar arrays to the batteries. Similar in design to those used in OSCAR 10 and OSCAR 13, these regulators sense the charge condition of the batteries and regulate the flow of current from the arrays at a rate required to keep the batteries fully charged, but not overcharged. Constructed by a group at the Technical University of Budapest in Hungary, the BCR's are designed for reliability and efficiency. Two techniques utilized to improve efficiency are the sensing current flow from the arrays using magnetometry techniques, rather than dropping resistors; and controlling the current flow from the arrays by electronically shifting the operating point on the solar cells' I/V curve. While the basic design follows that of the OSCAR-13 units, considerable beefing up was necessary to handle the much heavier current flow from the larger Phase 3D arrays.

The first of three BCR's has been delivered to the Orlando Integration Facility and is undergoing testing. The remaining two are in fabrication at Budapest and are expected to be shipped shortly.

HOUSEKEEPING, COMMAND & CONTROL

IHU

The Phase 3D satellite incorporates a primary computer called the Integrated Housekeeping Unit (IHU). It is tasked with running all aspects of the satellite from power management to attitude control. It is the IHU which will command the turning ON and OFF the various transmitters, the switching of antennas etc. The Phase 3D IHU is similar in design to the one used on the previous Phase 3 satellites, OSCAR 10 and OSCAR-13. It employs a radiation hardened 1802 COSMAC microprocessor for the CPU. While this is a rather "old" device and performance improvements might have been achieved by the use of newer technology, it was decided that it would adequately serve the needs of this spacecraft. It is a "known quantity" with proven capability to act as an excellent multi-tasking system controller. Much of the needed onboard software already in-hand written in a high level language called IPS (Interpreter for Process Systems). IPS was created by the AMSAT-DL group specifically for the purpose of operating the Phase 3 satellites. The primary differences between the older IHU and the Phase 3D design is summarized as follows:

- The Phase3D IHU contains 64k bytes of error-detection-and-correction (EDAC) memory, compared to 32k bytes for AO-13.

- The physical size of the IHU modules is different. The one used in AO-13 measures 200mm x 300mm, whereas the Phase 3D module is smaller - 200mm x 270mm.

- The AO-13 IHU occupied two double-sided PC boards with a wiring harness joining them and attaching the connectors to the rest of the spacecraft, while the Phase 3D IHU is on a single, multi-layer PC board with all connectors soldered directly to the board. There is no internal wiring harness in the Phase 3D IHU.

- The AO-13 IHU required a separate command decoder, housed in a separate module. The Phase 3D IHU incorporates the command decoder on its PC board.

The design of the IHU is complete and a breadboard unit has successfully passed all tests. The flight unit is now under construction in Tucson, Arizona. A prototype unit has been delivered to the Orlando Integration Facility to assist in early integration activity.

RUDAK

In addition to the IHU, Phase 3D computing compliment also includes a digital communications experiment, called "RUDAK". RUDAK is an acronym from the German "Renerativer Umsetzer fur Digitale Amateurfunk Kommunikation." This roughly translates to "Regenerative Transponder for Digital Amateur Radio Communication." The name is taken from a similar experiment built by Amateurs in Germany and flown on AO-13 and a Russian amateur satellite, RS-14 (AO-21). On the latter, it was used for some time in an "FM Repeater" mode; receiving FM voice transmissions on 70 cm, digitizing and processing them, and finally retransmitting them as analog voice FM modulation on 2 meters. This mode became quite popular and did much to bring satellite operation to amateurs not heretofore exposed to it. Unfortunately, this satellite ceased operation in October 1994. While RUDAK is primarily designed as a communications device, it also incorporates powerful computing capability and can, through the CAN bus next described, share computing tasks with the IHU as well as support the high data rates required by the GPS Receiver Experiment and the JAMSAT SCOPE Camera Experiment. The RUDAK to be flown on Phase 3D is being designed, constructed , programmed and will be commanded by a team of individuals from AMSAT-NA and AMSAT-DL.

Early in the operational life of the satellite, it is planned to support packet-based communications similar to that performed by the existing MICROSATs and UoSats. Flexibility in the design will allow it to be reprogrammed to support newer digital communications techniques that are likely to be developed during the life of the mission.

Like the IHU, the RUDAK design work and prototyping is largely complete. The RUDAK is being designed and constructed by the Tucson group.

CAN Bus

The Phase 3D IHU incorporates an experimental high data rate networking adapter called the Controller Area Network (CAN) Bus. Based on an automotive standard widely used in Europe and Japan as well as the U.S., the CAN bus will be used to tie the RUDAK and the IHU into the other spacecraft computer-based systems, particularly those with high data rate requirements such as the GPS Receiver and the JAMSAT SCOPE Camera.

The CAN Bus design has been frozen and interface circuits have been designed and tested. Some of the electronic modules will incorporate this design into their electronics boards. For others, separate interface boards have been fabricated and are being provided to the builders.

ATTITUDE CONTROL SYSTEM

Previous Phase 3 satellites have been spin stabilized and normally only pointed Earthward during a small portion of their orbits. A key design requirement for Phase 3D is to be oriented toward Earth throughout its orbit to permit full time use of high gain antennas and thereby significantly improve communication links.

Commercial communications satellites normally depend on a spinning body and despun antennas to achieve pointing and depend on cold gas jets to maintain orientation and station keeping. In order to obtain as long a life as possible for Phase 3D, it was decided early-on that some means other than stored gas had to be used to maintain proper orientation of the satellite. Thus the decision to go to reaction wheels. The momentum, associated with the spin of these wheels can be used to orient and hold the spacecraft in position. The remaining degree of freedom (rotation of the spacecraft about the antenna boresight axes) will be used to maximize the amount of sunlight illuminating the solar panels.

This is not a simple system. For three-axis active control, Phase 3D requires not only the interaction of the three magnetically suspended, orthogonally mounted reaction wheels, but also a complement of Earth and Sun sensors and associated electronics, two rings of electromagnets, the field of which can be stepped through six directions, six nutation dampers, all under control of the IHU and the Sensor Electronics Unit (SEU). Successful functioning of all six of these systems is necessary to achieve and maintain attitude control. The sensors provide the necessary references for accurate pointing; the three reaction wheels, acting like gyroscopes, use their momentum to provide the spacecraft with the means to hold its position and the magnets provide a means for unloading momentum buildup from the wheels. The SEU processes the sensor data and performs other housekeeping tasks in support of the IHU.

"Navigation" requirements add considerable complexity to both the hardware and software design. First, the satellite must "know" its orientation with respect to space and then calculate its orientation with respect to Earth - depending on its location in the orbit. Sun and Earth sensors provide information to the spacecraft main computer which then calculates the satellite's spatial orientation. To do this, the IHU must be able to rapidly solve equations in several reference systems. However, merely determining the orientation solves only part of the problem. Once orientation is known and the necessary changes made to point to earth, it is then necessary to continually correct for misorientation caused by the satellite traversing its orbit as well as smaller drifts that build up over time.

Reaction Wheels

A key technology innovation being introduced in the Phase 3D is the magnetically suspended reaction wheel. Commercial momentum wheels depend on precisely manufactured and carefully lubricated bearings to support them. These are subject over time to failure due to evaporation of lubricant or the frictional wear over the life of a spacecraft. The Phase 3D wheels, designed, developed and fabricated by the AMSAT-DL group, avoid this problem by using magnetic force to suspend them. By using a combination of rare earth magnets and electromagnets the wheels are suspended and spun up. When the wheel is operated, sensors establish position of the wheel and this data is electronically processed and fed to the electromagnets to modulate the force of the fixed magnets to keep the wheel centered. Another set of coils are used to spin up the wheel in a manner similar to driving the armature of an electric motor. With three wheels, mounted 90 degrees to each other, it is possible to redistribute momentum between the wheels by simply controlling the speed of each individual wheel. Since the initial momentum of the spacecraft is conserved, and thus fixed in space, the only way a redistribution of momentum can take place is by the spacecraft itself changing its attitude. Each wheel is expected to consume about 5 W of power for a total of 15 W. A cut-away drawing of one of the wheels is shown in Figure 2 .

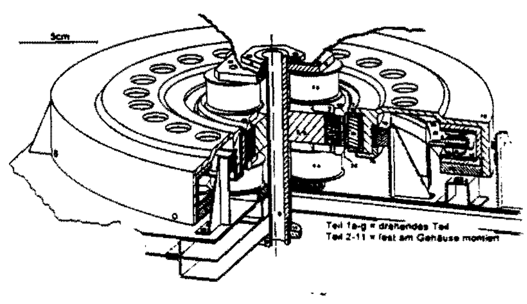


Figure 2

Cut-away drawing of reaction wheel.

A prototype momentum wheel has been built in Marburg and been operated successfully for some period of time. Flight units are currently under construction. Figure 3 is a photograph of the prototype wheel. Support for flight electronics boards is being provided by the Tucson group.

Magnetic Torquing System

The magnetic torquing system, is similar to the ones developed for use in OSCAR-10 and OSCAR-13. It consists of two hexagonal rings of electromagnets magnets circling the spaceframe made up of 12 wire wound rods. Working against the Earth's magnetic field at perigee, where the field is strongest, the system provides a capability to control both the spacecraft's attitude and spin rate during its spinning mode.

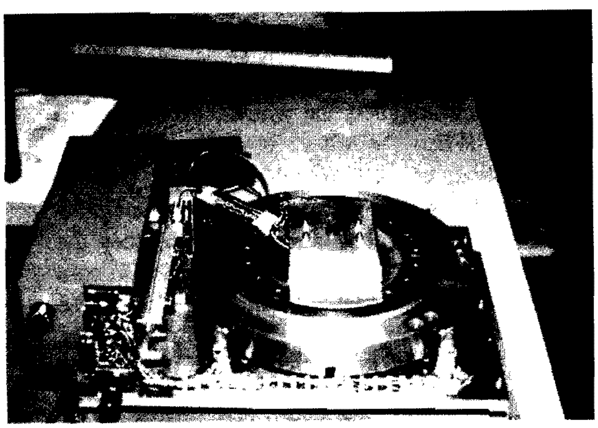


Figure 3
Prototype Reaction Wheel at Lab in Marburg, Germany

The two magnet rods, one each side, are in series, with a parallel connection to the two rods on the opposite side. This allows for a total of three magnet combinations, each one of which is switched by the IHU to send current in either of two directions. Thus, six possible polar conditions are available. As the current to the rods is computer controlled, it can be quickly switched to take care of spinning conditions. The total power dissipation is about 10.7 W. The rods are operated at a flux of about 1.2 Tesla (12,000 Gauss).

Following launch, the first task of the torquing system will be to stabilize the Phase 3D spacecraft, then orient it and spin it up in preparation for 400 Newton motor burns. After the major orbit changes are made, the spacecraft will be despun and the solar arrays deployed. For the remainder of the mission the primary use of the torquing system will be to off-load momentum that builds up in the reaction wheels. It is unavoidable that solar radiation pressure will exert a small, but finite, force on any spacecraft. It would be very unusual, and fortuitous, if this force were to pass through its center of gravity. Since it doesn't, this misalignment of radiation pressure causes some small amounts of torque that can act to change the satellite's orientation. Compensating for these "nuisance" torques will result in a buildup of speed in the wheels that could, eventually lead to their structural failure. Preventing this, requires periodic "momentum dumping" by using the torquing magnets acting against the Earth's magnetic field as a source of the necessary force.

The torquing magnets have been fabricated and are currently installed in the flight spaceframe at the Orlando Integration Facility.

Nutation Dampers

Since Phase 3D will be spin stabilized during its early life in orbit and through the first motor burns, it, like AO-10 and AO-13, will have the need for nutation dampers to keep the spin axis true. The units to be used on Phase 3D are residual hardware from the earlier projects. Curved aluminum tubes evacuated and sealed at both ends containing a mixture of glycol and water are placed in several locations on the outer perimeter of the spacecraft. They act to take out any wobble in the spin axis.

SEU

The Phase 3D Sensor Electronics Unit (SEU) is closely patterned after those used in OSCARs 10 and 13. This proven module is responsible for processing a variety of input/output tasks in support of the IHU. These include processing the outputs of the Earth and Sun sensors, monitoring currents in the power buses, controlling the antenna relays and issuing commands to the LIU.

The flight SEU is being constructed by a group of volunteers in San Antonio, Texas. Their task has been to repackage the electronics to fit in a Phase 3D standard module size and to update the design as necessary to utilize currently available components.. Their design work is complete and released to a board house which will produce the flight boards.

PROPULSION SYSTEMS

To move the spacecraft from the low-inclination, geosynchronous transfer initial orbit provided by the Ariane 502 launcher, to the highly inclined, more eliptical orbit required by the Phase 3D spacecraft - and keep it there - two onboard propulsion systems are required. The primary system is a higher thrust bi-propellant liquid rocket motor with its associated tankage, plumbing and control circuitry. The other is a much lower thrust arc-jet system using ammonia gas as the reaction mass.

The 400 Newton System

The higher thrust bi-propellant propulsion system is a repackaged version of the one used successfully in the OSCAR 10 and 13 satellites. It is designed around a 400 Newton (95 pound) thruster, that has been provided by a German aerospace company. This motor burns mono-methyl-hydrazine (MH) for fuel and nitrogen tetroxide (N_2O_4) for oxidizer. A photograph of the motor to be used in Phase 3D is shown in Figure 4.

Figure 4
Licquid Fuel 400 Newton Rocket Motor to be used in Phase 3D

Because of the mass of the Phase 3D spacecraft and the need to maintain balance, multiple tanks (two for each propellant) are required to carry the quantity of propellent needed for the mission. This amounts to over 60 kilograms of fuel and 130 kilograms of oxidizer. The plumbing required for loading the system and feeding the propellants from the tanks to the thruster has been designed for simplicity, but with sufficient redundancy to assure safety and reliability. Helium gas from a high pressure storage tank is reduced to the system operating pressure by a regulator that uses an electrically operated gas valve referenced to the feedback from a pressure transducer, a technique known as a "bang-bang" system. A second electrically operated valve, in series with the first, provides redundancy and stand ready to take over the regulating task should the first valve fail open. Helium is then fed to the propellant tanks through redundant check valves to force the propellants into the motor. Ullage is provided by spinning the spacecraft up before and during each burn to assure proper propellant flow.

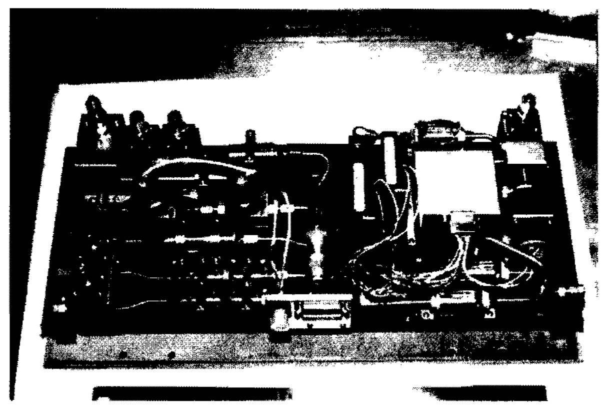


Figure 5
Flight-ready PFA

PFA

The Propellant Flow Assembly (PFA) Figure 4) provides the mounting base for most of the hardware required to support the operation of both the 400 Newton system and the arc-jet system described below. It concentrates all the fill and drain valves for loading and unloading all propellants. In the 400 Newton section, are the pressure regulating valves, pressure transducers, the redundant check valves through which the propellant tanks are pressurized, the helium gas connection to the 400 Newton thruster and a relief valve to protect against system overpressure. The arc-jet section includes the ammonia fill point, a heater to assure that only ammonia gas reaches the arc-jet, redundant mass flow controllers and three solenoid valves to direct the flow of ammonia gas. Pressure transducers measure input and output pressures.

The flight PFA (Figure 5) is complete and mounted on the spaceframe. Leak tests will be conducted on the overall propulsion system shortly.

LIU

The Liquid Ignition Unit (LIU) is the electronic module that controls the 400 Newton motor system. After receipt of validated firing commands, this module initiates the firing sequence by operating the pressure regulating valves that pressurize the propellant tanks, commands the opening the motor valves, clocks the burn time and safes the system at the end of burn. This system has been flight tested in previous Phase 3 missions and has proved fully capable of supporting the multiple burns necessary to reach the final orbit.

The flight LIU is under construction at the Orlando Integration Facility.

ATOS Arc-jet System

Once the Phase 3D spacecraft nears its final orbit the propulsion task will be shifted a small arc-jet thruster, (ATOS), to make final adjustments and provide for orbit maintenance. Compared to the 400 Newton thrust of the primary propulsion system, this motor puts out a mere 100 milli-Newtons thrust, but it does this with much higher efficiency than the larger motor. A photograph of the arc-jet thruster to be used in Phase 3D is shown in Figure 6.

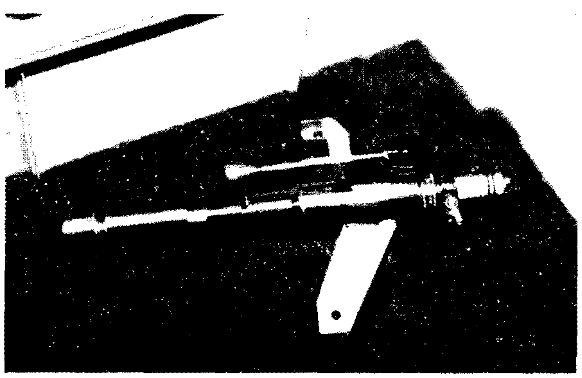


Figure 6
Phas 3D Arc-jet Motor

The arc-jet thruster was developed by a group at the Institute for Space Systems at the University of Stuttgart in Germany, with support from AMSAT-DL. While the principle of the arc-jet is well known, coming up with a reliably operating device proved to be a daunting task, requiring long iterative process of design, testing, redesign and more testing. This was made more difficult by the necessity to conduct thruster firings under vacuum conditions. A lifetime testing of a flight quality thruster has proved the design to be sound. Figure 7 shows one of the arc-jet firing tests.

To operate the arc-jet system, a high voltage high current DC pulse is generated to strike an electrical arc at the motor's nozzle. Immediately following initiation of the arc, voltage is reduced to the 80 volt level necessary to maintain the arc. Ammonia gas is then metered through the arc and hence heated to a very high temperature, causing it to rapidly expand in the nozzle and thereby generate highly efficient thrust. The arcjet provides long-term capability to perform the minor adjustments necessary to correct for the orbit instabilities introduced by the lunar and solar perturbations causing the re-entry of OSCAR-13.

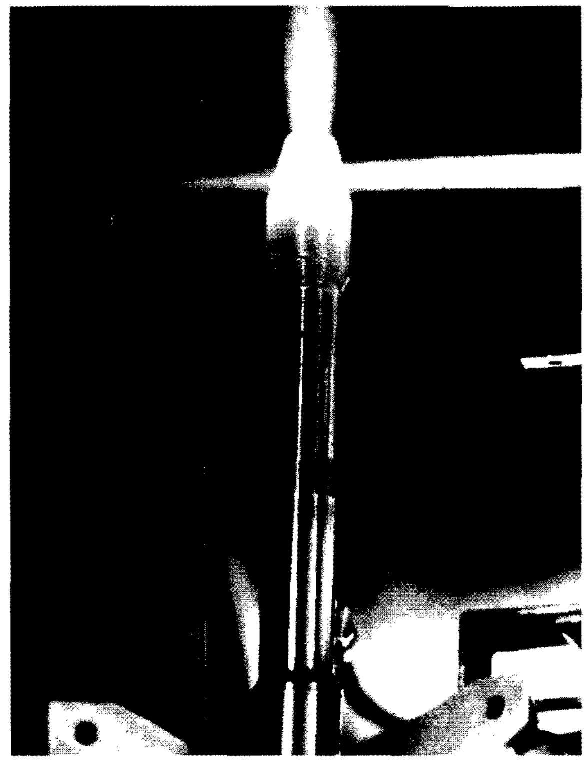


Figure 7
Arc-jet Firing Test in Germany

EPU

The Electric Propulsion Unit (EPU) is the module that contains the control electronics and electrical circuits needed to generate the voltages and currents required to operate the arc-jet. It also controls the ammonia gas generator, valves and mass flow controllers located in the arc-jet section of the PFA.

The EPU prototype has been used for the arc-jet motor testing. The flight unit is under construction by the AMSAT-DL group in Marburg.

A block diagram of the Phase 3D propulsion system is shown in Figure8

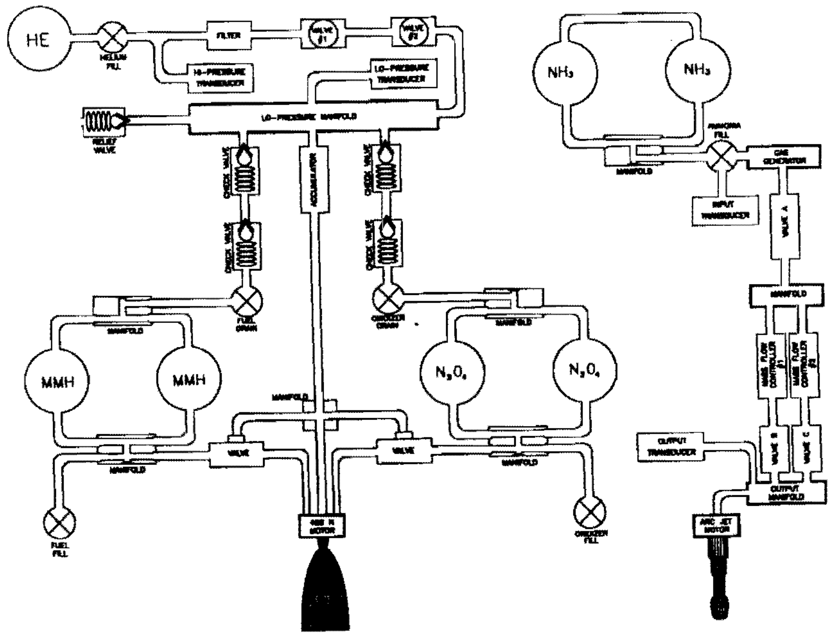


Figure 8
Propulsion System Block Diagram

THERMAL CONTROL

The earlier Phase 3 satellites handled the balancing of temperatures within the spacecraft by spinning, rotisserie fashion. The requirement for three axis stabilization makes thermal control much more difficult. for Phase 3D. Once in its desired orbit and orientation, Phase 3D will be fixed in three-dimensional space, with the antennas continually facing Earth and with the solar arrays pointed in the direction of the sun. This causes some interesting thermal design problems as the spacecraft is baked on one side by the Sun and exposed to the cold heat sink black space on the other. The .solution chosen to overcome these problems combines the use of heat pipes and thermal coatings.

Heat Pipes

A heat pipe is a thermal linkage of very high conductivity consisting of a closed, evacuated tubular chamber with walls lined with a wick and partially filled with a fluid. The fluid used in the Phase 3D heat pipes is anhydrous ammonia. The ammonia is vaporized at the hot end. The vapors then move through the hollow core of the tube, and condense at the cold end from which the resulting liquid is returned through the wick to the hot end by capillary action. By this process, heat is continuously transported from the hot to the cold end. Heat pipes typically offer a heat transport capability many times greater than the best heat conducting materials. The process requires no power and operates satisfactorily in zero-G.

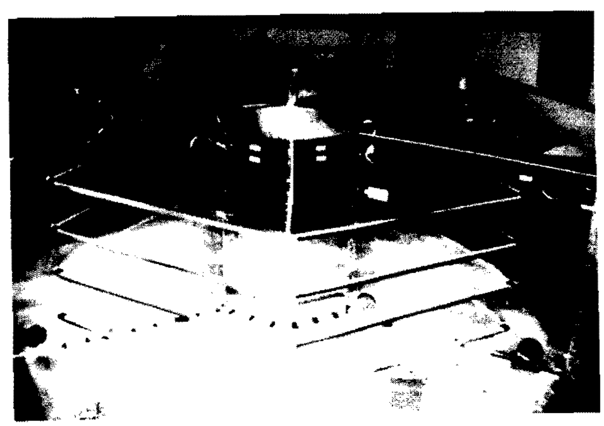


Figure 9
Heat Pipes

In the case of the Phase 3D spacecraft, four internal ring-shaped heat pipes are employed in a manner that can be likened to a rotisserie in reverse, as they remove heat from one part of the spacecraft and re-distributing it to other parts where it is ultimately transported through the sides of the spacecraft and radiated to space - the ultimate heat sink. What is believed to be a unique feature of this heat pipe system, as employed on Phase 3D, is that none of the heat pipes come in direct contact with space-facing panels. Instead they depend upon indirect re-radiation of the heat from internal equipment mounting panels to side panels that are deliberately allowed to become cold. Thus, the electronic equipment modules maintain their desired temperatures because of the thermal influence of the heat pipe system, regardless of whether those modules are mounted on the solar heated side, or on the cold backside of the spacecraft.

The heat pipes were procured from a commercial source and have been installed in the flight space frame at the Orlando Integration Facility. Figure 9 is a phot of the heat pipes.

Coatings and Surface Preparation

While the heat pipes go a long way toward solving the problems of heat transfer within the spacecraft, thermal characteristics of the external spacecraft surfaces must still be dealt with. The earlier Phase 3 satellites employed multi-layer thermal insulation blankets on their top and bottom surfaces to maintain the desired temperatures. As the required assembly technology is very exacting, such blankets are difficult to fabricate. The thermal design chosen for Phase 3D eliminates the need for thermal blankets. Side panels will be painted black to enhance heat rejection. The top and bottom panels will be mostly solar energy absorbing metallic finishes of several different types, depending upon the location and desired temperatures of that section of the spacecraft. In general, this thermal design calls for the mean spacecraft temperatures to be between -5 and +20 degrees C for the expected range of sun angles from -80 to +80 degrees.

Extensive computer thermal analyses have been conducted to provide confidence that this design will achieve the desired results. In order to give accurate results, these analyses required complex iterative calculations incorporating a large number of nodes in the spacecraft. Early thermal analytic computations for Phase 3D were carried out using a home computer of the 80486-DX2/66 class; a process that required crunching numbers for 10 to 13 hours per run to produce a series of temperature performance curves.

Once a 90 MHz Pentium was installed, these runs were cut to 3 hours.

THE ORBIT

Considerable analysis and discussion went into selection of the Phase 3D spacecraft's final orbit. Like all of the other design considerations, it too has been engineered to bring the most benefit to as many amateurs through out the world as possible. As did OSCARs 10 and 13, Phase 3D will go into a 60-some degree inclined, highly elliptical orbit of the Molniya variety. But there, the similarity ends. The apogee (high point) will be much higher than the previous satellites - about 48,000 km versus 36,000 km for the earlier satellites. The perigee (low point) will also be higher, about 4,000 km. This yields an orbital period of 16 hours.

Because the Earth rotates once every 24 hours (twice in 48 hours), a 16 hour orbit results in three complete orbits every two days. This two day repetition will make it much easier for those using the satellite to remember when Phase 3D will return to a given position. Furthermore, Phase 3D will go through apogee every 16 hours. In this time, the Earth rotates 240 degrees or 16 time zones. The result will be to place one apogee over North America, the next over northern Europe and the following one over the Far East. Because of this synchronism between the satellite's orbit and the Earth's rotation, it will go through apogee at approximately the same local time for each area every two days. To illustrate how this will work, consider the example of an amateur in the Midwest section of the U.S. Phase 3D will be visible for many hours, at a high elevation angle, centered on, say 8:00PM Central Time. It will then drop rapidly and reappear 16 hours later over Asia. But it will be high enough so that it will be within sight of much of the Country. Thus, it will appear to rise rapidly in the northwest and hang for a number of hours and then drop very suddenly. Sixteen hours later it will do the same thing, this time in the northeast during its European apogee. But the local times for each apogee will always be centered on 8:00 PM.

The Keplerian elements from Table 1, when entered into a satellite tracking program, will serve to illustrate how Phase 3 will behave at any particular location.
Of course, some of these elements may vary somewhat from the final orbit Phase 3D attains, but they should serve to illustrate how you will be able to use the new bird.

Table 1

Phase 3D Orbital Elements

1991	
Epoch	91 80.0000000
Epoch Rev.	1
Mean Anomaly	0.0000000000 Deg
Mean Motion	1.5000000000
Inclination	63.4343490 Deg
Eccentricity	0.67743780
Argument of Perigee	220.000000 Deg
RAAN	225.000000 Deg

PAYLOADS

The Important Stuff

So much for all the necessary things that must be there in order to build a satellite, now for the stuff we hams are most interested in - the receivers, transmitters and antennas. After all, it is these that we will be directly interfacing with when we work through Phase 3D.

A New Approach

Previous amateur radio communications satellites have incorporated one or more communications transponders, dedicated systems that receive signals on one band of frequencies and put out an amplified replica of these same signals on another band of frequencies. Instead of transponders, which limit flexibility, Phase 3D's communications package consists of a series of receiver front-ends and transmitter mixer/power amplifiers linked by a common intermediate frequency (IF) matrix. The outputs of the receiver front-ends are connected to the IF Matrix, which in turn can drive any of the mixer/power amplifiers - all under computer control. This means that uplinks and downlinks can be set up on any of the bands for which hardware exists on the satellite. This is very important, because no one can say with certainty what bands will be most viable for uplinks and downlinks in the years to come. By configuring the satellite in this manner, a variety of circumstances can be accommodated over Phase 3D's expected 10 to 15 year life. A block diagram of the communications system, indicating the various uplink and downlink frequencies, is shown in Fig 10.

Table 2

Phase 3D Band Designations.

Band	Uplink	Downlink
15m (21 MHZ)	H	None
10m (29 MHZ)*	None	T
2m (146 MHZ)	V	V
70cm (435 MHZ)	U	U
23cm (1260 MHZ)	L	None
13cm (2.4 Ghz)	S	S
5cm (5.6 Ghz)	C	None
3cm (10 Ghz)	None	X
1.25cm (24 GHz)	None	K

* The 10 meter transmitter is for furnishing bulletins and similar information only, and is not configured to support two-way communications.

Because of this flexibility to interconnect various receivers with various transmitters; the old "Mode" designations, which amateur satellites have used for years, has become obsolete. A new system of designations will be put into use on Phase 3D that calls for separate letters designating the various uplink and downlink bands. Each uplink/downlink configuration will employ one or more letters depending on which link(s) are activated. The uplink(s) will come first, followed by the downlink(s). The various bands,currently planned for Phase 3D, will be designated as shown in Table 2. Thus, what is currently called "Mode B" will become "Configuration U/V". Because of the flexibility offered by the matrix, combinations such as "Config. UL/VSX are possible. Naturally, combinations such as U/U, V/V or S/S are not possible, even though both receivers and transmitters exist for these bands, because transmitters and receivers cannot be operated simultaneously on the same band.

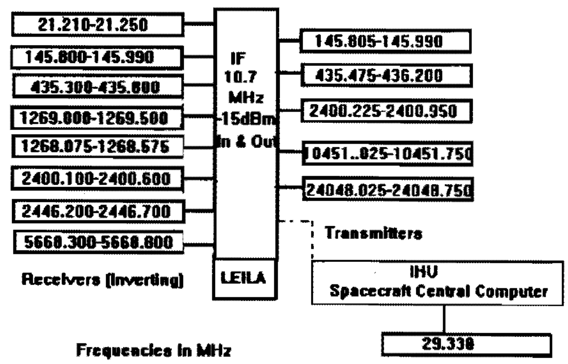


Figure 10

Communications System Block Diagram

Overall Design Considerations

Four specific design features are being incorporated into Phase 3D to provide greater ease of use and to increase its flexibility. First, the transmitters will have significantly higher output powers than either OSCARs 10 or 13. Second, the antennas on Phase 3D will have higher gain than their cousins on the earlier satellites. Third, if everything goes as planned, Phase 3D's high gain antennas will always point toward Earth.

Both OSCARs 10 and 13 were designed to be spin stabilized in inertial space. Thus, for only part of their orbits, their "high" gain antennas might be oriented toward Earth, but for the rest of the time, they are pointed out into space. In order to provide some operation during this time, both satellites include low gain antennas which are used during these times. Table 3 shows how Phase 3D will compare with OSCAR 13 when that satellite's "high" gain antennas are in use.

Table 3

Transmitter PEP and Antenna Gain for Phase 3D & AO-13

	AO-13 Xmtr Pwr W	Ant gain dB	EIRP W	P-3D Xmtr pwr W	Ant gain dB	EIRP W	P-3D Advantage dB
2m	50	5.5	180	75	11	600	6.5
70cm	50*	9	400	250	15	8,000	13
13cm	1	9	8	50	19	4,000	27
3cm	--	--	--	50	20	5,000	--
1.25cm	--	--	--	1	20	100	--

* This transmitter is no longer functioning.

Receivers

It is planned that Phase 3D will have receivers for 15 meters, 2 meters, 70 cm, 23 cm, (1269 MHZ), 13 cm (2.4 GHz) and 6 cm (5.668 GHz). Actually, there will be two receivers for 13 cm, one at 2,401 MHZ and another at 2,446. MHZ. The latter is especially included to assess the possible use of this part of the spectrum for uplinks for possible future amateur satellites in the presence of microwave ovens.

The receivers are being constructed by various European groups and are either complete or nearing completion.

IF Matrix

The IF matrix provides the facility to be able to connect, under control of the IHU, any receiver with any transmitter. It also includes the LEILA, discussed in the following paragraph. The IF frequency used is 10.7 MHZ and the system has an input and output level of -15dBm.

LEILA (The Alligator Eater)

The LEILA or "LEIstungs Limit Anzeige", or Power Limit Indicator, is designed to counter one of the problems faced since the first amateur satellite carried a transponder - that of the "power hog", sometimes also referred to as an "alligator". Most of the linear transponders average transmit power over the current users in the passband. They also incorporate AGC circuits that reduce the gain of input signals to control transmit power. Thus, a ground station which uses much more power than necessary to produce a useful signal through the satellite, in effect, reduces the receiver sensitivity for others attempting to use the transponder. In the past, the only recourse, other than turning the satellite OFF completely, was to warn the offending operator or refuse to talk to the person. Phase 3D will incorporate the LEILA circuit, designed to counter "power hogs". If a signal above a certain threshold is detected, LEILA will first put a Morse transmission on the frequency. It might say something like "PSE QRP". If that does not cause the offender to turn down the wick, LEILA will place a notch on the frequency - which should accomplish the desired objective. A block diagram of LEILA is shown in Figure 11.

Flight hardware for the IF Matrix/LEILA, designed and constructed in Slovenia, are in Marburg.

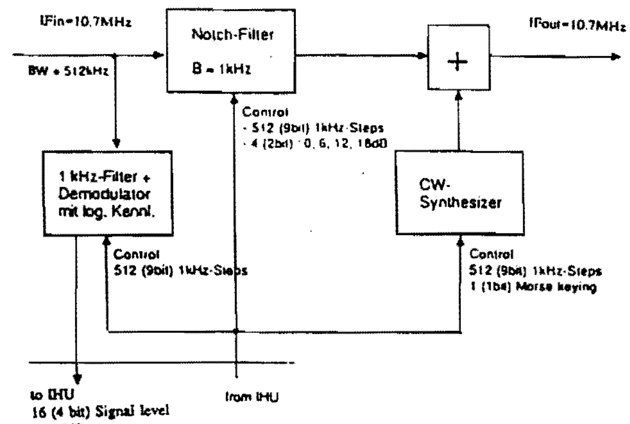


Figure 11

LEILA Block Diagram

Transmitters

Phase 3D will incorporate six transmitters for 29 MHz, 146 MHz, 435 MHz, 2.4 GHz, 10 GHz and 24 GHz. All except the 29 MHz transmitter will be connected to the IF matrix, so that they can accept input signals from any of the receivers. The 29 MHz transmitter is intended to transmit bulletins, primarily near perigee, and is being constructed by the South African AMSAT group. All other transmitters will be connected to the matrix and have bandwidths of a nominal 500 kHz, except for the 146 MHz transmitter which is limited to 200 kHz by the available space for satellites on the 2 meter band. The expected powers of the various transmitters, along with the associated antenna gains is shown in Table 3.

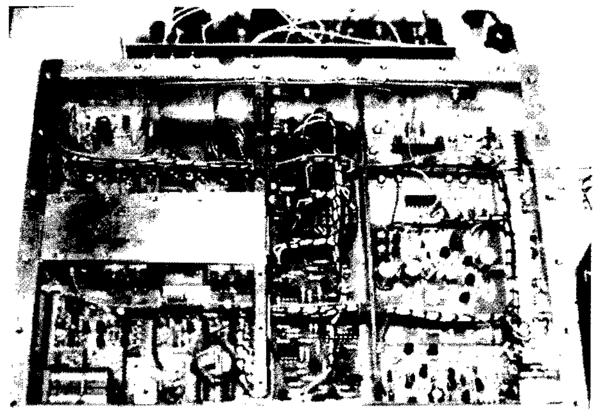
The U.K. 2 meter transmitter is a more-or-less conventional design, solid state unit. Both the 70 and 2.4 GHz units, coming from Germany, are of . advanced designs, employing the HELAPS circuitry, described below. There are actually to be two 10 GHz amplifiers with a common exciter, being produced by a Finish group with help from a Belgian group.. One amplifier is a solid state unit producing in the order of 10 Watts. The other is a traveling wave amplifier (TWTA) with a rated output of 60 Watts. The Belgian 24 GHz transmitter is experimental in nature, with an output of about 1 Watt.

The frequencies associated with each uplink/downlink combination are shown in Figure 10.

In addition to challenging the spacecraft power system, higher power transmitters also require careful circuit design, particularly at the microwave frequencies. High power, at microwave frequencies, is hard enough to come by in itself, but in a satellite, more difficult yet. In order to produce relatively high power, and live within the tight power budget imposed by satellite's power system, high efficiency RF power amplifiers are a must. Attaining high efficiency, particularly at microwave frequencies, is a formidable task. Fortunately, this problem has been previously addressed by the amateur community. The technique used is called "HELAPS" and stands for High Efficiency Linear Amplification by Parametric Synthesis. It has been proven on the 2 meter and 70 cm transmitters employed in AMSAT satellites since OSCAR 7. HELAPS techniques will be used on the high power amplifiers of the 70 cm and 13 cm transmitters aboard Phase 3D. Designing such amplifiers is a very exacting process, and a technology not understood by very many microwave designers - amateur or commercial. Design, construction, troubleshooting and final checkout of these amplifiers are among the most difficult tasks that confronted the Phase 3D design team.

The SA-AMSAT 10 meter transmitter is nearing completion. The 2-meter transmitter has been delivered to Marburg. Good progress is reported on the other transmitters and delivery is expected soon.

Two of the Phase 3D RF modules are shown in Figure 12 and 13.



Figue 12
HELAPS Modulator for 70 Transmitter

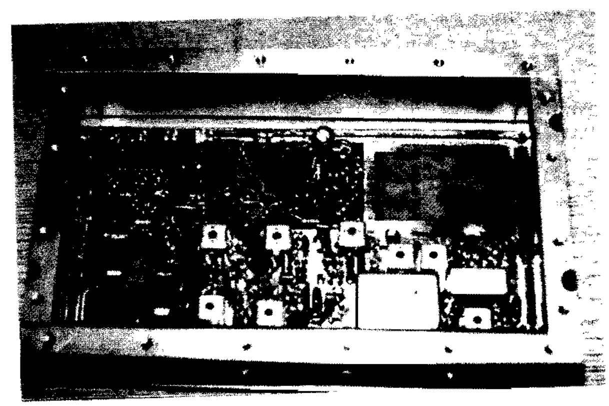


Figure 13
One of the two 23 cm Receiver Modules

THE ANTENNA FARM

Link Performance

Phase 3D will initially be launched into a GTO, or geosynchronous transfer orbit, on the way to it's final positioning into the 16 hour Molniya orbit. This places multiple requirements on the antenna system. Initially the satellite will be spun about its Z axis to maintain stability. The Z axis will be oriented 90 degrees to the major axis of the orbit and in line with the orbital plane. When the spacecraft reaches the final orbit, it will be despun and three axis stabilized using reaction wheels and magnetic torquing. The solar panels will be deployed increasing the power available by a factor of three, and the spacecraft will be reoriented to point the +Z surface at the Earth for the entire orbit.

To assure reliable command and control of the spacecraft, as well as good communications links, both omni-directional and high gain antennas are required.

Phase 3D's antenna design features are intended to accommodate smaller ground stations through the use of spacecraft antennas with higher gains than employed on previous amateur satellites. However, there is a limit to how much gain is desirable, if full Earth coverage is to be provided. At Phase 3D's apogee of 48,000 kilometers, the Earth has a diameter of approximately 13 degrees. A half power beamwidth of 13 degrees corresponds to a gain of approximately 20 dBi. On a 2.5 meter (8 feet) diameter satellite, such gain cannot be achieved on 70 cm or lower. But, for 2.4 GHz and above, antennas with such gains are small enough to be accommodated. Thus, on the higher bands, antenna gain is limited by the desire to provide full Earth coverage, while on the lower bands it is driven by available spacecraft real estate.

The planned orbit means that the average range to the satellite varies from 4,000 km to 48,000 km, or slightly more, during the sixteen hour orbit. With 3-axis attitude control, the high gain antennas are expected to be used throughout the orbit. Maximum gain was not the only criteria for antenna design. The primary goal of the antenna design was to provide greatly improved signal levels to all amateur satellite users across all portions of the Earth visible from the satellite. Table 4 shows the path loss at 1269 MHZ, along with the angle subtended by the Earth's disk for various points in the orbit. Table 5 gives path loss data for the various bands at apogee and perigee.

Looking down at apogee (48,000 km high) the earth is 13 degrees wide, thus all stations in view of Phase 3D will be within 6.5 of the center of the antenna pattern. At perigee (4,000 km), the earth is 68 wide and stations near the edge of the Earth (those with low elevation angles) would experience squint angles of up to 39. This means that such stations would see a loss of satellite antenna gain of more than 15 dB. However, with the 20 dB increase in signal level as the spacecraft descends stations will see an increase of 5 to 20 dB depending on their squint angle. The challenge has been to design antennas that will maintain the same or better signal levels for all stations at perigee, as exist at apogee. This requires antennas with slightly reduced gain (15 to 20dBic) and very smooth patterns at wider pointing angles (13 to 39 degrees).

Phase 3D will have 11 antenna arrays covering frequencies from 4 MHZ to 24 GHz. The satellite has receivers and transmitters on 12 different frequency bands with transmitter power levels as high as 300 Watts. All the antennas are mounted on a satellite less than eight feet in diameter. Multiple receivers and transmitters are expected to operate at the same time.

Table 4

Path Loss at 1269 MHZ

Orbit hrs	Phase	Range km	Path Loss dB	Earth Width Deg.
8	128	49,800	185.5	13.0
7	112	48,900	185.4	13.5
6	96	46,600	185.0	14.5
5	80	43,000	184.3	15.0
4	64	38,000	183.2	17.0
3	48	31,500	182.6	20.0
2	32	23,700	180.2	25.5
1	16	15,800	177.9	38.5
0	0	4,000	163.6	68.0

Note: The change in path loss from apogee to perigee is about 20 dB and is the same for all frequencies.

Table 5

Typical Path Losses for Various Bands

Frequency	Perigee	Apogee
29.4 MHZ	135.8 dB	155.8 dB
146 MHZ	149.7	169.7
436 MHZ	159.2	179.3
269 MHZ	168.5	188.5
2.4 GHz	174.0	194.0
5.6 GHz	181.5	201.4
10 GHz	186.4	206.4
24 GHz	194.0	214.0

All the high gain antennas are placed on the top of the spacecraft (the +Z face with an area of 3.7 sq. meters) with the principal radiation direction along the +Z axis. A design change made several years ago allowed an increase in height availability for the high gain antennas from 75mm to 330mm. This was accomplished by relocating the 400 N. motor from the bottom to the top of the spacecraft and inverting the spacecraft's orientation on the launch vehicle. While this increased the selection of possible High Gain antenna types, it also placed the motor nozzle in the center of the 2 meter and 70 cm arrays. These antennas had to be redesigned to fit around the nozzle and to resist the radiant heat generated during motor burn. Computer antenna models, and actual tests, confirm little effect from the presence of the motor nozzle on the performance of these antennas.

The high gain antennas, located on the +Z face are described in the following paragraphs:

The 2 meter (145 MHz) antenna consists of a circularly polarized array of 3 folded dipoles mounted 150mm above the +Z surface. The elements are 880mm long and constructed of 10mm diameter .4mm wall silver plated aluminum tubing. The feed system consists of a 3 to 1 power divider feeding three 50 ohm delay lines cut to give 120 deg phasing between elements to produce circular polarization (CP). The maximum gain of the 2 meter array is 12.2 dBic with 12.0 dBic at 13 deg beam width and 8.7 dBic at 68 deg beam width.

On 70 cm (435 MHz), an array of 6 circularly polarized patch antennas is used. The patches are .6 mm aluminum disks 317 mm in diameter mounted directly on the top cover panel by ten 13mm ceramic spacers. In addition to their role as radiating elements, the patches serve to structurally stiffen the top panels. The optimum spacing of the array had to be reduced to fit on the spacecraft structure, reducing the gain to 15 dBic but allowing the removal of the seventh center element to accommodate the motor nozzle.

The 23 cm (1269 MHz) antenna is a Short Back Fire (SBF). This antenna consists of a circular flat pan two wavelengths in diameter with a 1/4 wavelength high outer ring and a ½ wavelength high post in it's center supporting a .6 wavelength diameter reflector and a turnstile at a 1/4 wavelength from the reflector. The antenna has a gain of 15 dBic and has a very smooth pattern. This antenna also had the most gain for any 500mm diameter configuration of all the antenna types tested.

The 13 cm (2.401 GHz) antenna is a 500mm parabolic dish with a F/D ratio of .4 and a gain of 21 dBic. The feed is a turnstile inside a cup reflector. The turnstile feed is circular polarized using a single feed and requires no hybrid for circular polarization.
The 5.6 GHz antenna is a 250mm dish, also with a F/D ratio of .4. The spun aluminum dish, which weighs just 175 grams, has been received from a group in Belgium, The estimated gain of this antenna is 22 dBic.

The 10 GHz antenna is a pair of 23+ dBic circular horns. Each horn is connected to it's own source of RF via waveguide. One amplifier is a solid state unit and the other is a TWTA.

A full scale model of the top of the spacecraft, with test antennas mounted, is shown in Figure 14. This was but one of the many pieces of test hardware constructed to confirm the operation of this complex assembly of antennas.

For 10 meters the antenna is a two element "ground" mounted 2 element Yagi. It consists of a 1/4 wave whip of 13 mm flexible tape measure stock with a single director. The director is 2100mm long and mounted on the -X edge of the top +Z surface points in

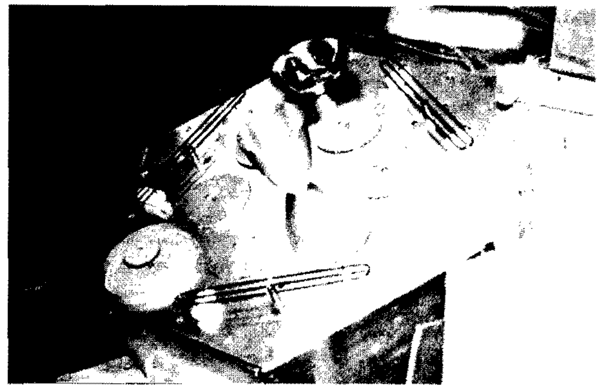


Figure 14

Full scale mock-up of top of spacecraft, used to test antennas.

the -X direction and is canted up 30 deg. The driven element is 2670mm long and mounted on the -X edge of the bottom -Z surface and points in
the -X direction. This antenna has a gain of 4 dBi and its pattern is close to ideal at perigee.

Omni-directional antennas are also necessary to permit commanding the spacecraft during the period immediately following launch and during subsequent motor firings, when it will be necessary to point it directions other than the normal +Z-face-toward- Earth orientation. The omni antennas are mounted on the -Z face of the spacecraft, a surface providing a large flat ground plane with a height limit of 140mm. These antennas are whips constructed of tape measure stock installed for 2 meters, 70 cm and 23 cm (1269 MHZ), arranged to form a 5 element tri-band omni-directional vertically polarized array. This array is mounted 250mm behind the arc-jet motor nozzle, which is positioned 78mm forward of the center on the bottom of the satellite and protrudes about 140mm from the surface. The motor is in this location to put it on the center of gravity of the spacecraft once the solar panels are deployed.

In addition to the communications antennas, a cluster of small disk and patch antennas are located near the outside edges of the spaceframe providing reception for the Global Positioning System (GPS) receiver experiment.

Much of the antenna construction and testing is being accomplished at the AMSAT Integration Facility in Orlando Florida. Several models of the Phase 3D spacecraft s were constructed to permit testing the various antennas. Included was a full scale model, a 1/3 scale a 1/5 scale and a 1/15 scale model. Antenna patterns of the six element 70 cm patch array were plotted using 1.2 GHz test range using the 1/3 scale model. The 1/15 scale model was used to evaluate the 10 meter antenna. In addition, a full scale mockup of the satellite was used on a 30 foot "A" frame mast to test the resonance and VSWR of the 10 meter antenna. The 1/5 scale model was also used in testing the omni antennas and the 70 cm patch array.

Good progress on all fronts in the antenna business. The RF switching unit has been installed in the space frame, most of the mechanical work has been done on the 2-meter high gain antennas and the 70 cm patch antennas. Both V and U-Band couplers are being built. The higher frequency antennas have been prototyped and tested and construction of flight units is about to begin.

GPS EXPERIMENT

Phase 3D will be among the first satellites, amateur or otherwise, to utilize the Global Positioning System (GPS) satellite cluster for position determination. It will be the first to do so in a high elliptical orbit. GPS will enable the satellite to determine its own orbit, transform this information into the form of Keplerian elements and transmit them to the ground via the telemetry system. It is estimated that data from the GPS experiment will be accurate enough to determine the Phase 3D orbital position to within an accuracy of 10-20 meters. This knowledge will be especially important for evaluating the performance of the arc-jet motor. As an added service, the GPS experiment will know UTC time to an accuracy of better than 1 millisec.

In addition to orbital position, the GPS experiment is being designed to provide a backup capability for determining the Phase 3D spacecraft attitude. This is to be accomplished by applying interferometric measuring techniques to the signals from the several GPS antennas mounted on the edges of the spacecraft.

Further details on the GPS experiment are provided in a separate paper.

JAMSAT SCOPE CAMERA EXPERIMENT

Another experiment carried on Phase 3D is a two-camera system being provided the Japanese AMSAT group, JAMSAT, to provide color imaging of the Earth. The cameras are commercial camcorder CCD units modified for the space environment. One camera will take wide angle shots, the other, narrow angle images of higher resolution. The images from these cameras will be digitized and transmitted to Earth using the RUDAK high data rate link. Software programs will be available to translate these images into formats commonly used by desktop computers.

The flight unit of the SCOPE Camera experiment has been essentially completed by the JAMSAT group. Some final coordination on the interface with the CAN Bus is being conducted prior to finalization and shipment to the Orlando Integration Facility.

GROUND COMMAND, CONTROL AND OPERATIONS

While the Phase 3D spacecraft is designed to operate autonomously for long periods of time, there is still a need for a ground command capability to assure control of radio emissions, change operating schedules, run health checks and deal with unforseen events.

The Phase 3 ground command team currently watching over the final days of OSCAR-13, is already well along with planning for Phase 3D operations . The team assembled in Marburg in May 1996 to initiate detailed planning for Phase 3D command and control operations. Primary command stations are located in England, Germany, Australia, and the U.S. Backup stations stand ready to step in if needed.

While the command stations have sole responsibility for issuing commands to the spacecraft, telemetry is continuously transmitted over several beacon frequencies and software is widely available to decode these transmissions so that many in the radio amateur community have the opportunity to assist the command stations in collecting and archiving this valuable housekeeping information.

General policy with respect to the schedule for various combinations of uplinks and downlinks for the Phase 3D spacecraft will be determined by a governing group called "The Program Council". This group is composed of a single representative from each organization that has, by the time of launch, contributed a specified substantial sum of money and/or effort toward construction of the satellite. Currently, this Council includes AMSAT-DL, the German Ministry of Science and Technology, AMSAT-NA, AMSAT-UK, DARC and ARRL. Guidelines established by the Program Council.will be provided to the Command Team.

SPACECRAFT ASSEMBLY AND CHECKOUT

Assembly and check-out of the Phase 3D spacecraft is well under way at the Orlando Phase 3D Integration Facility located in Orlando Florida where AMSAT-NA is leasing space in a facility located in a free-trade area of the Orlando International Airport. Within this space, is installed a portable clean room, complete with air filters, donated by a company that had declared it surplus. This is providing the extra-clean environment necessary for the integration activity. At this facility a small staff of technically highly qualified individuals is bringing the spacecraft together.

Current status is that the spaceframe is mounted in the clean room with the propellant tanks and associated plumbing lines and wiring harness installed. The spacefraim is ready for the arrival of the electronic modules will be arriving shortly. When they do, they will be integrated and checked out in accordance with a phased schedule designed to assure that basic housekeeping functions are trouble-free before the communications packages and other experiments are brought on line. Environmental testing, vibration and thermal vacuum testing will follow in early 1997.

Figure 15 shows the spacecraft in the clean room at the Orlando Integration Laboratory.

A TEAM EFFORT

The design, financing and construction of the Phase 3D satellite project is the product of an international team effort that began over five years ago. Despite the problems inherent in operating with an internationally dispersed and largely volunteer work force, the team has built on the technology base and management techniques developed during earlier AMSAT projects in undertaking what is clearly the most costly and complex spacecraft development ever undertaken within the amateur radio satellite community. Without the dedicated efforts of all of those involved, this ambitious project could not be completed. Whether it is the tists and engineers who come up with the innovative design approaches, the technicians who fabricate the various spacecraft component parts, those who coordinate the arrival of these parts at the required time, or those whose support is restricted to financial contributions; all participants on this team are contributing to the successful completion of Phase 3D. When it is launched into orbit on the Ariane 502 launch vehicle, everyone who participated can take justifiable pride in their accomplishment.

Let's make sure that all of us have done as much as we possibly can to assure the success of Phase 3D.

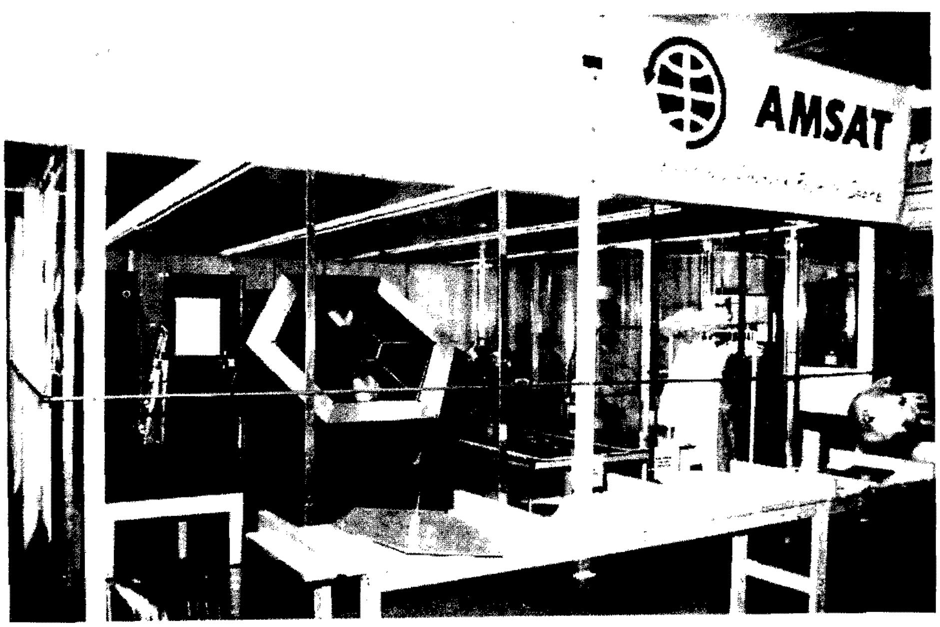


Figure 15
Phase 3D Spacecraft in Clean Room at Orlando Integration Laboratory

Phase-3D GPS Receiver Progress Report

Bdale Garbee, N3EUA
n3eua@amsat.org

Overview:

This paper documents progress made on the experimental GPS payload for the Phase-3D satellite since the report given at the 1995 annual meeting.

The GPS experiment is primarily intended to demonstrate our ability to determine the orbital position and three-axis attitude of the spacecraft, by analysis of the radio signals emanating from the constellation of GPS satellites. There are several secondary experiments planned, the most interesting of which is our intent to map the (unpublished) antenna patterns of the GPS satellites outside their orbits, since Phase 3D's orbit will take us high above the GPS constellation at apogee.

Of these objectives, only the attitude determination task has any potential impact on the management of the satellite. If we are successful at providing attitude information, it will be of great assistance to the command and control team for the satellite. The orbit determination task is mostly a proof of functionality test, and the antenna pattern mapping task and other potential scientific efforts are entirely experimental.

The unusual requirements placed on a GPS receiver in the orbital environment dictate the need for a receiver somewhat different from the typical GPS receivers available for terrestrial use. We set out to build a custom receiver for the P3D GPS project, based on the GPS front-end chip set from GEC Plessey and a processor board based on the AMD 29200 embedded RISC processor. The hardware architecture of this receiver was well documented in my 1995 status report, and papers it referenced.

The CPU portion of this custom receiver is essentially ready to fly, with flight and flight backup units through most of their test suite, and a boot ROM which is flight-capable. However, the RF board housing all of the Plessey parts has not been completed. Plus, there had been enough attrition from the project in the last year to raise concern about whether software would be completed in a reasonable time frame even if the receiver hardware were to be completed and delivered before launch.

We are, therefore, now engaged in executing a contingency plan that involves flying Trimble TANS VECTOR receivers communicating through the Rudak communications processor.

What We Now Expect to Fly:

The Phase-3D program has been offered access to a pair of Trimble TANS Vector receivers. These receivers are commercial attitude determining receivers that each use 4 antennas, consume about 7 watts of power, and communicate using asynchronous RS-422 at 38.4 kbaud. In order to meet our mission objectives, we need to fly two of these receivers, one attached to antennas on the +Z surface, and one attached to antennas on the -Z surface. The antennas on each surface will have different gain characteristics, since the predicted path loss from the GPS satellites we expect to be able to track is substantially different at apogee than at perigee.

At the time of this writing, it appears that all of the antennas will be patch antennas donated by Ball Aerospace. We had already secured a donation of patch antennas for use at perigee, and Ball has now agreed to donate four air-loaded GPS patch antennas with a gain of 9.5 dBic (RHCP) for use on at apogee... replacing the helibowls originally envisioned.

Integration of the TANS Vector receivers in place of the AMSAT GPS receiver will require some rework of the external interfaces on the Rudak digital communications package. Fortunately, Rudak has not yet been completed, so this will be easily accomplished. Formerly, the two V53 processors in Rudak were each expected to provide a serial port which would be switched so that either CPU could talk to the GPS receiver's 29200. The required change is to update this switching to support connection of two external devices (the two Trimble receivers), giving each V53 the ability to command either receiver to minimize the potential for single-point failures.

Additionally, the Trimble receivers do not provide an internal power switch, thus we will design and fabricate a power switch using ideas already tested in other module designs. This will allow the IHU to control overall power to the GPS receivers, and allow Rudak to reset either receiver by power cycling.

The GPS service task for Rudak will be quite similar to the service task that had been partially written for the AMSAT GPS receiver. The primary differences pertain to the different command set of the Trimble receivers, and the use of an asynchronous instead of synchronous interface to the receivers. There is some concern about having the V53's communicating at 38.4k async, since their interrupt load to service async ports is one interrupt per character. If this turns out to be a problem, NK6K has agreed to investigate a special SCOS device driver that would do DMA reception into fixed size buffers.

At the time of this writing, the detailed task list for integration of the Trimble receivers with Phase-3D is undergoing rapid evolution. There are many issues yet to be completely resolved, but none represent significant technical barriers to success.

Conclusion:

This has been a very frustrating year for the Phase-3D GPS project. The most significant lessons learned involve group dynamics, particularly the chaos that can result from attempting large multi-person projects with significant technical risk without applying some basic project management techniques. As late as May 1996 we might have been able to pull together to complete the original receiver design, but by early August it became clear that we needed to switch to our contingency plan.

I'm pleased that the critical few individuals necessary for execution of the current plan to fly Trimble receivers on Phase-3D have all signed up and committed to do their part. I believe we will have a GPS capability on the satellite, and if there's a positive slant to our current plans, it is that we may well be able to provide attitude information earlier in the spacecraft's lifetime than would have been possible with our custom receiver. This should please the command and control team.

Acknowledgements:

Many individuals have contributed in some way to the Phase-3D GPS project at various stages. Some of these were identified in last year's status report.

For effort on the now-abandoned custom receiver design project in the last year, I would like to particularly recognize the following folks for their significant contributions:

N3EUA: testing and evaluation of the second revision of the CPU board, testing of the flight and flight backup CPU boards, development of the boot ROM for the CPU board, and maintainence of the software development tool set for the 29200

KD9KX: testing and evaluation of the WA1UVP RF/correlator board, followed by significant effort towards a redesign of that board to meet our operational requirements

WD0FHG: testing and evaluation help on the 29200 CPU board, both during completion of the tests on the engineering units, and during turn-on and testing of the flight and flight backup boards. Wrote a cross-platform (DOS / Linux) ground support program that interacts with the boot ROM. Significant work in support of the CAN bus interface on the GPS CPU, writing test software and porting his ground support interface to use an ISA CAN interface under Linux.

N0ADI: for his astoundingly high quality work assembling the double-sided surface-mount, multi-layer boards for the GPS CPU engineering units, and flight and flight backup units... both of which turned on and worked the first time!

At the time of this writing in early September 1996, the following folks have committed to support some portion of the contingency plan now in effect to fly Trimble TANS VECTOR receivers:

N3EUA: project management, Rudak GPS service task
WA7GXD: Rudak hardware changes, power switch schematics
N0ADI: PCB design for and assembly of power switch

N0MMA:	design and construction of preamps
WD0FHG:	as needed / available for software and testing
WD4FAB:	packaging interface to spacecraft, installation mechanics
W3XO:	arranging funding for / donation of TANS receivers
NK6K:	application integration support for Rudak GPS service task
W5DID:	installation implementation into P3D

References:

Information about the Trimble TANS Vector receiver may be found on Trimble's Web site, the URL as of this writing being:

http://www.trimble.com/cgi/products.cgi/pd_ml007.htm

A Possible Phase 3D Follow-on Project

A Proposal for an Amateur Continuous Worldwide Communication Facility

by

Bill Tynan W3XO

Disclaimer

Let me make it clear that, in making this proposal, I am speaking for myself as an individual AMSAT-NA member - not as its President or a member of its Board of Directors. The views I express may or may not be shared by other Board members.

Summary

This paper proposes a system consisting of three near-geostationary spacecraft using existing technology and the simplest possible design to provide instantaneous, full time worldwide amateur satellite communication.

Our Ultimate Goal

Ever since I attended that January 1969 meeting in Perry Klein's apartment in Southwest Washington, which resulted in the founding of The Radio amateur Satellite Corporation, I have believed that the ultimate goal of the amateur space program should be to provide hams all over the world with continuous, real-time, 24 hour per day voice and data communication. I understood and agreed that other less ambitious satellite systems would, by necessity, have to proceed achieving this goal; but I have always been convinced that providing this kind of service for Amateur Radio should remain the amateur space community's ultimate objective.

Various Potential Approaches

There are various ways in which this goal can be achieved. The most obvious is the approach taken by commercial satellite operators - the use of geostationary satellites. For real-time, continuous, worldwide coverage; three such spacecraft located close to 120 degrees around the globe would be required, along with some kind of relay between them. This can be accomplished either by direct links between the satellites or through appropriately located ground terminals.

Another potential approach to achieving the objective is through the use of many low earth orbit (LEO) satellites. Various commercial systems of this type are ready to begin launches very soon. The best known of these is Iridium, being promoted by Motorola and a number of the world's telephone companies. LEO satellites have the advantage of less signal loss between the ground users and the satellites. Thus, it is possible to access the system with low power handheld transceivers, much like cellphones. We amateurs actually pioneered the use of LEO satellites for communication when the commercials had given up on them as useless compared to geostationary spacecraft. As early as 1972, the potential for low earth orbit analog communication was shown by AMSAT OSCAR-6 and later by AMSAT OSCARs 7 and 8. The MICROSAT, UoSat and Fuji series of amateur satellites demonstrated the utility of LEO spacecraft for relaying digital data from one part of the world to another. First, AO-21, and more recently AO-27 and SAFEX, have been used for to relay FM voice communication using groundstation equipment down to handhelds. Now, there are many commercial companies which wish to exploit the data relay capability pioneered by us amateurs and are even eyeing our frequencies as potential spectrum allocations in which to do it.

For any LEO system to accomplish worldwide real-time communication, numerous inter-satellite relays must be provided. Each spacecraft serves only an ever-moving circular footprint, the size of which depends on its altitude. As with the three geostationary spacecraft case, this relaying can, in theory, be accomplished by direct linking between satellites or through ground terminals. However, with the LEOs a large number of relays must be provided. If ground terminals are used, many of such stations would have to be set up in numerous locations, including some very out-of-way places around the world. Relaying between satellites would require considerable complexity in the spacecraft as well as consuming a significant portion of the available power. There is a significant difference in complexity of a LEO system if its intent is merely to provide non-real-time data relay (flying mailbox service), as opposed to real-time communication. In the case of systems like Iridium, worldwide real-time coverage will be accomplished by provide non-real-time data relay (flying mailbox service), as opposed to real-time communication. In the case of systems like Iridium, worldwide real-time coverage will be accomplished by linking through existing telephone facilities. After all, that's what the Iridium network is for - to provide hand-held wireless telephone service to all spots on the globe.

In my opinion, the objective of the eventual amateur system should be to provide 24 hour-per-day communication between licensed amateurs throughout the world - preferably without dependance on commercial communications facilities. One approach to an amateur LEO system was the subject of a paper presented at a past AMSAT Space Symposium. [1]

Aside from many LEOs and three geostationary satellites, there are other potential ways to accomplish real-time nearly continuous communication throughout the world. One might be two or more drifting near-equatorial orbit satellites similar to the orbit used by the French amateur radio satellite Arsene. Three such spacecraft in orbits slightly higher or lower than geostationary, can provide continuous worldwide coverage if relays are used. This approach has the advantage of providing worldwide access for part of the time, even with only a single spacecraft. Thus, part-time worldwide coverage capability is achieved with the successful launch of the first spacecraft. The disadvantage of this approach is that ground station antennas must be continually re-pointed to access whichever satellite is in view at the time. This is not a huge disadvantage for fixed stations. Many amateurs are already doing this with the aid of their computers, appropriate software and rotator control hardware. In the case of mobile and portable installations, such an approach is generally not practical. But, if the satellite(s) provide sufficient transmitter power and antenna gain, even mobile installation (but not handdelds) may be able to have communication, although at a lower quality than fixed stations using higher gain antennas. Phase 3D will give us the opportunity to evaluate this capability.

Another possible approach to providing worldwide coverage is several spacecraft in orbits similar to those used by the GPS constellation. These satellites are in near polar orbits at about 20,000 km (12,000 miles). Three amateur satellites in such orbits would provide continuous coverage and two would provide near-continuous coverage. An advantage of this type of orbit is that it affords coverage of the poles, which any equatorial orbit does not. The path loss is less than that associated with geostationary, or near-geostationary altitude, possibly eliminating the necessity of gain antennas on the ground and the associated antenna pointing requirement. Such satellites would have to be somewhat more complex than geostationary or near-geostationary satellites because of the need to keep their antennas pointed toward Earth. The GPS spacecraft accomplish this through the use of reaction wheels, similar to those used in Phase 3D. Gravity gradient stabilization is an attractive approach at lower altitudes, however, it is not practical at the 20,000 km GPS altitude.

Last but not least, the orbit we have been using for years cannot be overlooked. This is, of course, the very elliptical Molniya orbit pioneered by the Soviets and used by AO-10, AO-13 and soon for Phase 3D. Certainly, several Phase 3D type spacecraft in properly spaced orbits could, with ground relays, provide worldwide real-time coverage. Ideally, some of these satellites would be in orbits with apogees in the southern hemisphere, rather than the northern hemisphere as Phase 3D will. The use of Phase 3D-like spacecraft would, of course, necessitate all the complexities of Phase 3D, but the engineering work would already have been done. On the plus side is the fact that Mouinya orbits, like Phase 3D's affords the opportunity to unload the reaction wheels at perigee by use of the magnetorqing rods interacting with the Earth's magnetic field.

Don't Bite Off More than We Can Chew!

In many discussions in the AMSAT-NA Board and elsewhere, the caution has been advanced that, anything that is done in the way of building satellites beyond Phase 3D, must have simplicity as the watchword. An often repeated guideline is that the project should be one that can be completed in three years or less, as it is difficult to keep volunteers focused on an effort that is much longer duration than that. There is no doubt that Phase 3D is not simple and it has taken over five years to complete. But, Phase 3D was never advertised as simple. Its complexity stems from the missions envisioned for it. Principle among these is to bring satellite communication within the reach of as many licensed hams throughout the world as possible. That dictated three axes stabilization with high gain antennas always pointed toward Earth and the solar panels always pointed toward the sun. High gain antennas are needed so that lower performing groundstation equipment can be used. That objective also dictated the use of higher power transmitters than used on previous Phase 3 satellites. Multiple high power transmitters, especially in view of the fact that it is desired to power up more than one at a time, dictates the use of large deployable solar arrays. The fact that the solar arrays must be deployed is another factor which adds to Phase 3D's complexity. Phase 3D is also intended to serve as a transition to the higher amateur bands while providing capability on the bands presently used for satellite work. As such, it is equipped with six transmitters from 29 MHz to 24 GHz, and nine receivers from 21 MHz to 5 GHz. To borrow from an oft repeated political cliche, used in the 1996 U.S. Presidential campaign, "it is to serve as a bridge to the 21st Century". To interconnect and select these transmitter/receiver combinations, Phase 3D will include a computer controlled IF switching matrix. To keep it pointed toward Earth throughout its orbit and to keep the solar panels pointed in the direction of the sun, Phase 3D will include three orthanigonally mounted, magnetically suspended, computer controlled, reaction wheels. To be able to de-spin the wheels and thus keep them from overspeeding, a system of magnetic rods is to be used. These will be activated at perigee using the Earth's magnetic field as a brake, in a manner similar to that used for orienting AO-13. There is no fundamental reason why all of these Phase 3D systems won't work perfectly, but it cannot be said that the satellite is simple.

Phase 4 - A Little History

An active study was undertaken by AMSAT-NA during the latter half of the 1980s to design a geostationary amateur satellite. It was dubbed "Phase 4". The design that was produced cannot be characterized as simple, anymore than Phase 3D is. It used Yagi arrays for bands as low as 2 meters. This required some method of stowing these ungainly arrays before launch and early flight and deploying them after separation from the launch vehicle. Also required was a method of keeping these antennas pointed toward Earth while the satellite traversed its orbit. Yes, geostationary satellites do orbit! It was recognized that the type of Phase 4 spacecraft envisioned would be large, complicated and expensive. The total cost was estimated at about $4,000,000. Since Phase 4 was to serve only North and South America, this entire sum would have had to be raised from the Western Hemisphere. There was also no identified launch opportunity. Various approaches, including the Shuttle, were discussed as possibilities, but that is as far as it went.

In the light of all of these obstacles, not the least of which was the funding challenge; the AMSAT-NA Board, in 1990, decided to drop all effort on the Phase 4 Project. The other reason for shelving, Phase 4 was that the Board concluded that a more achievable goal would be to join our German compatriots on the Phase 3D Project. Much design work had already be done and Karl Meinzer and his associates had already succeeded in raising well over $1,000,000 to support the project and they had identified a launch opportunity. So, to keep AMSAT-NA in the satellite building business and do our part in providing amateurs with a significant new capability, the AMSAT-NA Board opted to participate fully in the Phase 3D Project. I was a member of the Board at the time and believed, as the other members did, that this was the best course we could follow.
I remain convinced that this was the correct decision.

As most AMSAT members must be aware, Phase 3D has been our all-consuming endeavor since that time. With significant help from ARRL, we have raised well over $1,000,000 here in North America. We have also been very active in the design of the spacecraft itself and in its integration and testing. We have provided some of the key electronic modules including construction of the IHU (the spacecraft's central computer), the RUDAK computer, the GPS experiment and several smaller electronic subassemblies. Since signing on to the Project, AMSAT-NA, and a number of its members, have been devoting ALL of their time to Phase 3D. Nevertheless, it was felt that some thought must be given to what the our organization will do following the successful launch of Phase 3D. As President, I asked Keith Baker KB1SF, our Executive Vice President and a Board member, to begin a study of this question.

As a first step, Keith conducted a survey to ascertain the kinds of satellites the members want. Not surprisingly, many respondents opted for what we already have. A significant number wanted more easy-to-use low altitude birds. Many wanted more digital capability. A significant number wanted continued capability typified by AO-13. (Phase 3D should take care of this need.) But a significant number asked for wide-area continuous communication capability. This information along with other data he had collected was presented by Ray Soifer W2RS at the International Amateur Satellite Symposium held at the University of Surrey in England in July 1996.[2]

A Proposed Approach

The use of three appropriately placed geostationary satellites seems to be the most obvious choice and is probably the most desirable from the user point of view.

A plus for this type of orbit is that most launches go to geostationary transfer orbit (GTO). However geostationary satellites present some significant complexity issues. For one thing, if true geostationary performance is to be achieved, some means of station-keeping must be provided to precisely maintain the satellite at the exact geostationary altitude, above the equator and at its assigned longitude position. To accomplish this, commercial geostationary satellites carry on-board propulsion systems, usually employing cold gas. An important factor in determining the life of such satellites is the amount of station keeping propellant they can carry. Some means of pointing the spacecraft in the proper direction for each firing must also be provided. This requires a knowledge of the satellite's orientation and a way of changing it to the desired one, prior to each firing and then changing it back following each firing.

Keep it Simple

In order to keep the complexity of the satellite(s) as low as possible, geostationary spacecraft are not proposed for this amateur application. Instead, a system consisting of a constellation of three drifting near-geostationary satellites is suggested. This approach will be the subject of the rest of this paper.

The satellite design will definitely follow the "KISS" principal. Every effort will be directed toward keeping the satellites as simple as possible, even at the expense of adding some complexity on the ground. Some of the ways in which it is proposed to accomplish this are as follows:

1. The satellite(s) will be in near-geostationary orbit with no provision for station keeping.
2. Only a few frequency combinations will be supported (possibly a single uplink and a single downlink).
3. Only microwave frequency combinations will be supported.
4. The spacecraft will spin..
5. Antennas will be directed toward Earth (de-spun) without the use of moving parts.
6. Ground based linking between satellites will be used rather than direct satellite-to-satellite links.
7. Every possible advantage will be taken of existing designs.

Let's look at these points one at a time and see why each is important to keeping the cost down and making the project achievable.

As already discussed, true geostationary satellites must have the station-keeping capability. A satellite that is allowed to drift, does not have this requirement.

Keeping the number of frequency combinations low, simplifies antenna design and minimizes the need for switching. Incidentally, it also simplifies groundstation requirements, as fewer uplink/downlink combinations are needed.

Simplicity of design dictates that the proposed satellite would not attempt to cover the wide range of bands that Phase 3D does. Limiting it to microwave frequencies makes high gain spacecraft antennas smaller and simplifies their de-spinning as well as leading to significant simplification of the spacecraft's mechanical design. The use of the microwave bands also affords the wide bandwidth (5 to 10 MHz) considered necessary for any worldwide continuous access satellite system. It is envisioned that spread spectrum techniques will become an increasingly important approach to efficiently using this type of facility.

It is believed that Phase 3D will make microwave operation more palatable to the user community than it is today. The reason for this is ,as already noted, that it should serve as a "bridge" between what we have today and what we will have, and be comfortable with, five to ten years from now. By including equipment for 2 meters and 70 cm as well as the microwave bands, Phase 3D will demonstrate the superiority of the microwave bands for satellite communication. Thus, in the next three to five years, much more microwave equipment suitable for satellite use will become readily available and at considerably less cost than today. This should lead to such equipment being in many more shacks than is currently the case.

Spinning the spacecraft eliminates many problems. There will be no need for moving parts such as the reaction wheels used in Phase 3D. Although the heat pipes used on Phase 3D are not complicated, they are somewhat costly. Spinning the satellite eliminates the need for heat pipes as the spin causes the heat to be distributed around the spacecraft. Almost all the commercial geostationary TV and telephone relay satellites are spinners. Spinning carries with it the disadvantage that considerably less power is generated by the solar arrays (approximately one third as much). This is one driving force behind not proposing multiple transmitters running simultaneously on various bands.

Spinning the spacecraft also requires some method of keeping the antennas always pointed toward Earth. The commercial satellites do this with an electric motor driving the platform, on which the antennas are mounted, at a speed equal to, but in the opposite direction, from that in which the satellite is spinning. The equipment mounted on the platform must, of course, be connected to the rest of the spacecraft through slip rings. This adds complexity and decreases reliability.

For this proposed amateur near-geostationary satellite system, a group of 12 radially directed antennas, probably horns, will be mounted on the top plate of the spacecraft and 12 more antennas on the bottom plate. (See Figures 1 & 2.) One set of antennas will be for receive and the other set for transmit. All of these antennas will be fixed to the spaceframe. As the satellite spins, the antennas facing Earth at the time will be switched ON and all others will be OFF. For the transmit side, it is anticipated that this switching process would be done at a low RF level using PIN switches or similar devices. This will entail the use of multiple power amplifiers, each feeding its own antenna. The use of multiple power amplifiers will increase cost somewhat, but it will also provide some redundancy. Severe QSB would result if a power amplifier should fail, but communication would still be possible. To conserve power, the amplifiers not in use will be biased to draw little or no current. The use of these multiple amplifiers might seem to increase complexity, but since all will be identical, only one design effort is needed. The various amplifiers could be "mass produced", possibly at several sites. Earth sensors would be used to provide the information necessary to switch the

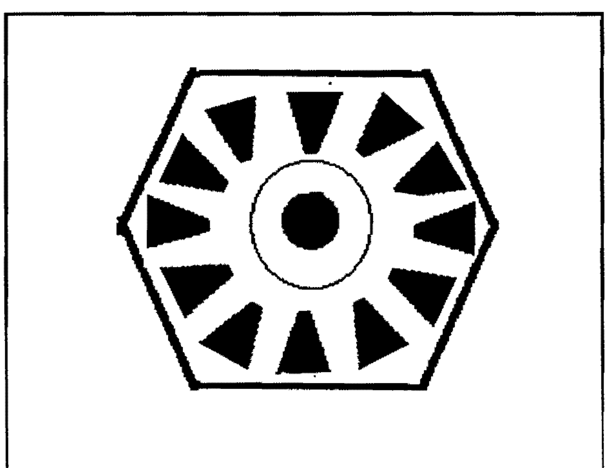


Figure 1

Motor side of proposed near-geostationary satellite showing twelve horn antennas.

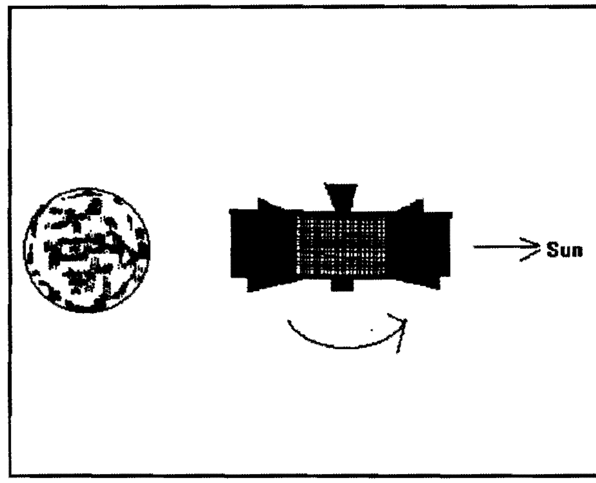


Figure 2

Sketch of how the proposed near-geostationary satellite might look in space.

proper antennas ON. Switching of the receive antennas will be done in a similar manner. Each antenna will be connected to a dedicated pre-amp and switching will take place after the pre-amps. As with Phase 3D, a common IF would be used to connect the various receiving and transmitting ports. The IF might include the LEILA circuit developed for Phase 3D. A block diagram of the proposed design is shown in Figure 2.

RF circuit designers are urged to begin work on amplifiers capable of the meeting bandwidth, linearity and efficiency standards necessary for this kind of spacecraft equipment.

Mandating that inter-satellite linking be accomplished through ground stations rather than between the satellites themselves, eliminates a great deal of potential complexity from the spacecraft design. For example, none of the spacecraft's power need be used in linking and there is no requirement for additional antennas that must bee kept pointed toward adjacent satellites.

As stated, the proposed spacecraft design would draw heavily on the Phase 3D heritage. I propose that it use the Phase 3D spaceframe. If a launch can be obtained on a future Ariane 4 or 5, it would use the same launch interface, including the Specific Bearing Structure (SBS) which will be proven in by the launch of Phase 3D. A liquid propellant motor, similar to, but smaller than, the 400 Newton unit on Phase 3D, will be required to get to final orbit from the GTO into which a launch vehicle would place the spacecraft. However, the process of

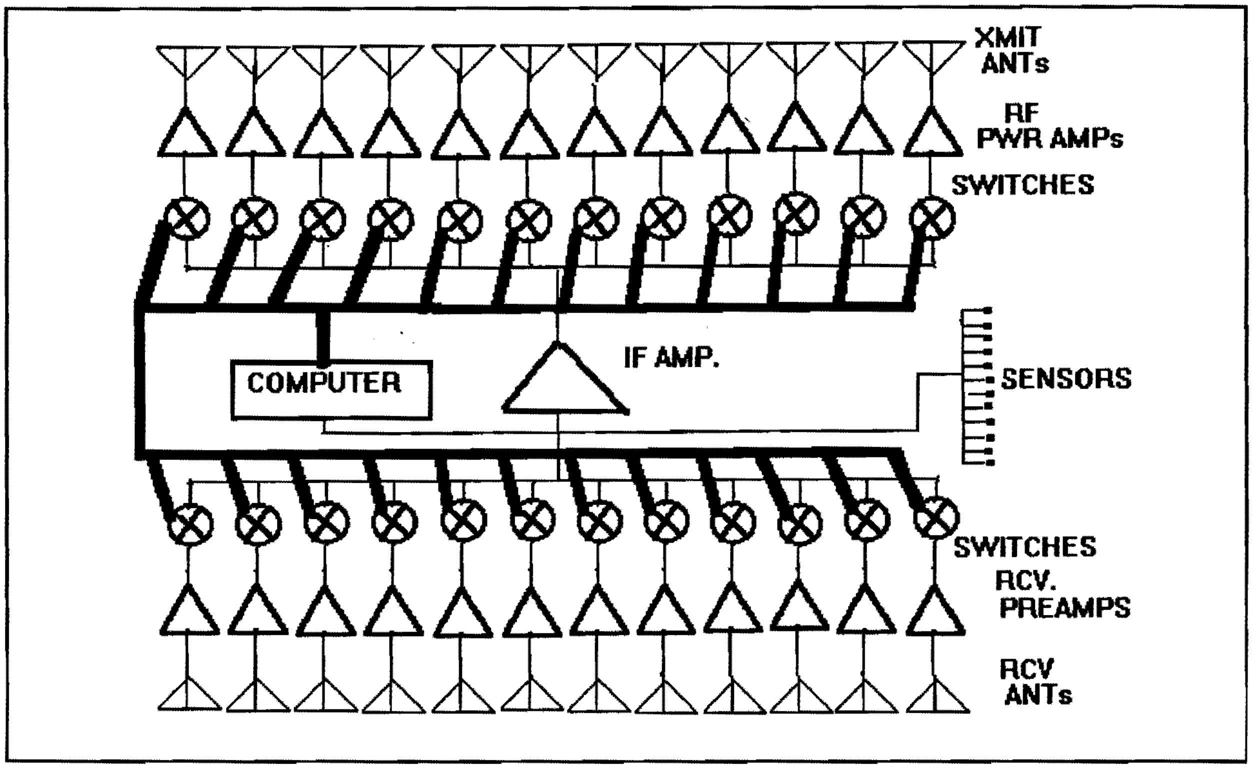


Figure 3

Block diagram of proposed satellite.

getting to final orbit will be much less complex and require much less time and fuel than is the case with Phase 3D.

Of course some of the systems used in Phase 3D, but not needed in this design, would be eliminated. These include, the reaction wheels and associated electronics, the magnetorquing rods, solar panel deployment mechanism, arc-jet motor and associated tankage and control equipment and the heat pipes. Not only does elimination of much of this hardware simplify, and reduce cost of the spacecraft, but other complexity is lessened because of eliminating the need to accomplish various tasks. For example, when the Phase 3D solar panels are deployed, the dynamic characteristics of the spacecraft change. This requires appropriate changes in the software to properly control it. Every time the Phase 3D's main motor or arc-jet is fired, the spacecraft must be re-oriented to the proper direction and then pointed back toward Earth following the firing. Eliminating the arc-jet has another plus. A smaller battery can be used. The battery in Phase 3D is sized to accommodate the approximately 1 kW of power for one hour necessary to operate the arc-jet.

Conclusion

This is merely a brief outline for one possible spacecraft design to achieve continuous worldwide communication for licensed amateurs throughout the world. Obviously, if the concept were to be pursued, much detailed design work would be required. However, it is believed that this proposal is consistent with minimizing that effort as the spacecraft requirements are made as simple as possible, and every advantage is taken of technology already existing in the amateur space community.

This represents but one thought on what the future of amateur satellites might be. It is not even clear that worldwide continuous communication via satellites is what amateurs want. Some might even feel that it will spoil the "mystic" of DX much as some believe the Internet has done. AMSAT members, and satellite operators in general, need to get involved and make their wishes known. Beyond that, they need to get behind whatever approach is decided on and support it, both with their money and their labor.

References:

1. Vekinis, Peter: Participate in Picosats: Proceedings of the AMSAT-NA 13th Space Symposium and AMSAT Annual Meeting 1995 Page 77

2. Proceedings of the 1996 International Amateur Satellite Symposium held at the University of Surrey (England)

THE AMATEUR SATELLITE SERVICE IN 1996

Ray Soifer, W2RS
Vice President - International Affairs
AMSAT-NA

60 Waldron Avenue
Glen Rock, NJ 07452
Internet: w2rs@amsat.org
Packet: W2RS @ WA2SNA.NJ.UEA.NA
or W2RS @ GB7HSN.#32.GBR.EU

[The following paper was originally presented at the Eleventh AMSAT-UK Colloquium, held at the University of Surrey, England, July 25-28, 1996.]

My original intention was to prepare a paper on the future of the Amateur-Satellite Service, as a contribution to the IARU planning process for WRC-99. However, when I sat down to begin my outline, it quickly became apparent that we have very little information about the actual usage and participation patterns in our service today, e.g.:

- How many amateurs are involved with amateur satellites?

- Where are they located?

- How many have operational stations, and how active are they?

-Which satellites and modes do they use?

- Are they members of AMSAT organizations?

It cannot be overemphasized that the primary justification for the retention and expansion of Amateur-Satellite Service frequencies is our continuing contribution to technology, not our numbers. However, without knowing where one is, it is very hard to figure out where one should be going. So, I determined to come up with the best information I could about the actual state of the Amateur-Satellite Service in 1996.

As it happens, AMSAT-NA had asked Steve Grant, N8AJD, to conduct a mail survey of our membership in mid-1995. After working with Keith Baker, KB1SF, to formulate the questions, Steve sent out questionnaires to approximately 10% of the members, selected at random, and received responses from about 30% of those surveyed. It would not have been practical to ask every AMSAT organization in the world to do the same thing; besides, I was somewhat concerned that the self-selection inherent in a mail questionnaire (what about the 70% who did not choose to return it?) might have biased the results in some unpredictable way.

So, I developed my own questionnaire and sent it to each of the 23 AMSAT groups (now 24) which subscribe to AMSAT-International@amsat.org, the Internet distribution list for AMSAT organizations worldwide. Including AMSAT-NA, for which Keith and I adapted the results of Steve's survey to the present circumstances, eleven AMSAT organizations responded, which eleven are believed to account for more than two-thirds of the AMSAT members and active amateurs in our service today.

This AMSAT-International questionnaire, a copy of which is appended, was addressed to the leaders of each AMSAT organization and asked not for a scientific survey of their membership -- as difficult and expensive as that might have been -- but rather for the leaders' own educated guesses about Amateur-Satellite Service activity in their respective countries. Armed with the survey data from those responding, I then made my own less-educated guesses to fill in the blanks of non-responding organizations and parts of the world with no AMSAT organizations at all.

What we have here, then, is not a collection of hard, irrefutable data but simply a series of educated guesses by those in the best position to know about Amateur-Satellite Service conditions in their own countries and regions. Until something better comes along, however, I am convinced that it is reasonably accurate, at least to within an order of magnitude, and certainly provides better data than we had before.

The results of these educated guesses are presented in Tables 1-5, which you are invited to study at your convenience and to form your own conclusions. However, I have already formed a few conclusions of my own, to wit:

- More than 18,000 amateurs currently participate in the Amateur Satellite Service in one way or another. Of these, nearly half operate on the birds at least once a month, and about 16,000 belong to an AMSAT organization.

- These figures are more impressive than they may seem at first glance. For example, DXCC is the most popular operating awards program in amateur radio and it had 7,670 active participants in the year ending September 30, 1995. About 3,000 amateurs enter the ARRL DX Contest annually.

- According to ARRL data, for every US amateur presently active on one or more satellites (about 3,000), there are at least five more who have been on the birds at some time in the past and are nolonger. If this ratio is representative of the world at large, there may be as many as 40,000 to 50,000 amateurs who have gained at least some experience with OSCAR satellites since 1972. This is again comparable to DXCC, which has issued some 75,000 certificates since 1945, which figure includes multiple certificates to the same individuals, e.g., five to me alone (Mixed, Phone, CW, Satellite and 5BDXCC). About two-thirds of these 40,000-50,000 would be former AMSAT members or may never have been AMSAT members.

Activity in the Amateur-Satellite Service, then, appears reasonably comparable to those of other facets of amateur radio which require similar levels of commitment on the part of the amateur. It should not be compared, for example, to FM repeaters, local packet radio or HF ragchewing, for which the required levels of technical knowledge and station equipment are significantly lower than for satellite operation, HF DXing or contesting.

Within our service, about 25% of those with stations have equipped themselves to use digital spacecraft. Earth stations for 9600-baud spacecraft outnumber those with 1200-baud equipment by approximately 2.6:1. However, it must be borne in mind that 75% of present Amateur-Satellite Service earth stations are equipped for analog modes only. Apart from P3D, comparatively little of today's satellite construction activity is going into serving their needs.

Mode B (70cm up and 2m down) is by far the most popular analog mode with a 60% share of AMSAT members' stations. This is followed by Mode A (2m up and 10m down) with 40% and Mode K (15m up and 10m down) with 20%. The evident continuing popularity among users of Modes A and K is also well worth noting by prospective satellite builders.

Of AMSAT members with satellite stations, only about 3% are currently equipped for Mode S (70cm up and 13cm down). Another way of looking at this is that of those already equipped for Mode B, ie with transmitters and antennas for the 70cm uplink, about 95% have not set up the 13cm receiving facilities which would put them on Mode S. With the imminent demise of AO-13, whatever growth in Mode S activity we are likely to see will have to await the actuality of P3D.

Virtually every AMSAT member with a working station is equipped to communicate with manned space vehicles, ie MIR and SAREX, due to their comparatively simple earth station requirements. The effect of this may be observed frequently during missions.

Regional differences in activity are about what one might have expected, with about 90% concentrated in the Northern Hemisphere and another 90% in Regions 1 and 2. However, users in the Southern Hemisphere and in Region 3 appear to be more technically advanced, on average, than those in other parts of the world, judging by their greater proportional representation on the digital satellites and on Mode S.

AMSAT organizations report that approximately 3% of their members do not engage in satellite operation at all but are involved exclusively in technical pursuits such as satellite design, construction and software development. This undoubtedly understates the total number of "techies" among us, since some of them operate as well. Or do they?

Another 3% of AMSAT members are said to listen and/or copy telemetry rather than operating through the satellites themselves. I'm only reporting the numbers I have, but where are these people when the command stations need telemetry data?

Although not included in my AMSAT-International survey, N8AJD asked AMSAT-NA members two specific questions about their preferences for future satellite projects and their potential willingness to support them financially. These questions, and the responses received, are presented in Tables 6 and 7, respectively.

From these responses, it is reasonable to conclude that both types of orbits presently utilized by amateur radio satellites -- Phase 3 and LEO -- still represent desirable alternatives for future programs, although the Phase 3-type orbit is preferred by a 2:1 margin and were a suitable opportunity were to come along for a geosynchronous orbit, AMSAT-NA members would be favorably disposed toward such an effort.

As to the type of payload desired, linear (analog) transponders are still far and away the most popular choice. However, among those members who asked for digital spacecraft, there was a strong preference for 9600 baud over 1200 baud; many digisat users asked for even faster data rates and the consequently wider bandwidths. Parenthetically, one cannot help wondering whether all the members who asked for faster data rates than 9600 baud fully realize that the earth stations for such satellites would have to be more complex and expensive than are present stations, since in all probability they would require microwave uplinks, spread spectrum or both.

If the answers to Steve's financial support query are extrapolated to AMSAT-NA's membership as a whole, taking into account the 30% response rate to his original questionnaire, our members told us us that they, collectively, would be willing to pledge about $100,000 annually for satellite development, construction and launch efforts. Bear in mind, however, that each respondent assumed that the satellites that would be built are the ones he or she wanted! It is a given, of course, that nobody can please all of the people all of the time. On the other hand, our intensive fundraising effort on behalf of P3D has done somewhat better than the $100,000 annual figure indicated here, so this response should be taken as indicating an order of magnitude rather than as hard data.

Then, too, this order-of-magnitude figure includes only direct financial support from AMSAT-NA members. It does not include members of other AMSAT organizations, support from IARU societies such as ARRL, funding from non-amateur radio sources or contributions in forms other than cash.

It must also be noted that the AMSAT-NA membership survey upon which Tables 6 and 7 are based, by definition, surveyed only present members of AMSAT-NA, not potential or prospective members. Whenever we ask them (e.g., at convention forums, radio club talks, etc.), most of these non-members say that they would prefer satellites that are simpler, easier and less expensive to use (ideally, with the equipment that such amateurs already own for terrestrial applications) than the members' responses in Table 6, and the present activity patterns in Table 4, would suggest. Were potential members included in the survey, Modes K and A, analog FM on Modes B and/or J, geosynchronous orbits and 1200-baud FSK packet radio all would have ranked higher in the charts.

So there we have it: the composition of the Amateur-Satellite Service in 1996. Now that we've figured out where we are, give or take a reasonable degree of measurement error, we're ready to begin thinking about where we should be going. May all of your thoughts be productive!

APPENDIX

To AMSAT-INTERNATIONAL Subscriber Organizations:

For a paper I am writing (hopefully to be presented at Surrey and submitted to IARU), I would very much appreciate your answers to the following questions about Amateur-Satellite Service usage in your country. Your answers will not be published individually, nor will individual-country data be listed in any way. Rather, all I am trying to develop are rough, aggregate figures for the world in general and, data permitting, for each ITU Region.

For my purposes, the timeliness of your response is more important than its precise accuracy. I'd rather have your rough "educated guesses" within a day or two than to have you do a lot of work and revert to me three weeks from now. Your guesses will be better than mine, and given the inherent uncertainties of the subject matter, any increased accuracy really wouldn't be worth the added effort on your part.

If you don't believe yourself to be capable even of guessing the answers to some of the questions below, please feel free to answer only what you can.

Ready? Here goes...

1. Approximately how many members does your AMSAT organization have?

2. Of those, roughly how many have EVER operated through an OSCAR satellite?

3. Of those who have operated, approximately how many would you say presently have stations capable of operating through one or more of the following:

a. LEO analog birds:
- Mode A?
- Mode B?
- Mode J?
- Mode K?
- Mode T?

b. LEO digital birds:
- AO-16/LO-19?
- UO-22/KO-23/KO-25?

c. AO-10/AO-13:
- Mode B?
- Mode S?

d. MIR/SAREX?

4. Of those you listed as "satellite-capable," roughly how many would you say are presently active operators, i.e., use that mode at least once a month?

5. About how many members do you have who are not satellite users themselves (they may not even be licensed) but who:

a. participate personally in AMSAT satellite design, construction and/or software development activities?

b. listen to or capture telemetry, files etc from Amateur Radio satellites (including MIR/SAREX, UO-11, WO-18 and what have you)?

6. Approximately how many "active" satellite users (i.e., at least once a month) do you think there are in your country who are not members of an AMSAT organization? (Remember, we won't be publishing your response!)

Please respond via e-mail to me at w2rs@amsat.org. Thank you very much for your help.

73, Ray

Table 1
AMSAT Membership

	AMSAT Members	Active Members	Total
Region 1	6,200	1,400	7,600
Region 2	7,900	1,000	8,900
Region 3	1,900	100	2,000
North	14,700	2,400	17,100
South	1,300	100	1,400
Total	16,000	2,500	18,500

Table 2
Activity Patterns of AMSAT Members

	Have Operated	Currently Active	Satellite Capable	Not Active but Listen Only	Total Members
Region 1	3,700	1,800	1,900	200	6,200
Region 2	6,100	3,100	3,000	100	7,900
Region 3	1,500	700	800	250	1,900
North	10,300	5,200	5,100	400	14,700
South	1,000	400	600	150	1,300
Total	11,300	5,600	5,700	550	16,000

Table 3
Amateur-Satellite Service Usage
AMSAT Members and Active Nonmembers

	Active Users	Other Satellite Capable Members	Member Listeners	Total
Region 1	3,200	1,900	200	5,300
Region 2	4,100	3,000	150	7,250
Region 3	800	800	100	1,700
North	7,600	5,100	350	13,050
South	500	600	100	1,200
Total	8,100	5,700	450	14,250

Table 4
Present Capabilities of AMSAT Members' Stations

	Region 1	Region 2	Region 3	North	South	Total
LEO Analog Satellites:						
Mode A	1,700	1,900	800	3,600	800	4,400
Mode B	1,100	400	900	5,000	800	5,800
Mode J	1,000	400	900	1,500	800	2,300
Mode K	1,100	1,100	200	2,200	200	2,400
Mode T	900	1,100	100	1,900	200	2,100
LEO Digital Satellites:						
1200 Baud	300	500	200	900	100	1,000
9600 Baud	800	1,500	300	2,400	200	2,600
AO-10/AO-13:						
Mode B	2,200	3,800	600	6,000	600	6,600
Mode S	100	100	100	250	50	300
MIR/SAREX:						
	4,100	6,100	1,100	10,400	900	11,300

Table 5
AMSAT Members Who Don't Operate

	Design, Construction, and Software	Listen, but Don't Transmit	No Activity At All, Ever
Region 1	200	200	2,100
Region 2	150	100	1,550
Region 3	100	250	50
North	350	400	3,650
South	100	150	50
Total	450	550	3,700

Table 6

What types of satellites would you like AMSAT-NA to construct and launch in the future? Rate your desires on the scale of 4 (most) to 0 (not at all).

P3D-Type Orbit	54%
Geosynchronous	51
Low Earth Orbit	26
Analog SSB/CW	60
9600 BPS FSK	29
Analog FM	26
Wider-Band	25
Higher Speed FSK	23
1200 BPS FSK	10

(Figures add to more than 100% because of the multiple weighted responses requested. The "percentages" in this table do not represent the percentage of members desiring any particular alternative, but only the total points scored by each divided by the number of responses received.)

Amateur Satellites - Is There a Future ?

A discussion paper from Richard Limebear, G3RWL and John Branegan, GM4IHJ
Presented at the 1996 AMSAT-NA Annual Meeting and Space Symposium by G3RWL

Satgen 371 Digi: -Mania or -Phobia by GM4IHJ, 4 May 96

Over the years, the automobile industry has produced some spectacular models. But on today's highways the Rolls Royces and the Ferraris are few and far between. Most of us drive the standard pickup, tin lizzie, or Dagenham Dustbin (explanation for those unfortunate enough to live outside the UK - Ford UK locate at Dagenham Essex). Roughly the same rules apply with amateur satellites, for reasons of cost or general harmony (the kids need shoes, we didn't have a holiday last year).

Most satellite users gather on RS10, RS12, RS15 or FO20. Uncomplicated but thoroughly useful birds which deliver hundreds of good QSOs each day. However, in spite of this clear user preference, Amsat et al no longer build these simple satellites. The dichotomy Amsat worldwide appears to be ignoring is that, while there is a vociferous group anxious to build more complex expensive to use digisats, it is the simple analog satellites which get the heavy usage.

It is of course understandable that the folks who put weeks and years into building our satellites like to build new gadgets. The more complex, the more exciting. But surely there needs to be a compromise somewhere. For years now, the cop-out excuse has been that - the Russians build the BEGINNERS satellites - so WE do not need to provide any. That excuse is evaporating fast, and we cannot go on expecting our Russian friends to provide for ever.

Despite the above, there has been very clear evidence at times that "WE" have no intention of changing. This was forcefully demonstrated a year or so ago at a Surrey Colloquium, when a long time Amsat stalwart who presented a paper on Mode A satellites was rudely abused by the Digicrats who make most noise at meetings of that sort. This despite the fact that :-

a) That particular amateur had contributed more to Amsat through his magazine columns, papers, and operating (AO6 to the present sats), than the whole Digi crowd put together.

b) The majority of Amsat members want modes A, K, J and KT, and it is their continuing funding which is needed to swell Amsat coffers, making them just as important as the Digicrat builders.

So where is the even break for the relatively silent majority? Indeed are they likely to continue to contribute to Amsat if there are no satellites that they can use ? We will not all be able to afford Phase 3D operation, with its 29 MHz digital speech etc. Probably a good experiment, but to the ordinary Amsat user it sounds a mite like the work of the guy who habitually goes from Boston to New York by way of San Francisco.

The fact is we need both analog A, K, KT, J sats and digisats, so is there any hope that Amsat will come down at least partially from Digital Cloud Seven ? If you want to make sure they do, please make your views known to Amsat boards and or committees around the world. It is all very well that you write to me as you have done, but it is the opinions at the top that you have to shift.

After John published this bulletin there was some debate on the Amsat internet reflector (Amsat-BB) as to what should be done next after the Phase-3D satellite is launched. Opinions reflected most attitudes but a clear majority were saying that, while they personally wanted hi-tech etc, there will always be a need for low-complexity, entry-level systems.

"What to do after P3D" was also discussed at this year's Amsat-UK Colloquium but, unfortunately, this was inconclusive due to lack of time. What DID emerge from the Colloquium was the wants of the individuals who attended which, broadly speaking, boiled down to the use of microwave in orbits higher than LEO for high-speed data, possibly with an imaging or science capability. Only one person wanted RS-style operations but the points were made that: 1) unless the new modes on P3D get used, the price of equipment for those bands won't come down to an affordable level; and 2) it is important to keep the builders informed of the wants of the users - planning and building a satellite takes a long time.

But those wants need to be qualified: they are the desires of people who could afford to come to Surrey; few, if any, were from developing countries where access to technology is hard. Sadly there wasn't time for altruism.

Debate on Amsat-BB (and international Amsat meetings too) also needs to take into account the people debating; who are they ? They are generally computer users with internet access; not third-world nationals with a keen interest but few resources, who have almost no way of expressing their desires to the bodies who decide on amateur satellite facilities. Beginners too, wherever they are, often have either not developed links to the main organisation (some cannot afford it) or, if they have, are hesitant to say.

Is there substance in John's claim? Let's look at present and planned spacecraft:

Present

Voice/Analogue	Digital
AO-10 (1983) *	UO-11 (1984)
AO-13 (1988) *	AO-16 (1990)
FO-20 (1990) *	DO-17 (1990)
AO-27 (1993)	WO-18 (1990)
RS-10/11 (1987)	LO-19 (1990)
RS-12/13 (1991)	UO-22 (1991)
RS-15 (1994)	KO-23 (1992)
(Mir/Sarex)	KO-25 (1993)
FO-29 (1996)	IO-26 (1993)
	(Mir/Sarex)
	FO-29 (1996) *
	MO-30 (Unamsat) (1996)

* = Non-LEO

Future

Voice/Analogue	**Digital**	**????**
--------------	-------	----
P3D	P3D	Pansat (s/spect)
UoS Minisat	Techsat	France
Sunsat	TM-sat	Finland
RS	UoS Minisat	Sedsat
	Sunsat	
	RS	

The future does indeed look grim for beginners !

Think back to how YOU started in amateur satellites: someone talked about it at the local club, or you saw it at Field Day, or you saw something in QST; you had someone to ask questions. I started with Oscar-6 on the island of Barbados in 1972. I had no-one to ask questions of: when/where, antennas, modes, freqs, all I had was some old magazine articles; its the same story in the third-world. (There was only mode-A at that time and it was still pretty hard; the learning curve went sky-high when I discovered Amsat but the earlier lessons were uncovered the hard way.)

Although my first love is HF CW, on the satellites I'm mainly a digital operator; but does the average beginner equip himself for 9600 bps satellite packet before starting? No, he'll use "ordinary" HF/VHF equipment (maybe borrowing one piece) and try voice or CW; cost can be quite a big factor in this but, with a taste of success, the motivation level rises. I have a friend who is a beginner; an experienced HF operator with help available, he still finds it hard but the challenge is there and he is getting a lot of fun from mode-K. Others may try mode-A or mode-B depending on the resources available.

Now read what John, GM4IHJ, has to say about the usage of modes A and K; I'll come back afterwards.

The Continuing Need for Mode A and Mode K Satellites

There is an inherent contradiction in Amsat affairs at this time (August 1996). Amsats appear to have lives of roughly 10 years at most, and most Amsats presently in operation are more than 6 years old with many of them being over 8 years old .

These operational Amsats divide naturally into 2 distinct groups. Those which do, and those which do not, support real time voice or cw qsos. The former group (AO10, AO13, RS10, RS12, RS15, Fuji20) are generally much older than the second group, which is composed exclusively of satellites using store and forward digital techniques and specialised experiments.

Taking the reasonable assumption that the analog voice and cw satellites were constructed to meet a real need, and have demonstrated a consistently high level of usage and an exceptionally high mean time between failures, it has to be asked "What replacements are in the pipe-line ?" With the exception of the Phase 3D system scheduled to replace AO10 and AO13 there are no effective replacements in sight. By contrast there are presently in process of building and launch at least eight more of the little-used digital satellites. By 1998, just 2 years from now, it will probably be the case that we will have no low earth orbit Mode A or Mode K simple satellites in orbit.

Several groups of Radio Amateurs will be affected by this break in a service which has existed for more than 20 years:

GROUP 1: The large group of enthusiastic radio amateurs who simply cannot afford the expensive equipment required for either Phase 3 operations or digisat operations. Noting that Phase 3 and digisats require about $2000 worth of equipment over and above that required for Modes A and K.

This extra equipment comprises a minimum of: bigger and better antennas with antenna rotors, higher powered transmitters, lower noise receivers, special modems, superior feeder cables and masts, plus computing facilities capable of multitasking both the communications protocol and the satellite tracking software. This situation is totally outside the reach of most third-world radio amateurs i.e. those radio amateurs who will have an enormous part to play in Amateur Radio's future.

GROUP 2: The satellite newcomers. Satellite operations are an acquired skill. No one starts on a satellite one day and is a proficient operator the next. Permitting the removal of Mode A and K satellites from the Amsat inventory will cause the supply of new satellite operators to simply dry up. Amsat is already in the position of being being top heavy with many who will not see their sixtieth birthday again. Elimination of the easy route to satellite operating will only hasten a process which could result in a permanent decline in Amsat numbers and fortunes.

GROUP 3: The Experimenters. The mode A and K satellites are a most prolific source of science experiment opportunities. Papers at Radio Amateur and Professional Symposia have in the past added lustre to the Amsat image; and these papers have for the most part concerned experiments using Mode A and K satellites. In the field of Propagation Studies alone it is very clear that all recent papers of note have come from Amsat members; not from the much larger community in the rest of Amateur radio.

Despite the above, there is no sign that Amsat authorities understand that, in failing to encourage and support the construction of Mode A and K LEO satellites, they are hazarding their own future - destroying their seed corn. The satellite building groups presently concentrated in Universities are concerned, for the most part, either to build clones of digital satellites which are out of date at launch, or are packed with highly specific equipment packages which have little or no relevance to Amateur Radio communications. Present usage studies suggest that, aside from the large blocks of Amsat operators who regularly use the analog satellites, there is only a small dedicated group of two hundred or so amateurs who regularly use the 9 digisats. It is further very noticeable that the frequent breaks in service from these satellites go almost unreported, simply because there is a surfeit of satellites and a dearth of actual users. One digisat has spent less than 30% of its life since launch in useful service and no one has complained.

Question the Amsat membership at large and you unfortunately get a biased set of answers: because most of the beginners and the third-world stations using the simpler sats cannot afford Amsat membership or even postage. Even so, it is clear that the Amsat membership as a whole is much more interested in analog voice and cw qsos than they are in digital operations. Geostationary and Molniya satellites feature large in the "Want Lists" of most affluent western Amsat users, but even in the affluent west about 40% of operators want mode A and K LEO sats.

In view of the above it is difficult to view the present dearth of new mode A and K LEO sats as anything but a clear sign of Amsat's failure to attend to its roots, and a portent of its gradual decline into an affluent old gentlemens' club; denying access to newcomers and pricing 3/4 of the world out of the picture.

This is hardly in keeping with the professed altruism which is supposed to be a major plank of amateur radio.

Addendum: Typical examples of the problems of satellite users around the world as reported to GM4IHJ by packet, e-mail, and ordinary postal services.

India: A regular A/K mode satellite user. Unable to meet the expense of Phase 3 equipment. Apologising for temporary absence from satellites, reported that the problem occurred when his antenna system collapsed onto the roof of the house, because termites ate through the bamboo support pole.

Digital equipment: Several correspondents in India, Malaya, Brazil and

Pakistan have asked for details of modem circuits for digisats to see if they could home brew clones. In no case could they get further. When they saw the circuits they realised they could not even afford the micro chips. Equally frustrating, the best computer any of them had was a Commodore 64. No use for the complex pacsat communications protocol.

Publications: There are frequent enquiries to IHJ for copies of the regular Satgen bulletins. These are easily supplied on disc and over 100 have been sent world wide. But very few would-be satellite users have computers that can read floppy discs. So I have instituted a copy by mail service of back numbers. This resulted in two original requests for Block copies of all the Satgens relating to Mode A and K LEO sats. Indeed the only topics most of the third-world are interested in are A/K LEO sats. This trend even extends to USA and Canada where I have granted permission for them to use Satgen extracts in their local club publications. Without exception the extracts used have been those concerned with A/K LEO sats.

Those against A/K LEO sats: As far as mail to IHJ is concerned, there has been very little received complaining about IHJ satgens devoting attention to LEO analog sats. Where complaints have occurred, the affluence of the complainants has been obvious. One Swiss retired airline pilot who is obviously not poor complained bitterly but said nothing constructive. Equally lacking in constructive advice were the two complaints received from USA, both of which were simply abusive and used phrases like "Get with it" and "Get a Life," which clearly illustrate the mental sub-sets of the authors.

Perhaps the most cynical comment received was from a pro A/K LEO using N3 station, who said "Years ago when Phase III was first mentioned, the general message from them (Amsat) was - You'll never get into this thing yourself, so you had better hope someone builds a gateway in your local area. Satellites are built by hams with money for hams with money, and that is that." I sincerely hope that over the next few years we find that the gentleman who wrote that previous paragraph was wrong.

John Branegan, 10 August 1996

G3RWL again:

While I don't necessarily agree with all of John's comments, I believe his contribution goes to the heart of what could become a problem for the amateur satellite community - recruits.

Ray Soifer presented a paper on user statistics to this years Amsat-UK Colloquium (See

"The Amateur Satellite Service in 1996" printed in this publication. ed.) : there are some eighteen thousand current satellite operators and in the past it is calculated there have been about ninety thousand others; this shows quite a fluid movement and is probably typical of the nature of our hobby.

Satellite operators, as we can see, come and go. Some (as John says) won't see sixty again. Losses need to be replaced: no operators = no funds = no satellites = no operators ... = no Amsat-future.

We are, in a way, victims of our own success: satellites were seen, amongst other things, as good educational tools. They were also valuable assets to our negotiating position in the conferences where frequencies are determined. So the builders had our support because they built satellites but Amateur Radio moves on, so does technology, and so do the builders.

No builder wants to keep on producing copies of Oscar-6; the technology is exciting to them and they want to continually do better things - who can blame them for that. The problem is that the advance of technology, while good for the builders and the public image of amateur radio, is self-defeating for us. New recruits, especially in developing countries where amateur radio needs to prove its use to government, will have nothing to start with. We MUST maintain entry-level technologies, however boring they may seem to the builders, or this aspect of our hobby will shrivel up and die; the satellite bands will be left to technical colleges or claimed by commercial interests.

There is no advantage to the present producers to build entry-level systems although they may toss us the occasional crumb; new builders are needed. But new builders, after a simple start, will also want to extend their skills. While this may at first appear to be a major problem I suggest we could learn from University of Surrey methodology whereby many countries want to develop a technology base so UoS take native technicians with their national requirements and then build at Surrey. The technicians then go home and start their own industry. Called technology transfer, many governments and international institutions find this rewarding - it is often financed by international aid programs.

Amsat-World should harness this emergence of technology; IARU are trying to promote Amateur Radio in the third-world - this would be an excellent area for mutual co-operation. But its not just emerging in developing countries - educational establishments in "technical" countries are also starting to take an interest. We should offer help (what to do, how to do it, how to launch it), maybe even seed money. It goes without saying that it should be a fundamental part of any contract that the organisation being helped should then offer the skills gained from this exercise and help the next organisation to start (this suggestion came from someone in Amsat-NA but, unfortunately, I can't remember who it was).

So ... what can we do ? Ask !!! But when you ask, the answers are only those of some of the people who received the question - catch 22.

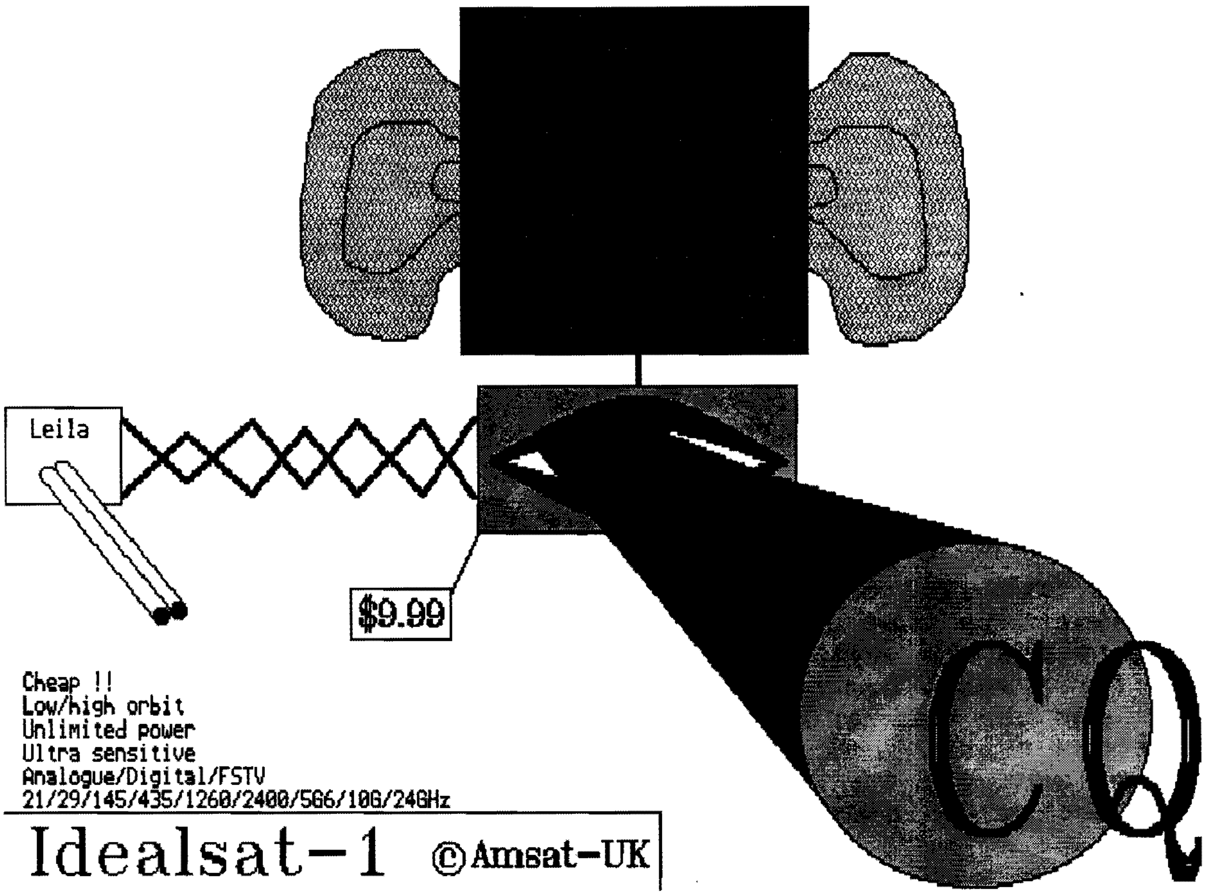
A good example of this was the recent Amsat-NA survey which asked:

What types of satellites would you like AMSAT-NA to construct and launch in the future?		-and-	How much annual financial support would you be willing to pledge?	
P3D-Type Orbit	54%		$0	20%
Geosynchronous	51%		$25	29%
Low Earth Orbit	26%		$50	27%
			$100	19%
Analogue SSB/CW	60%		$200	5%
9600B FSK	29%			
Analogue FM	26%			
Wider-Band	25%			
Higher Speed FSK	23%			
1200B FSK	10%			

(Figures add to more than 100% because of the multiple weighted responses requested.) As ever, radio amateurs (including AMSAT members) have champagne tastes and beer budgets!

[with acknowledgements to Ray Soifer W2RS]

The bottom line of user wants is best summed up in this sketch:



I believe that Amsat-World, while not guilty of neglect, have been over enthusiastic in their pursuit of excellence; we cannot blame them for that but what chance do the beginners have when users opinions are followed to the exclusion of all else ?

Whether the suggestions above are used, or other, better, ideas emerge, Amsat-World must re-appraise its objectives and look to the future. It is not enough for this just to be a talking point over the air - it is an argument which needs to be taken into the board-room. More Amsat officials than you'd think are sympathetic to the idea, but someone needs to push the boat down the slipway.

Whatever Amsat group you belong to, express your concern to them or this aspect of the hobby will disappear forever.

A SUMMARY OF AO-16 ACTIVITY FOR 1994-96

Robert J. Diersing
Dept. of Computer Information Systems
Texas A&M University-Kingsville
Campus Box 184
Kingsville, TX 78363
Internet: n5ahd@amsat.org

ABSTRACT

AO-16 activity is summarized for the years 1993-1995 and for the first five months of 1996. The summary, which is presented in both tabular and graphical forms, shows that AO-16 activity is slowly decreasing from a high of approximately 642 Mb transmitted in response to user requests in 1993 down to 561 Mb in 1995. The usage statistics presented are based on a data set with less than one percent missing data.

INTRODUCTION

Two years ago, AO-16 and UO-22 activity was examined in a paper published in these *Proceedings* [1]. That paper, which covered the time period from 1991 to mid 1994, also reviewed a number of operational events that affected AO-16's usage. The most important of these events was the switch to a new version of the Pacsat Broadcast Protocol (PBP) which has been in use ever since. The current version of PBP allows the automatic filling of holes in directory files stored at the ground station computer and automated downloading of files. This paper resumes the activity log and continues through mid-1996. Only AO-16 activity is examined.

DATA COLLECTION

Although a tabulation of missing data has not been included, in the 41 months summarized here, a conservative estimate is that fewer than a dozen daily log files are missing from the overall data set. Since one Activity Log (AL) and one Broadcast Log (BL) file is generated per day, this amounts to a dozen files from a total of 2,494 log files. Although both the AL and BL files were collected and processed, only data from the 1,247 BL files are included in the statistics since only broadcast mode activity is summarized. More often than not, the files not included were available but became corrupted either while they were stored in AO-16's RAM disk or during the downloading process.

DATA ANALYSIS

In [1] statistics were presented for both the connected mode and the broadcast mode but here only data for the broadcast mode is included. This is because only file uploading uses the connected mode

Table 1
Broadcast Mode Statistics for AO-16

	1993 complete	1994 complete	1995 complete	1996 thru 05-31
Average Transactions/Day				
Start+Fill Requests	646	701	658	470
Directory Requests	268	347	369	298
Average Byte Count/Day				
File Bytes	1,260,069	1,136,881	965,170	710,500
Directory Bytes	501,573	620,605	628,582	432,326
Average Transactions/Month				
Start+Fill Requests	19,649	20,747	19,291	14,204
Directory Requests	8,142	10,279	10,832	9,001
Average Byte Count/Month				
File Bytes	38,327,111	33,632,716	28,311,644	21,457,109
Directory Bytes	15,256,183	18,359,557	18,438,397	13,056,258
Total Transactions[1]				
Start+Fill Requests	235,792	248,964	231,497	71,022
Directory Requests	97,698	123,353	129,989	45,004
Total	334,490	372,317	361,486	116,026
Total Byte Count[1]				
File Bytes	459,925,333	403,592,597	339,739,722	107,285,545
Directory Bytes	183,074,192	220,314,678	221,260,765	65,281,289
Total	642,999,525	623,907,275	561,000,487	172,566,834

[1]Note the 1996 totals are not for an entire year.

of operation, and consequently, it represents a very small percentage of the total transactions processed by the spacecraft.

Table 1 summarizes the AO-16 broadcast mode activity from January 1993 through May 31, 1996. Figures 1-6 show daily average and total transaction and byte counts by month for 1994 through 1996 respectively. Each bar of each pair has two components. The left hand bar shows the number of file requests (start file and fill file) and the number of directory requests. The right hand bar show the byte count for transmitted files and directory entries.

In Figure 2, the month of September shows lower-than-average counts because AO-16 was out of service for ten days in September for a software reload. This was the only down time for AO-16 for the entire period covered by this paper. The fact that usage was back to normal levels the very next month shows that users did not consider the down time inordinately long nor did they think there would be any future unreliability of the satellite. They were correct on both counts.

Over the long term, though, usage of AO-16 is falling. Depending on whether one wishes to compare transaction counts or byte counts, the AO-16 usage for 1994 compared to 1993 is either 11% higher (based on transaction counts) or 3% lower (based on byte counts). For 1995 compared to 1994, the transaction count is 3% lower and the byte count is 10% lower. Even though 1996 data is incomplete, it looks as if the 1996 totals will be noticeably lower than 1995. It would be interesting to see if there is a corresponding increase in usage of the 9600 bps satellites--UO-22, KO-23, and KO-25. However, this author has discontinued collection of UO-22 activity logs primarily because the shorter lifetime of files on UO-22.

SUMMARY

This paper has presented a compilation of AO-16 activity logs for a two and one half year period. The logs show AO-16 activity decreasing slowly and it looks as though 1996 will show and even greater decrease. It is probably not surprising to see a decrease in activity since the "newness" factor for AO-16 has long since faded. As this is being written we are approaching four years of operation with the fully-developed Pacsat Broadcast Protocol. In addition, it may be that some AO-16 operators have migrated to the 9600 bps satellites like UO-22, KO-23, and KO-25.

A future paper will investigate AO-16 user characteristics by attempting to answer questions like: How long does a newcomer use the satellite before migrating to another satellite or other interests? How frequently does the typical user operate? Do previous users who have become inactive ever return to operate with any degree of regularity? What is the geographical distribution of users? These and other statistics will be extracted from a combination of activity log files and files of directory entries.

AO-16 is a distinctly different type of communications resource and the data summarized here is a testament to its reliability during the past several years.

REFERENCES

[1] R. Diersing, "A Long-Term Examination of AO-16 and UO-22 Activity Logs," in *Proc. AMSAT-NA 12th Space Symposium*, Orlando, FL, October 7-9, 1994, pp. 60-76.

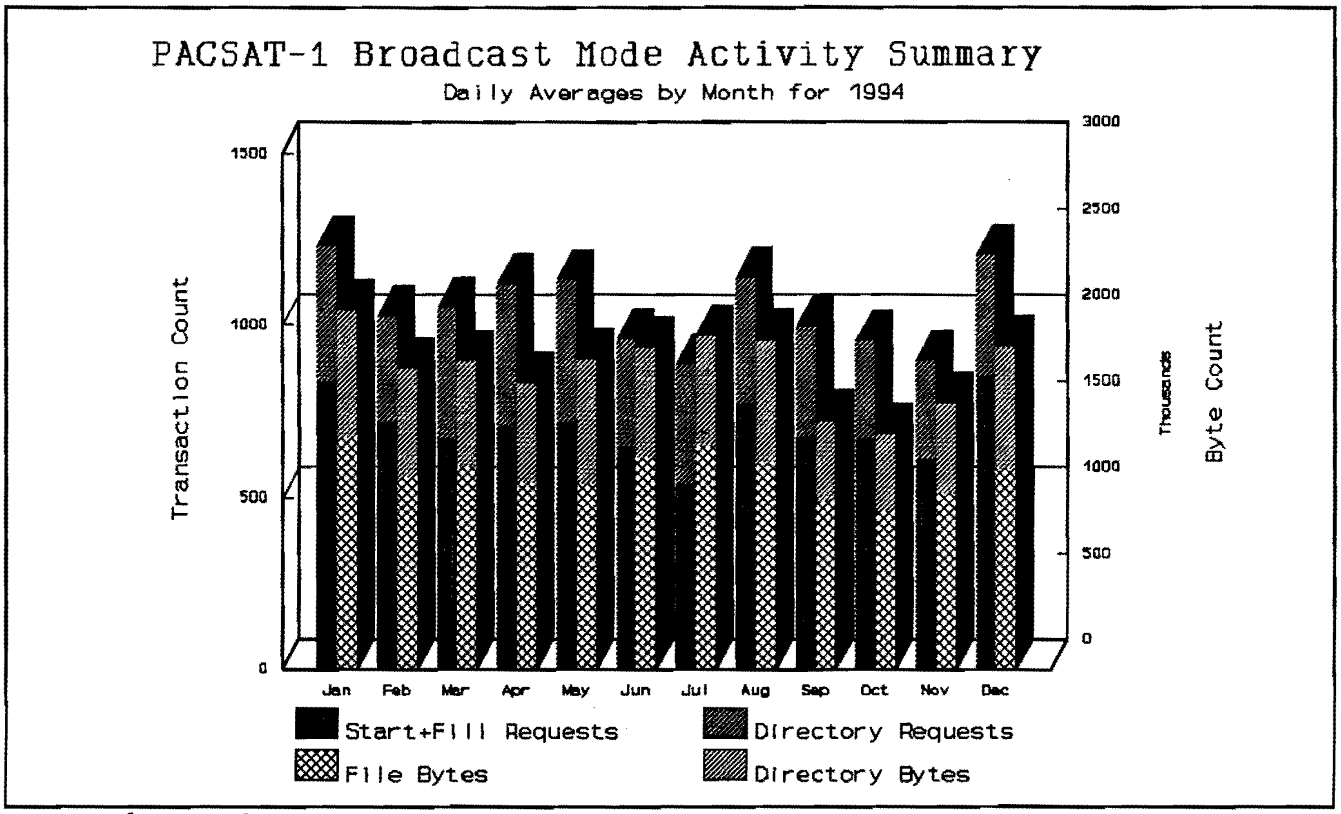


Figure 1.

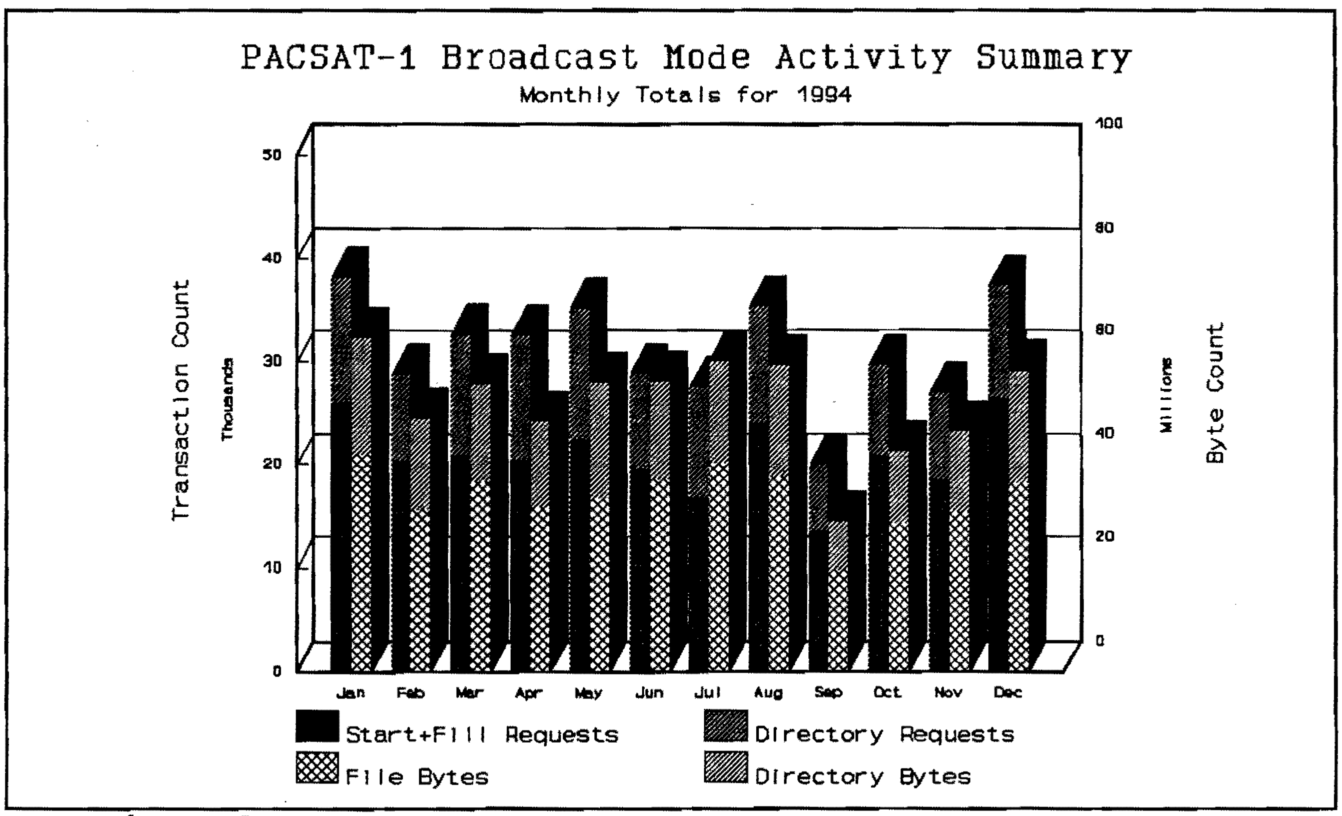


Figure 2.

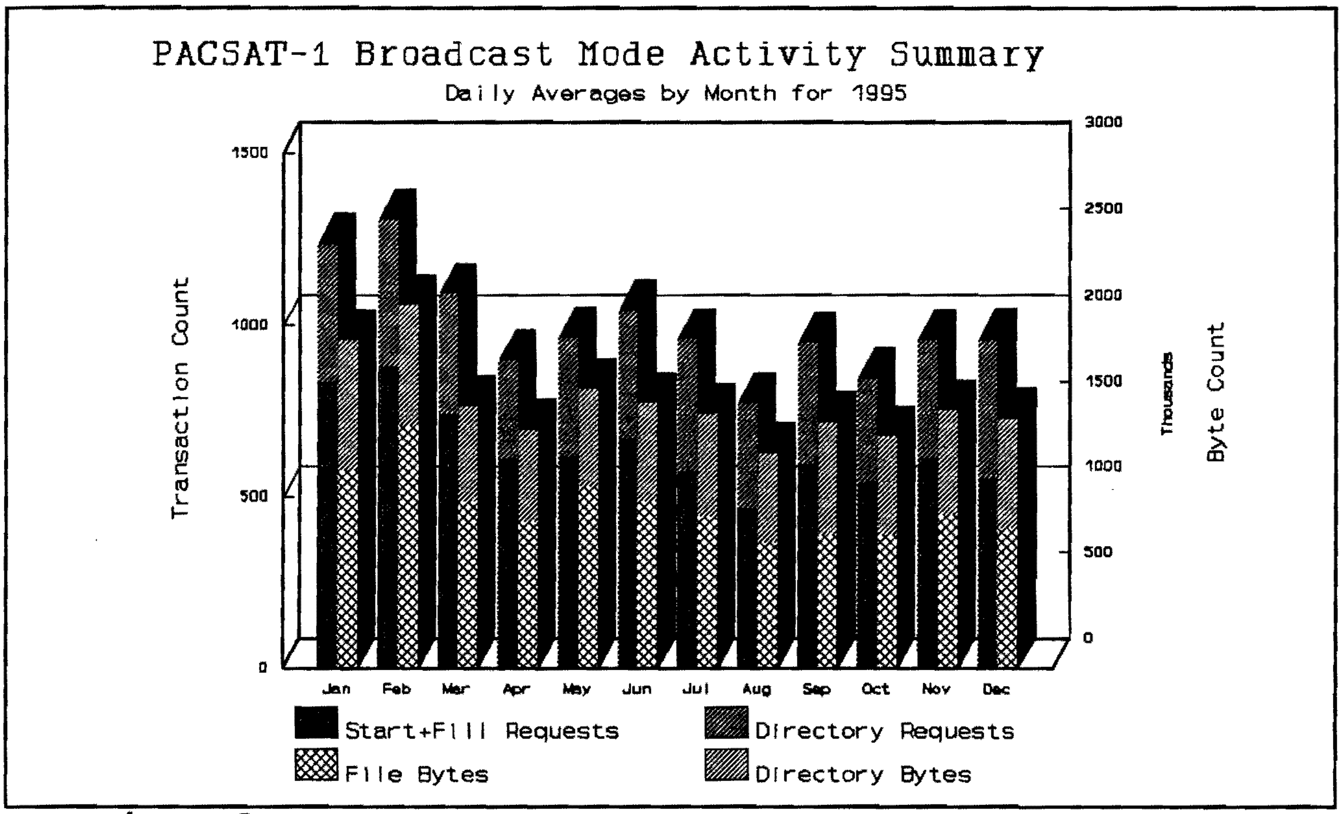


Figure 3.

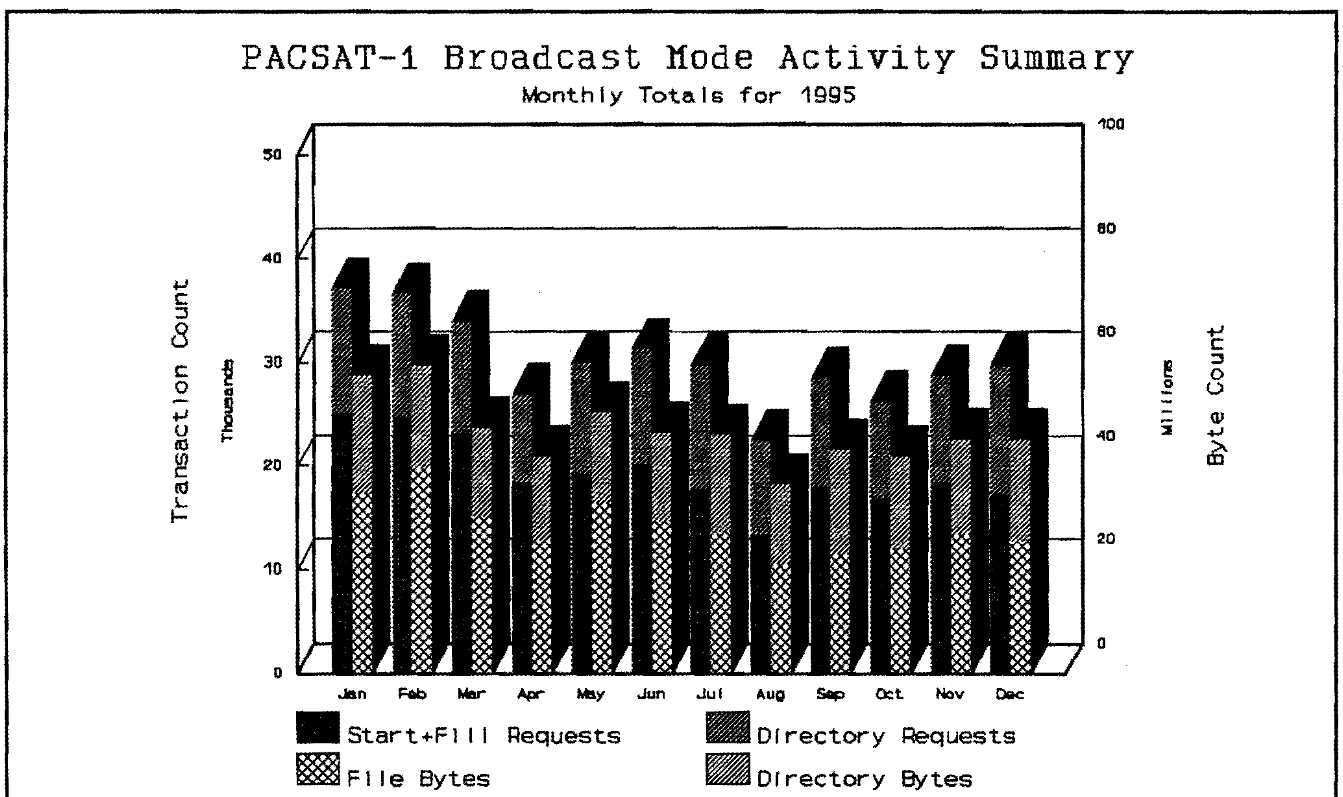


Figure 4.

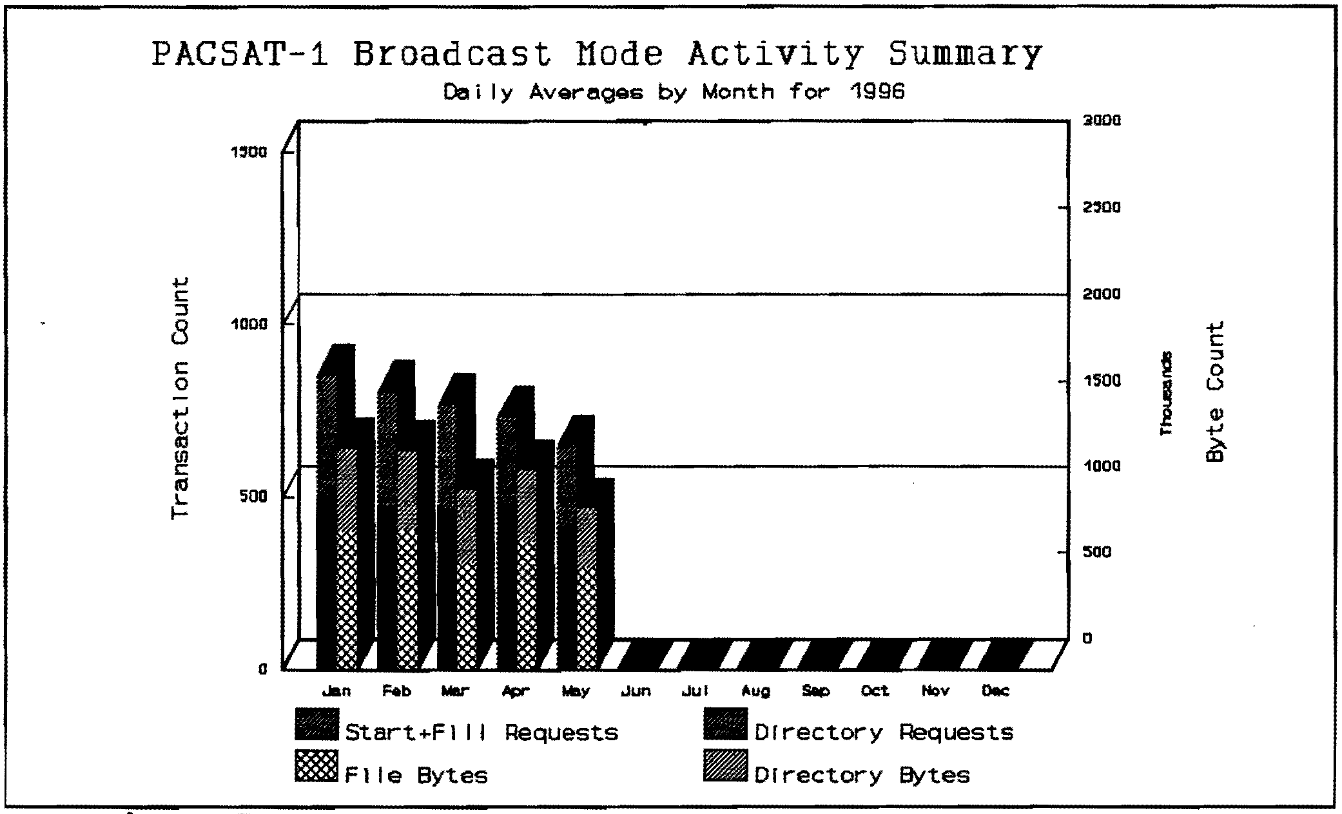


Figure 5.

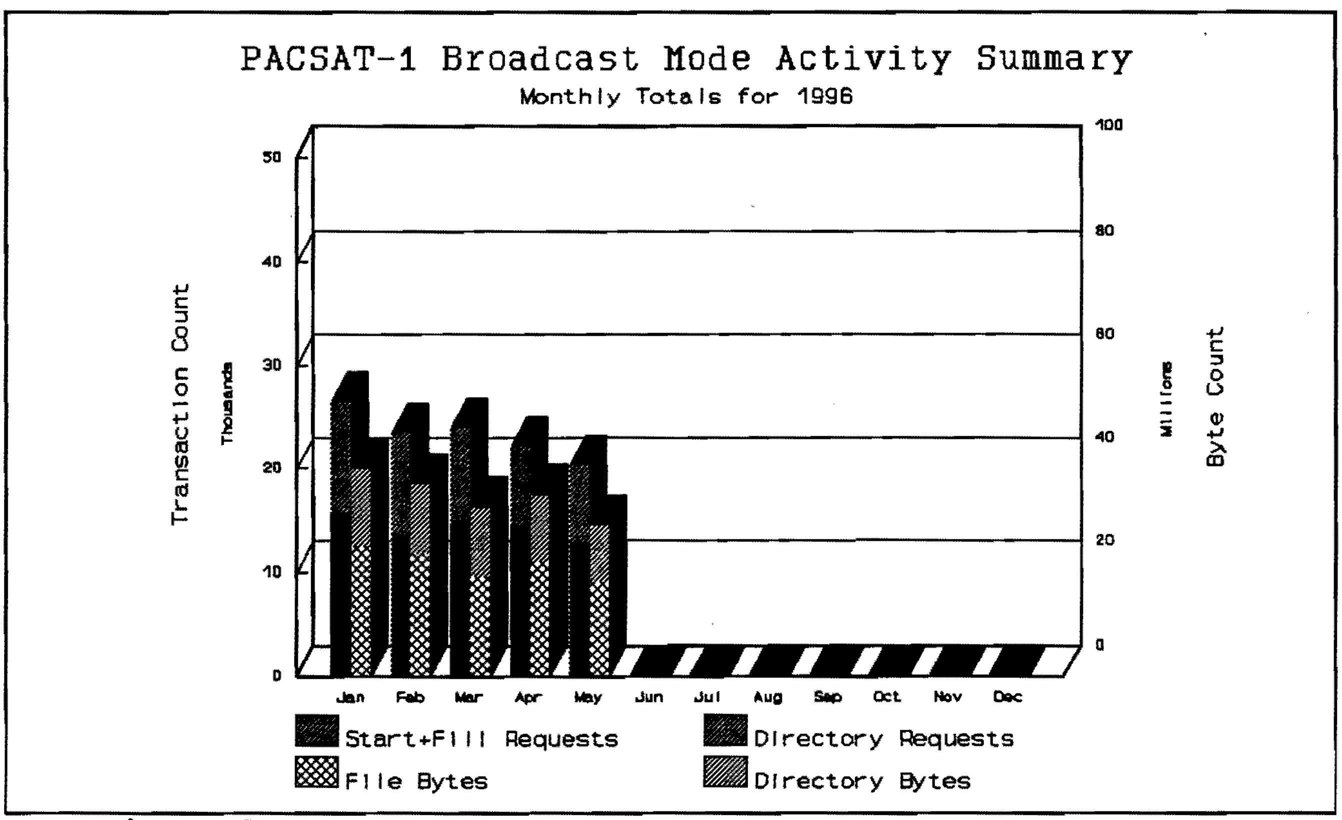


Figure 6.

ASUSAT 1: A LOW-COST AMSAT NANOSATELLITE

Shea Ferring[#], Joel D.Rademacher[*], Helen L.Reed[+], Jordi Puig-Suari[*]
and other members of the ASUSat 1 Team

ASUSat Lab
Mechanical & Aerospace Engineering, Box 87-6106
Arizona State University
Tempe, AZ 85287-6106, USA

ABSTRACT

In October 1993, the students at Arizona State University (ASU) were challenged by Orbital Sciences Corporation (OSC) to develop a 4.5-kg (10-lb) satellite (ASUSat 1) to be launched as a piggyback payload on a Pegasus rocket. The challenge also included the requirements for the satellite to perform meaningful science and to fit inside the Pegasus avionics section (0.02 m^3). Moreover, the students were faced with the cost constraints associated with university satellite projects. This unusual set of constraints resulted in a design and development process which is fundamentally different from that of traditional space projects. The spacecraft capabilities and scientific mission evolved in an extremely rigid environment where cost, size and weight limits were set before the design process even started. In the ASUSat 1 project, severe constraints were determined first, and then a meaningful scientific mission was chosen which fit those constraints. This design philosophy can be applied to future interplanetary spacecraft. In addition, the ASUSat 1 program demonstrates that universities can provide an open-minded source for the innovative nanospacecraft technologies required for the next generation of low-cost planetary missions, as well as an economical testbed to evaluate those technologies. At the same time, the program provides hands-on training for the space scientists and engineers of the future.

INTRODUCTION

University satellites provide a unique opportunity to combine the educational and research missions of a university in a single program. The students are presented with a multidisciplinary work environment, where team effort is a must. This experience, while it represents the real working environment of most engineers today, is still unusual in a university setting. On the other hand, the limited resources and rigid constraints placed on these kinds of spacecraft require the development of innovative technical solutions. These new solutions range from the design of new low-cost components to the development of manufacturing techniques that can be easily performed by students with little manufacturing experience.

In recent years, the space community has been faced with new constraints, lower budgets, shorter design times, etc. (the faster, better, cheaper philosophy). In this new environment, the kind of thinking found in university satellite programs may provide some of the solutions which are required for the success of space exploration in the future. This paper describes the ASUSat 1 project. This is only one of the many university satellite programs currently under development. It is the authors' opinion that such projects can make valuable contributions to the aerospace field, not only by training scientists and engineers, but also as a tool for the development and testing of new technologies.

PROGRAM OVERVIEW

The original challenge made to ASU students by Orbital Sciences Corporation (OSC) co-founder Scott Webster in October 1993 was to design and build a 4.5-kg satellite to perform meaningful science in space. The satellite would be placed in the avionics section of the Pegasus rocket, with dynamic envelope constraints of 31 cm in diameter and 26 cm in height. Given these mass and size constraints along with the limited resources of a university satellite project, some design limitations were placed on the spacecraft:

[#] Senior, Aerospace Engineering. NASA Space Grant Intern.
[*] MS Graduate, Aerospace Engineering. NASA Space Grant Fellow.
Current Position as of August 1, 1996: Systems Engineering Group, Jet Propulsion Laboratory.
[+] Director, ASUSat Lab. Professor, Mechanical & Aerospace Engineering. Associate Director, ASU NASA Space Grant Program. AMSAT Member.
[*] Assistant Professor, Mechanical & Aerospace Engineering.

(1) In order to reduce mass and complexity, which increases failure risks, the number of deployable systems was to be kept to a minimum. In particular, deployable solar arrays were not considered as an option, and power was to be provided exclusively by body-mounted arrays.

(2) Given the reduced power output from the small arrays along with the severe mass and cost constraints, active control systems were eliminated from the design.

(3) Given the strict mass constraint, innovative approaches had to be considered for structural design, including extensive use of composites.

(4) Due to the cost and mass of commercially available attitude-determination systems, it was decided that a low-cost student-designed attitude-determination system would be developed. Such a system could not guarantee great accuracy, hence the satellite should be able to perform its mission with limited attitude knowledge.

Given these constraints, the mission and final design of ASUSat 1 were dependent on the launch orbit provided by OSC. Launch availability has changed twice since the program began thus producing three missions and satellite designs.

The initial design was based on a 450-km-altitude, 6am-6pm, sun-synchronous orbit. In this orbit, the scientific mission was to measure the flux, mass, velocity, and temperature of microparticles in low Earth orbit. The scientific instrument developed by the students, the Micro Particle Recognition Experiment (MRE), incorporated the use of a thin, piezo- and pyro-electric polyvinylidine fluoride (PVDF) film to characterize interplanetary dust and microparticles[1]. The spacecraft design included a gravity-gradient boom for stability. After the preliminary design of this spacecraft was completed, the available orbit changed.

The new launch opportunity was a 325-km-altitude, 6am-6 pm, sun-synchronous orbit. Unfortunately, the PVDF film in the MRE would be quickly eroded by atomic oxygen at this lower altitude. Hence, a new experiment had to be developed. At this stage of the design, few components were completed and a significant redesign was still possible without large increases in cost. The new mission involved the study of the ionospheric plasma environment found in the highest layers of the atmosphere. The Ionospheric Plasma Research Experiment (IPRE)[2] involved the measurement of plasma flows and the effectiveness of Hall accelerators using the atmospheric plasma. In addition, the design incorporated two CMOS (complementary metal-oxide semiconductor) cameras for earth imaging which would also be used as a secondary means to determine spacecraft attitude[3]. The large aerodynamic forces associated with the atmospheric density at the lower altitude prevented the use of the gravity-gradient boom for stabilization. In the new design, the boom was re-designed to act as an aerodynamic-stabilization device. This innovative stabilization system would maintain proper orientation of the scientific instruments.

This design had to be abandoned when the launch was moved again, this time to a 550km-altitude, 10:30am-10:30pm, sun-synchronous orbit. Ion densities at this altitude are not sufficient to run the IPRE effectively, and the science mission required redesign once more. At this point, the development of the spacecraft was in a very advanced stage and some of the most important components, such as the structure, were already constructed. The decision was made to reduce the scientific scope of the mission to Earth imaging and the demonstration of low-cost satellite technologies, along with the AMSAT voice repeater. This new scientific scope required increasing the number of cameras to four. This, the current design, allows for a vehicle that can perform in a variety of orbits, thus reducing risk if further changes in the launch opportunity develop after the satellite is in advanced stages of construction. This latest version of the satellite is described in detail in this paper.

ASUSAT 1

The current mission of ASUSat 1 is one of technology demonstration, and earth imagery, along with AMSAT operations. ASUSat 1 currently has several innovative, low-cost aspects incorporated into its design. These include the four CMOS digital cameras, the mostly composite structure, the student-designed array of attitude-determination sensors, the terrestrial GPS (global positioning system) unit, the small gravity-gradient boom-deployment mechanism and gravity-anchored passive damper, and the low-cost student-designed electronics boards.

Structure

In order to meet the low-weight constraints on ASUSat 1, the satellite body is constructed of a low-cost, light-weight carbon fiber in a 954-2A epoxy resin manufactured by ICI Fiberite Composites. The composite is a 12-layer lay-up with 0°, 45°, -45°, and 90° plies. The total structural weight is 1100 grams. The main bus structure is a 14-sided cylinder inscribed within a 31-cm-diameter circle, with a length of 24 cm, and wall thickness of 0.8 mm. This extensive use of composite materials presents some uncertainties in the analysis of the in-orbit thermal behavior of the satellite, since experience with composites in spacecraft applications is limited. In order to address these uncertainties, ASUSat 1 incorporates a number of student-designed thermal sensors which will provide an accurate thermal picture of the spacecraft. This data will be valuable to validate currently available thermal computer models.

The structure consists of several sub-assemblies designed for ease of fabrication. This is an important issue since students, with limited manufacturing experience, will construct the satellite. The sub-assemblies are as follows: the 14-sided main body; the top bulkhead, mounted flush with the top end of the satellite; the science bulkhead, which is recessed 4 cm into the lower side of the spacecraft; two interior instrument and board mounting panels placed between the two bulkheads; the deployment guide rod tube running through the center of the satellite; and brackets at various angles to mount all sections together (Figure 1). The various components are assembled using a combination of epoxies and metal screws.

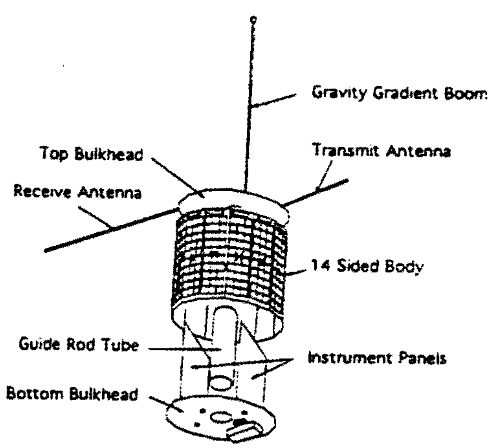


Figure 1: Structural components

The satellite is attached to a student-designed deployment mechanism, which can be easily mounted to an interface plate in most launch vehicles (Figure 2).

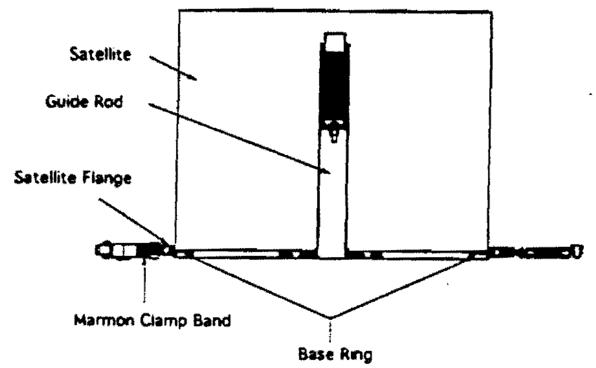


Figure 2: Deployment interface

Deployment

The deployment mechanism was developed to safely eject ASUSat 1 from the avionics section of the Pegasus rocket. This system was also designed to provide reliable deployment and a simple interface when used in other launch vehicles. This flexibility is important for future ASUSat missions given the limited resources of a university program.

The satellite-deployer system consists of the following components: a guide rod running through the center guide tube in the satellite; a separation spring attached to the guide rod; a clamp band to secure the satellite during launch; a bolt cutter; and a base plate to mount the system into the launch vehicle.

The deployment sequence begins with a pyrotechnic signal to the boom deployer. This guarantees that the satellite is deployed in a stable configuration. This is particularly important for ASUSat 1, since no active attitude-control system is present. After a 15-second delay, a second signal activates the deployment bolt cutter. This releases the clamp band, which is pulled away by retraction springs. The separation spring pushes the satellite out of the avionics section at about 0.5 m/s, and the antennae automatically deploy after the spacecraft separates from the guide rod (Figure 3).

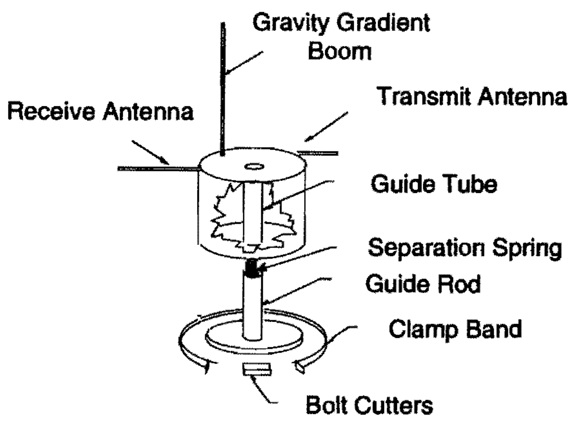


Figure 3 : Deployment

Dynamics & Control

The satellite uses gravity-gradient stabilization with a boom extended from the satellite top bulkhead (Figure 4). The student-designed boom deployer is based on currently available systems, but has been miniaturized to fit within a 8 x 5 x 5 cm volume. This mechanism deploys a 2-meter beryllium copper element with a 50g tip mass.

A passive damper is included in the design to eliminate oscillations on the satellite due to possible deployment misalignments or external disturbances. The damper is a gravity-gradient-anchored system[4]. In this device a gravity-gradient-stable mass is suspended inside a fluid. Given the near-polar orbit of the satellite, this passive damping system is superior to traditional magnetic dampers. In addition, if the mass is designed to be 3-axis stable, the system can provide 3-axis damping. The presence of the passive damper results in a much better imaging platform for the cameras. This gravity-anchored damping mechanism is one of the innovative technologies being tested on ASUSat 1.

A commercial (non-space-rated) GPS unit from Trimble Navigation provides position and velocity information. Modifications to the GPS receiver were performed by the students to improve its resistance to shock and vibration. The unit has been successfully tested to flight qualification levels, and software corrections will be incorporated to remove the COCOM altitude and velocity restrictions.

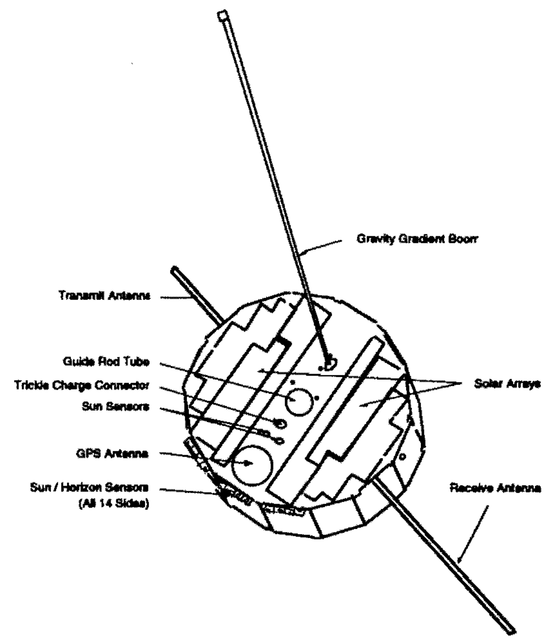


Figure 4 : Top bulkhead

A low-cost array of student-designed light-sensing diodes is used for attitude determination. A block of four diodes is mounted onto each of the 14 sides of the satellite. Three of the diodes sense visible light from the sun and one senses infrared radiation from Earth. Two more visible-light-sensing diodes are mounted on each bulkhead. All 60 sensors are read periodically to determine the orientation of the satellite. It is estimated that these sensors will provide attitude knowledge with an error of less than 10°. During the mission, Earth images from the cameras will be used to accurately calibrate the sensors and determine a more precise error estimate.

Imaging System

The imaging system on ASUSat 1 consists of four black-and-white CMOS cameras. Three of the cameras are mounted on the bottom bulkhead and provide overhead pictures of the Earth. One of these cameras incorporates an infrared filter. The other two operate in the visible range and have lenses which provide two different resolutions. The lens selection is still being finalized, but currently a maximum resolution on the order of 1 km per pixel is expected. The fourth camera is located on one of the sides of the satellite providing images of the horizon.

Electronics

The CPU is designed around the Intel 80C188EC embedded microprocessor. The board has a 2-KB

PROM for boot-loader software, a 256-KB EPROM where spacecraft-operations software is stored, and 1 MB of RAM with a two-bit error detection and one-bit correction system. The CPU will initiate power-switch control for the power board, connect to a Zilog Z85230 HDLC controller for digital communication, and interface directly to the GPS board.

Analog measurements from the attitude-determination and thermal sensors are handled by a separate dynamics-interface board. This board, along with the camera-interface board, will connect with the CPU through two I/O interface ports.

The satellite carries a total of 17 printed-circuit boards, plus 14 attitude-sensor boards. Six of the boards, along with the attitude sensors, are completely student-designed. A block diagram of the satellite control boards is shown in Figure 5.

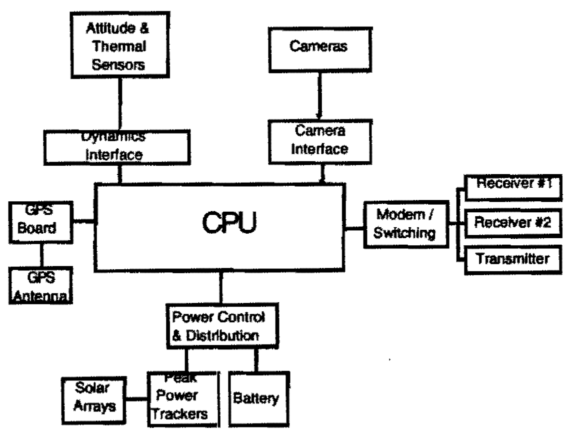


Figure 5 : Control board block diagram

Power

The power system consists of the solar arrays, two six-packs of Nickel-Cadmium (NiCd) batteries, and associated control electronics.

The solar cells are space-rated Gallium-Arsenide (GaAs) cells with 18.5% efficiency. They are body mounted on all 14 sides and the top bulkhead. Each of the 14 side-panels contains two 15-cell panels. Six additional 15-cell panels are placed on the top bulkhead. Approximately 13 volts are provided from the 34 panels in parallel. This system will provide an average of 8.5 to 10 watts depending on solar-array temperatures.

The batteries will provide backup power in high-power-demand situations and during eclipses. The two packs will be used one at a time during the mission. Each pack provides 7.2 volts to DC-DC converters. Battery recharging is controlled by three peak-power trackers. However, they do not provide enough power to run all systems during the 36-minute eclipse associated with the current orbit. The satellite will be placed in a low-power mode during eclipses. In this mode, in order to prevent the loss of software and data stored in RAM, only the CPU is on-line. In addition, critical systems, such as the transmitter and receiver, are kept warm to prevent temperature damage.

The power system is activated by the release of two redundant push-button switches upon deployment of the satellite.

The batteries are the heaviest component on the satellite, while the solar cells are the most expensive.

Communications

The communications system consists of a transmitter and a modem/switching board, both partially designed by students, and two receivers. The receivers are Motorola P-50 Radius Radio transceivers modified by the students for space use.

ASUSat 1 is an amateur class satellite operating in the amateur-radio-band frequencies. The transmission frequency is in the 70-cm band, while the two receivers operate at separate frequencies within the 2-meter band. One receiver is used for digital mode. The second receiver handles AMSAT voice communications and acts as a backup for the digital system. The modem operates at 9600 baud and interfaces with the CPU using HDLC-frame protocol.

The two receivers are enclosed within a thin aluminum mesh along with the GPS board for electromagnetic interference (EMI) protection. The layout of all internal boards is shown in figure 6. The antennae are simple carpenter's-tape segments. They are mounted as shown in Figures 6 & 7.

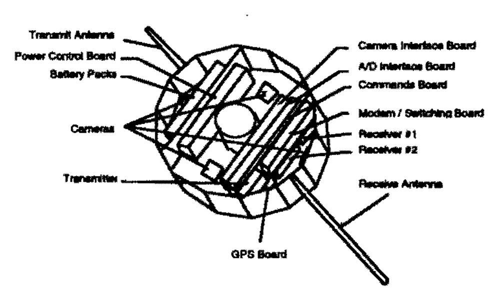


Figure 6 : Inside view

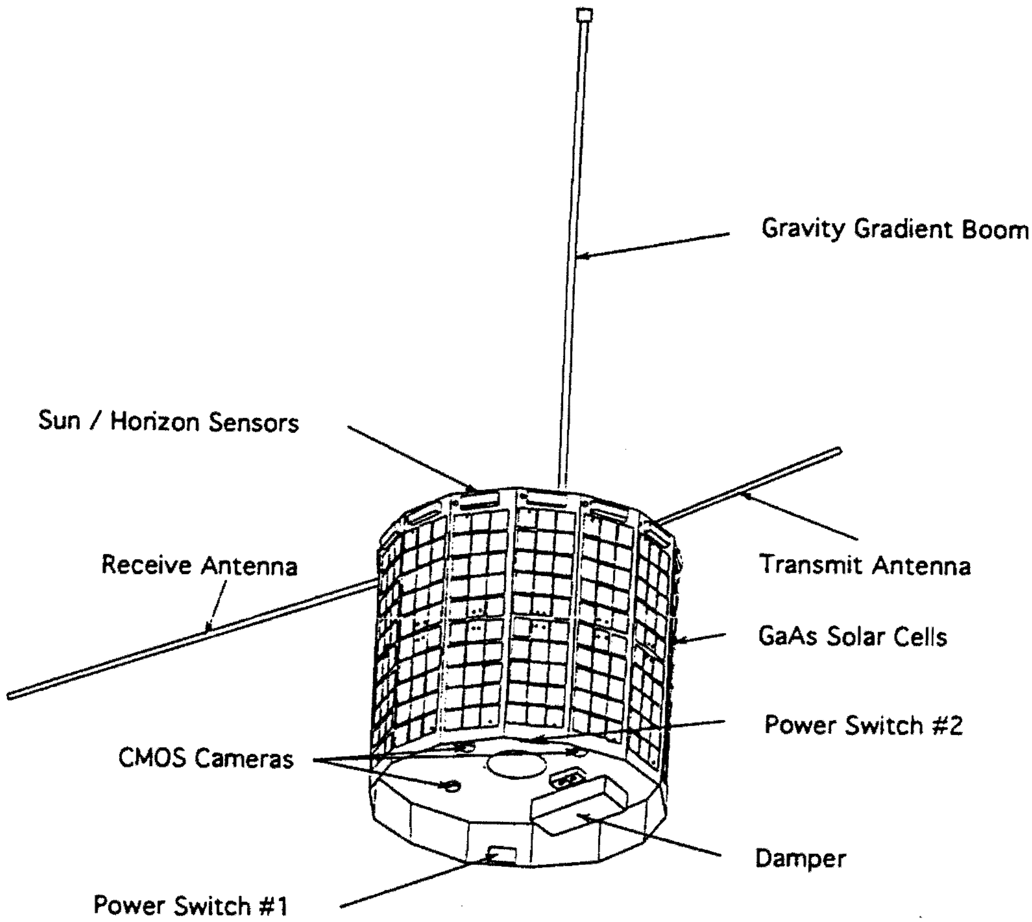


Figure 7: Complete configuration

Software

The software is designed around the BekTek Spacecraft Operating System. This operating system offers a real-time multi-tasking kernel, a message-passing facility, AX.25 protocol drivers, and a set of DMA/Interrupt-based I/O drivers designed for the Intel 80C188 microprocessor.

Within this powerful operating system, there are six applications running concurrently during the mission. These applications control all on-board operations and measurements. The modules are the watchdog timer, the attitude determination, power, science, thermal, and communications software modules, and the bootloader module.

The software system is designed to receive ground commands to run the imaging and GPS systems at desired times. Other operations, such as AMSAT voice communications, are controlled automatically depending on the power available. In addition, several onboard parameters, such as the time between thermal and attitude-sensor readings, can be easily modified from the ground.

Thermal

Temperature transducers are mounted on the CPU, battery box, transmitter, receiver mesh, and modem to monitor operation temperatures. The transducers on the CPU, transmitter, and modem are designed into the boards. If the temperature of any system exceeds operating limits, safety features in the software will turn the system off to prevent damage. Additional sensors are placed on the inside walls of the composite bus to monitor the thermal behavior of the composite material in the space environment.

Silverized Teflon is applied to all exposed surfaces of the structure to help reflect radiation. In addition, a thermally conductive paint is used on the interior of the satellite to ease passive thermal control.

System Integration

Integration of all subsystems into the final satellite system is handled by the systems team. Cross-subsystem communication and design is also monitored to ensure optimization of weight, volume, power, functionality, and construction process. Assembly and test procedures are handled by a combination of the systems team and ground support, and EMI shielding is dealt with by all subsystems designing printed-circuit boards.

Currently ASUSat 1 is scheduled for launch in March 1997. The development structure and systems are going through the final stages of testing. Most of the components are under construction and the qualification prototype is scheduled for completion in early Summer 1996. This system will go through full qualification testing during the Summer, and the final vehicle is scheduled for construction in the Fall 1996.

CONCLUSION

The small satellite is an important training tool for the next generation of space scientists and engineers. The ASUSat 1 project, has provided over 150 students with hands-on experience in a real space program. They have participated from the initial concept, through the design and instrumentation, and will participate on through flight, ground operations, and data collection. The result is an intricate package of low-cost, light-weight, student-designed electronics and mechanisms that function as a complete system (see Figure 7).

However, this system is also an important research endeavor. A variety of innovative solutions have been developed to meet the challenge to design and construct an advanced and innovative nanosatellite within very severe constraints on mass, size, and budget. The resulting spacecraft (ASUSat 1) incorporates a variety of innovative technological features: all composite structure, student-designed low-cost attitude-determination system, terrestrial components which were space-rated by the students, low-cost CMOS cameras, and so forth.

The future of interplanetary exploration must be based on the development of lower-cost missions, and the design philosophy applied to ASUSat 1 can help provide the fundamental change required to create the next generation of interplanetary nanosatellites. Cost and launch mass are determined first and a meaningful scientific mission is chosen which fits those constraints. In the spirit of this philosophy, then, the space community should be challenged to produce a valid scientific mission with seemingly impossible mass and cost constraints. The ASUSat 1 team feels that this is the kind of challenge required to provoke the fundamental change necessary to continue the exploration of the solar system in the 21st century.

ACKNOWLEDGMENTS

We would like to thank all students involved with the ASUSat 1 project since its conception in October 1993. Many thanks also go to Scott Webster (OSC), Rich Van Riper (Honeywell Space Systems Group), and all other faculty and industrial sponsors; without their help this project would not have been possible. We especially thank the students from the Machine Trades Program at Maricopa Skill Center (a Division of GateWay Community College, one of the Maricopa Community Colleges) for building low-cost on-board components.

Donations and support have been provided by organizations and companies throughout the Phoenix metropolitan area and the nation. Orbital Sciences Corporation has donated the launch, advising, and test facilities. The ASU NASA Space Grant & Fellowship Program has provided both student internships and fellowships. The National Science Foundation Faculty Awards for Women in Science and Engineering has also provided student funding. Arizona State University provided funding for the spacecraft hardware. Honeywell Space Systems Group provided advising in all areas of the project. The AMSAT Organization has provided technical advising, and the use of amateur frequencies. Intel's University Support has donated several 80C188 processors, support literature, an In-circuit emulator, and other test equipment. Motorola's Satcom and University Support provided technical advising for thermal, power, and communications systems, and donated several IC's and crystals for the command board, as well as three P-50 transceivers for communications. Hughes Missile Systems provided advising, use of facilities, and a cash donation. Others that have provided technical advising and support are:

Photocomm, Inc.: Solar array advising & facilities
Spectrum Astro: Advising, equipment, and communications testing
Applied Solar Energy Corp.: Reduced cost solar cells
Trimble Navigation: GPS board & antenna
Astro Aerospace: Advising, boom material donation
Universal Propulsion Co., Inc.: Advising, bolt cutter donation
ICI Fiberite Composites: Advising
Simula, Inc.: Advising
DynAir Tech of Arizona: Autoclave usage, fabrication

ASU Architecture & Environmental Design Shop: Machining facilities
ASU Electrical Engineering Department: Loan of testing equipment
National Technical Systems: Environmental testing
BekTek: Software advising
Lee Spring Co.: Proto-type deployment springs
Eagle Picher Industries: Advising, battery donation
Gordon Minns & Assoc.: Camera boards
KinetX: Advising - software & ground support
Rockwell: Non-flight solar cell contribution
Sinclabs, Inc.: Test antenna donation
Equipment Reliability Group: Equipment advising
Bell Atlantic Cable: Ground station cable donation
AERL (Australia): Peak power tracker
JPL: Advising, hardware
Space Quest: Communications advising
Dycam: On-board cameras

Additional information on the ASUSat 1 design can be obtained on the World Wide Web at:

http://enws229.eas.asu.edu/asusat/asusat.shtml

REFERENCES

1 Hewett, C.H., and Reed, H.L. "A Microparticle Recognition Experiment for Near-Earth Space on Board the Satellite ASUSat 1," *8th AIAA/USU Small Satellite Conference*, Logan, UT, 1994.

2 Hewett, C.H., Rademacher, J.D., Reed, H.L., and Puig-Suari, J., "The Ionospheric Plasma Research Experiment: ASUSat 1 & Advanced Spacecraft Technology Applications," AIAA 96-0719, *34th Aerospace Sciences Meeting & Exhibit*, Reno, NV, 1996.

3 DeLaTorre, J., "Earth Reference Imager Experiment for Satellite Attitude Determination," *9th AIAA/USU Small Satellite Conference*, 1995.

4 Kumar, R., "Gravity Anchoring for Passive Spacecraft Damping," *AIAA Journal of Spacecraft and Rockets*, Vol. 32, No. 5: Engineering Notes, 925-927, 1995.

The Picosat System™

by Peter Vekinis, KC1QF/EI4GV/SV0GV
Version 4.0. Amsat Symposium, Tucson Arizona, 1996

<u>Disclaimer</u>

The information presented herein is the sole responsibility of the author and does not necessarily constitute the views of any other parties.

Participate in Picosats!

The Picosat program is being designed on internet, a global electronic information exchange system. You can access internet from anywhere in the world. Most computer based networks offer internet, systems such as Compuserve, Delphi, you local BBS and others.

A web site exists: http://www.cordis.lu/esprit/src/picosat.htm

To sign-up to the picosat mailing list using an internet account:

1. send electronic mail to: majordomo@lists.stanford.edu
2. include in the message area:
   subscribe int-picosats@lists

You will get a confirmation and start getting messages.

After signing on to send mail to that list you use the address:
int-picosats@lists.stanford.edu

The author can be contacted through the following addresses:
Via PACKET to:
ON9CGV@ON7RC
Via internet E-MAIL
peter.vekinis@dg3.cec.be
or

kc1qf@amsat.org
Via Compuserve
100670,3437
Via FAX
+ 32 2 296 9229 (office)
TELEPHONE
+ 32 2 296 8154 (office) or + 32 2 657 3881 (home)
ADDRESS
Either
Vekinis
P.O. Box 1966
Arlington Heights, IL 60005
United States of America
or
Vekinis
Patrijzenlaan 2
1560 Belgium

Table of Contents

1. Introduction to the Picosat System

This is the third edition of the Picosat Systems manual.

The world is changing. We all know that. From the early days of HF radio to these days of instantaneous satellite communication, our world is getting smaller and smaller. We can now pick up a phone and dial anyone, anywhere in the world, even on a boat anchored in one of those idyllic islands one sees only on postcards.

Radio amateurs have followed and sometimes led this explosion and have in the process identified many new areas of splendor. Myself, as a young man, I tried to also get in the field. At my parents home, I used wood, aluminium plates and a hell of a lot of screws to construct a rough parabolic antenna trying to capture the Apollo mission voice prints. Little did I know then about how complex these systems really are. I did however had an idea. And the idea over the years took form and became what is now known as Picosats.

However, using satellites is not easy; in fact it is a pain in the neck. I found out that I would need a big antenna, an amplifier, at least an SSB rig and a lot of patience waiting for the bird to 'turn the corner.' The commercial world, sees it differently. They have geostationary satellites; great huge dishes and amplifiers and they sure dwarf our signals.

This commercial world, driven by the insatiable need for cash, has moved us one step further. Instead of taking us to the mountain, they are brining the mountain to us! They have created Iridium et al. And no ham has done anything about it. Until now.

Some of you in this room would like to 'play' with antennas and power amps and the kind. Others would just like to communicate. This Picosat project is for those of you that want to do the latter, easily, cheaply, and above all whenever and wherever you feel like it.

Picosats are very simple, small, efficient satellites that fly at Low Earth Orbits (otherwise known as LEOs). Their purpose is to offer easy-to-use communication anywhere. By being more than one and by flying low, a user would perceive continuous communications even though the actual satellite repeater would be changing all the time.

They are to be launched in LEO slots, should last about 4-5 years and should be powerful enough to be used by a little handheld radio, running ACSSB or FM.

Recent advances in telecommunications and the availability of cheap material as by-products of the cellular phone technology makes such a project a reality using block modules in both the transmitter and receiver circuits.

Picosats will be powered by solar cells that have an area of 10 x 13 cm x 13 cm.

In order to face the sun all the time (to guarantee adequate power) Picosats will also have active stabilization with the use of magnetic rods or compressed air bottles driving air vents.

Picosats will offer the ability to be used with an 2Watt HT using a simple antenna (rubber duck) - hey this is what Iridium is all about remember?). They will be launched in such a way as to be separated by a certain amount of minutes in polar orbits. The idea being that if you start using the first one, you should be able to continue to talk without interruption.

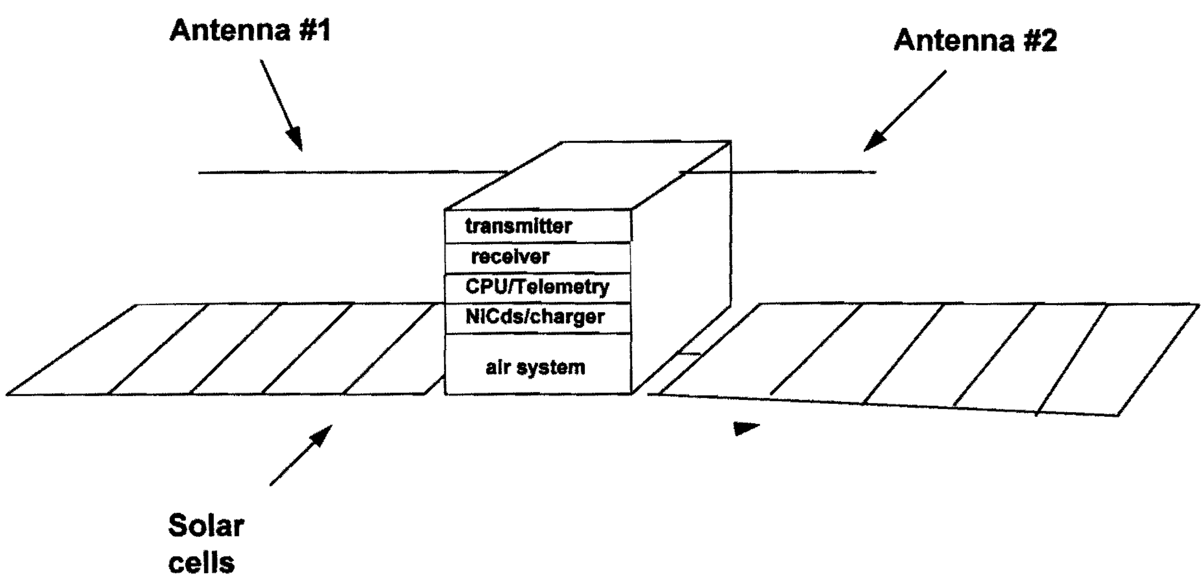
The initial launch calls for 16 Picosats plus 2 in-orbit spares.

Command of the picosats is to be via a command system with secret command controls making it very secure to operate the spacecraft. Information on the command structure, frequencies etc will remain confidential.

Picosats will offer at least 5 watt output power in the appropriate band. It is expected that with the availability of these easy-to-use birds and the expanded market they will create, manufacturers will build specific dual band USB/HTs.

A picosat is a small (6 inch cube) satellite which offers simple circuits, active stabilization and low mass. It is a satellite that will be placed in a LEO orbit and be able to offer transponder use to the user.

The satellite is composed of the following elements:



- It has two solar panel areas for gathering solar power
- It has 5 or 7 trays which hold the transmitter, receiver, control/control rx, battery and stabilization systems
- It has two antennas for receiving and transmitting
- In closed shape it is exactly 15cm by 15cm by 15cm

The satellite will use bands that must still be defined. It will use a 100KHz or 200KHz bandwidth to offer a minimum of 38/58 voice conversations in SSB or 9/19 conversations in FM.

The power output will be a maximum of 6 watts. The solar cells will produce a maximum of 14.4 watts of power. They will have the a of 5 x 13cm x 13 cm.

There is nothing like a picosat. All of the birds today are experimenter spacecraft. They need antennas, pointing systems, power and a good ear (or modem).

You can say that Picosats are to satellites, what HTs are to amateur radio.

Each Picosat satellite will have an onboard GPS system to provide information on its location over the earth. This information will be able to define precise orbits and altitude information for use by the control systems. Such information may be used for precise control of the spacecraft.

They are extremely easy to use spacecraft. Pick up your HT, tune to the frequency and speak. That's all there is to it. You don't need to know when a bird will pass overhead. You don't need to have a special antenna. You don't need lots of power. You don't need complex systems. You communicate from anywhere on this planet; in the jungle; on the sea, on the poles, in the cities, in the fields and up the mountains. You can build gateway stations to repeat into satellite sub-bands from any other frequency (2 meters for example). You can use Picosats to call for help from anywhere. As long as someone is in the footprint, the world opens with Picosats. They offer what other amateur radio satellites don't offer: practicality.

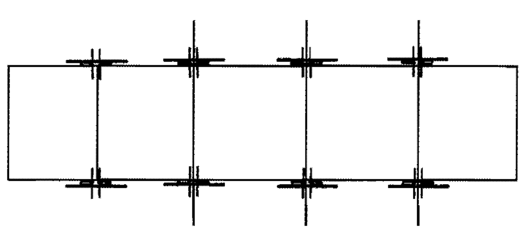
The reasons are many:
- Cost: a Picosat costs little money. A maximum of $30,000 for the cost of the satellite.
- Launch: Real easy. How hard is it to launch a cube the size of a rubic's cube?
- Easy of use: cant say that often enough

2. Electrical specifications

Solar Cells

A picosat satellite will take advantage of solar power and active stabilization.

Maximum electrical power output using 15% efficient solar cells is about 14.4Watts.



The solar cells will have worst case efficiency of 15%. They will have an area of 1690 cm2 providing 14.4 watts of power. As the birds will always face the sun, this power will be always available.

Picosats will also use Lithium (or NiCd) batteries which are tried and tested. The cells will hold 8A at 6V.

The power systems will operate at 6V. The transmitter module will use FET power modules rated at 6Volt. These are mainly used in cellular telephones and will work fine.

3. Electronic specifications

Picosats are designed to have simplified receive and transmit circuits. One receiver and one transmitter will be included plus an additional receiver. The bands have not been set yet, but suggestions range from 10m/2m, 2m/70cm or 70cm/1.2GHz

It is expected to use FET power output modules and simplified circuit design. The pass band is expected to be either 100KHz or 200KHz wide.

The Picosat system will feature linked satellites, connected with an modified AX.25 network, that will be able to function with DTMF (or similar) codes. A control receiver will receive commands and there will be additional, low power transceivers for inter satellite communications. All picosats will be individually controllable

Although, FM will be the main communications method, ACSSB is also envisaged. The choice of communications medium depends on the users. All of these have advantages and disadvantages.

FM is the best medium. Rigs are available today. However, there is still the problem of Doppler shifting which at the 1.2GHz area is in the order of about 30KHz. The HT will have to be retuned as the QSO progresses.

Amplitude Compandored SSB has been around for years, but no real use has come out of it. For this application, it will be necessary to offer ACSSB in order to automatically control the Doppler shift which may make SSB operation difficult.

ACSSB uses a pilot tone 10db down set at 3.1KHz above the carrier. For this use, the pilot carrier will decrease to 12db below the carrier but the frequency will remain the same(+3.1KHz). The carrier will be transmitted by the ground transmitter, and retransmitted by the satellite. The receiver will then lock onto to this carrier to offer automatic Doppler shifting. The pilot tone, which is 12db below will of course use power. This will decrease the amount of power available for the RF, but make Doppler adjustments automatic.

At the altitude Picosats will be flying, that is at LEO orbits, Doppler shifting of frequencies becomes a problem. Perhaps for experienced operators, Doppler shifting is old hat, but for newcomers and to fit the need of Picosats being easy to use, some sort of method must be found to compensate for Doppler shift.

In the Picosat LEO orbit, Doppler shift at 70cm would be about 10KHz and for 1.2GHz would be about 30KHz. This is both a problem for FM and SSB and this is where ACSSB comes into play. In FM mode the problem is not very serious (after al people can retune) but on SSB it is critical.

ACSSB has the pilot tone, which although uses power, can offer automatic adjustment of Doppler shifting.

In case where a setting satellite has a Doppler of say, -30KHz and the rising has +30KHz, some sort of procedure must be found to link the receivers. The best would be for the operator to have a handover time to switch satellites manually.

Each Picosat will use a GPS system. The GPS system, such as GPS-20 by Garmin, will supply precise orbit information. This information will be used by the control systems on the spacecraft to define paths over ground and other appropriate information.

4. User's guide to the system

The Picosat system is a system of satellites that are linked together, providing communications on amateur bands, on a continuous basis. As one Picosat sets, another one rises. This continuous communications facility is what makes the Picosat system unique.

On top of that, the Picosat system offers intersatellite communications so that users are knownb everywhere in the system. A ham in say, Melbourne, Australia, can call a friend in New York, and start a QSO with him if he is online on a specific channel. This interlinking, resembles a cellular telephone link, except that each cell is a satellite and the number of users restricted.

The Picosat system will permit users with direct path to the satellite, to transpond using a HT, with 5Watts output power feeding a whip, or less power feeding a 1/4 wave, or a 5/8 wave antenna. Mobile users will be easily able to use them.

This simple communications scenario is only a small part of the capabilities of the satellites which are enhanced with the following features:

- **Picosal Interface Link**
- **Users will register to receive their codes (like a phone number)**
- **Users will be able to interlink with satellite outisde their ground area**
- **The satellites will offer a simple messaging service**

Picosat Interface Link(PIL): This is a method by which Picosat users will be able to link and interlink with the satellite using the DTMF pads on their transceivers. A user will receive the downlink signal and listen in on the telemetry beacon. At the same edge of the band but on the transmitting band, he/she will transmit DTMF tones requesting specific actions. The telemetry will signal acceptance or rejection of the commands sent acknowledging the actions specified. The initial PIL codes defined are as follows:

*0A#	Report status
*1B#	Report time
*7Axxxxxxx#	Register my xxxxxxx code (must be numeric)
*1AxxxxxxDyyyyyyy#	Code yyyyyyy is calling code xxxxxxx
*4Cxxxxxxx#	Removing code xxxxxx from system
*6Cyyyyyyy#	Has code yyyyyyy registered and when?

When you use the PIL codes, the telemetry channel will pre-empt using voice responses. If a link muct be made between two users who are not in the same satellite, then interlinking will be setup and the response will indicate that the frequency is now global and users must move on to the specific frequency indicated. Global frequencies will change and be limited and timeout after three minutes. This way users will be able to take advantage of the features without misuse.

All commands start with a * and end with a hash(#).

*0A# This will cause the satellite to respond the status (different to telemetry). Status will include channels in use, number of hams active etc.

*1B# Report Time in UTC

*7Axxxxxx# Register user xxxxxxx active for the next hour. The user number, xxxxxxx is provided by the registering center (see below).

*1AxxxxxxxDyyyyyyy# User yyyyyyy is calling xxxxxxx. If user xxxxxxx is not online, a voice response on the telemetry channel will indicate as such. If the user is online, you will be notified of the frequency to use for both uplink and downlink and so will the other user. If the other user is in another area served by a different satellite, a response will indicate that the transmission is global. It will time out after 3 minutes and a reminder will be given at -30 seconds, -10 seconds and at -5 seconds.

*4Cxxxxxxx# A user can optionally remove himself from the system, instead of waiting for the system to cancel him/her after 1 hour.

*5AxxxxxxxDyyyyyyy#voice message (10 seconds maximum then timeout).

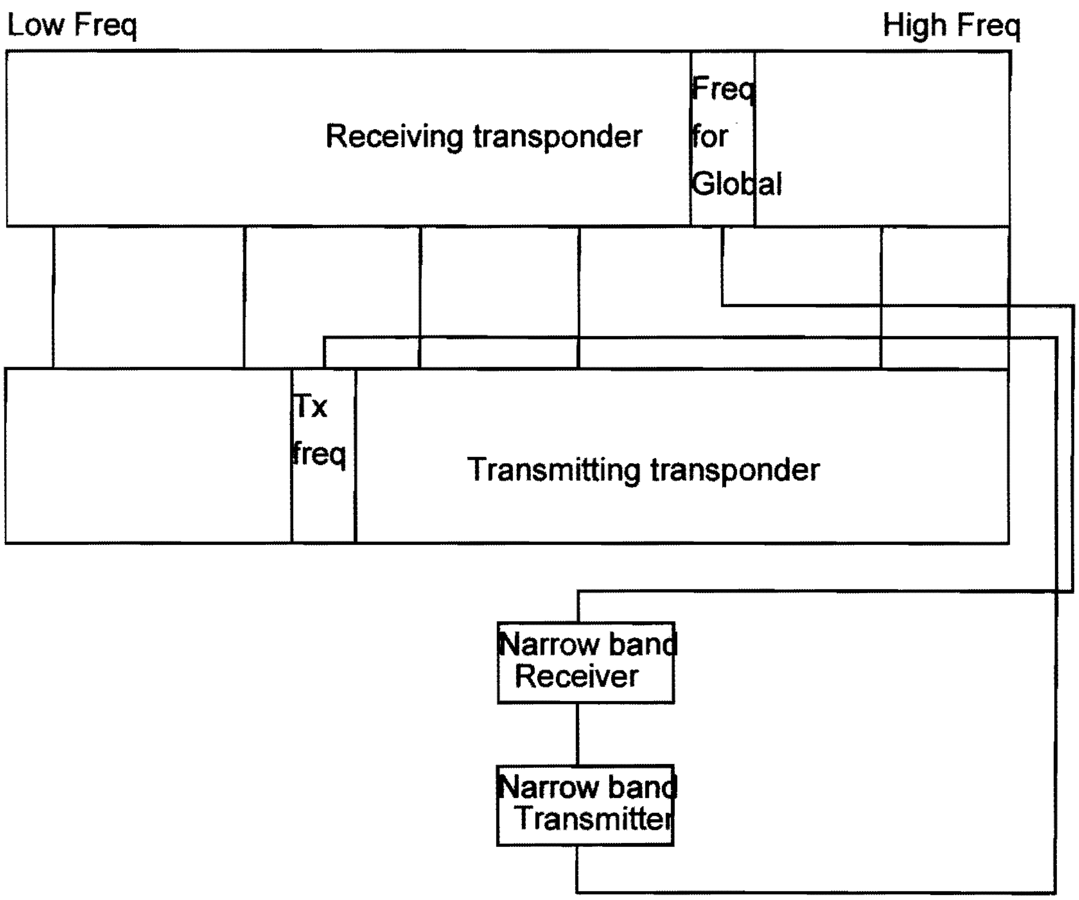
*5Byyyyyyy# Receive messages for yyyyyyy, one after the other. After they get transmitted, they are automatically erased.

*6Cxxxxxxx# This will tell the Picosat system to specify if a user is online, when he registered and where (in Lat/Lon).

Users will have to register with the PIL center to receive their codes. heir codes will be made up of their callsigns. The PIL center will be accessible via packet radio and via the internet.

Users will be able to interlink the system and take advantage of global communications depending on where the users are. If users are situated in different satellite footprints, their transmissions will be interlinked. The linking will use low power transmitters on the satellites to re-transmit the voice to other satellites until they get bounced back to the other user's location. To avoid misuse, the global frequencies to be used will be provided by the satellite on the two satellites that must be linked. Although the transmission will be heard globalwide, only the two participating stations would know the frequencies. Internally, a frequency of the transponder will be fed into a narrow band transmitter which will be fed into the output transponder on all the satellites. Lets take an example. Users #1, calls user#2 using PIL. Satellite finds that user #2, is hooked to a different satellite. Satellite with user #1 sends a signal to the Picosat System to open up the interlinking frequency and patch it to the used frequency which will be provided to user#1. Same happens for user #1. Communication continues.

The chart below shows how this could work:



A simple messaging service will be available using the registered codes. Depending on memory available on the satellites, a user will be able to send a message to the satellite which will be retreived by other users. The code of the user will be used as a voicemail indicator. Messages will be limited to 10 seconds, and they will automatically time out. Upon receipt they will be erased. Messages an be in any language.

5. Manufacture

The actual design of Picosats is undertaken by the Picosat project team. The design includes RF receivers and transmitters, control circuits, battery and attitude systems. The design will use FET RF power transistors to operate at 6V, a simple single CPU chip design, and solar panels similar to the ones used in Microsats.

The Picosat Project team will be composed of myself as well as students and members of Stanford University's Satellite lab, under the direction of Professor Bob Twiggs. They already have experience in satellite design and construction (projects OPAL for example).

6. Illegal use

We all know that illegal use of satellite systems is a real problem. We will overcome this situation with specific control. Specific Control of the satellite means the ability to turn off the system as and when specific conditions prevail. The Picosat system will have facilities to be able to turn off activity over a specific area of the globe, or deactivate PIL codes, or a combination. This is a necessity to ensure tha only bona fide amateur will be able to use the system.
Because of the easy availability of satellite equipment, illegal activities have been taking place at specific areas of the globe. We dont want to allow such operation (unless of course there is a real emergency) thus illegal operation will have to curtailed. Unfortunately, if the Picosat system excludes specific areas of the globe from use, bona fide radio amateur will suffer as a result. This may be seen as an incentive to ensure that the pirates in their area are brought to justice quickly and effectively by these bona fide amateurs.

7. Current Status

Since October 1995, many things have been done to get the project started. The series of events is as follows starting with **FUNDING**.

October 1995:
Meeting with Prof Bob Twiggs of Stanford University who agrees to take the project up as a student project. In his letter sent to me, Bob requests $7200 to start the project. The estimated cost per satellite would be in the region of $40000-50000.

November 1995:
I start contacting companies to raise the funding.
Microsoft: An e-mail is sent to Bill Gates, asnwered by his advisor who says he will look into the request. A month later, a message is received, saying that there is no interest for this project by Bill Gates.
IBM: I contact by fax, Lou Gerstner, IBM's Chief Executive. I am passed on to a PR person whoi sayd "I understand what this is about and I will pass the request to the appropriate people." Ten months pass and still no answer (I suppose we cvan fibure out what the "appropriate people" must be.

European Commission: A programme is starting which deals with University exchanges between the US and Europe. However, 9 months on and the programme has not started. In addition, as I work at the EC, such action would be very difficult for me to achieve. However, they donate 25 leather briefcases from the Esprit programme (the Esprit programme funds over $2 billion in support of the IT industry). These bags will be sold at the Amsat Symposium to raise funding. Cost of the bags (color blue, 16" x 11" x 2" (40cm x 30cm x 5cm), with plenty of pockets is $25 each, all of it going for the Picosat Project.
SUN: Contacted James Gosling, A Sun fellow and one of the owners who e-mailed me that he would be putting together a donation. A month later another message comes saying that there would be no donation.
Bellcore: Contacted the Director for Business Development, but till today (late August) no answer.
Spyglass (the people behind Mosaic). Also contacted them but still no answer.
IBM Atlanta: E-mailed but no answer received on this project.
Tekes(Finnish R&D support Institute). Contacted the head of investment and was promised support if a Finnish company or University could be involved together with Stanford U. This is still an open issue.
Windmill Lane Pictures (U2 fame). Still in negotiations on funding participation.

PROJECT

The project has been debated greatly by the people in the attached mailing list plus other participants. No actual work has been done yet, because some funding must be found to start. After this year's AMSAT symposium (1996), and assuming all the funding that can be raised has ben raised, the project will get a go ahead and be passed on to Prof Bob Twiggs to discuss it with his students who will be the backbone behind it. This SSSD group will work on the satellite components except the RF circuits and control. Experts for these two subsystems will have to be found within the amateur community.

AMSAT

I was not invited to discuss the issue at last year's AMSAT symposium and hope to do so at this. I have the broad support from many participants from this year's symposium and judging by the response of the individuals concerned, the Picosat System is the way to go after 3D. It is a low risk, high expectations and advanced systems project designed to move the amateur satellite community to the 21st century. Radio hams have shown the world over and over that they can do pretty much the impossible, and this is no exception. AMSAT support will be indtrumental for three reasons:

- we can use AMSAT's expertise in the technical field (they have worked with space system before)
- we can use AMSAT ability to raise funding
- we can use AMSAT international connections to properly market the project.

TODAY'S HAM ENVIRONMENT

Today's ham environment is very different from the one that was there a few years ago. The whole communications revolution has made easy the availability of cellular telephones, walkie Talkies and more. Anyone can have a cell phone, cheaply, and anyone with $200 can get a GMRS walkie talkie. In addition Radio Shack has made requested the creation of a family radio service which makes ham radio as a short range communications medium obsolete.

Granted, we hams are aware of all of these, but how long will it be before Radio Shack or someone else proposes a satellite system for GMRS radios? At the speed of today's comms, this is only a matter of time. If that were to happen, what impact will it have for us? What can we do about it?

Well, there is plenty.

First we must ensure we get funding for this project. The Picosat System is a state of the art, high peformance, advanced satellite system that can be done. To get funding we must mobilise many amateur radio operators from around the world. They must contact companies or CEOs or people who have the funds needed and to show them what it means to have a satellite named after them who serves an important purpose.

Second we must raise individual funding for this cause. If every ham offers $1, we would collect more than $600000 for this project, enough for most of the satellites! If ARRL can match funding from amateur radio operators(like the thing they did for Phase 3D), we would also have funding.

And thirdly, we plan to issue press briefings and releases to the media hoping to get the commercial contractors interested in the ptoject. We may get additional funding as a by-product of this project.

8. Project participants (from the picosat mailing list in no particular order) who support the Picosat System. I also want to thank the countless others who have sent in messages on this project. Your vision is what makes this project possible:

Robert Twiggs	<btwiggs@leland.Stanford.EDU>
GwynReedy-W1BEL	<gwyn@paccomm.com>
Harold Price	<hprice@bektek.com>
K5YFW	<k5yfw@sacdm10.kelly.af.mil>
ArtJayes	<Art.Jeyes@jhuapl.edu>
Dan Schultz N8FGV	<n8fgv@amsat.org>
Kaj-OH6EH	<oh6eh@amsat.org>
WA2GSY	<wa2gsy@ka2qhd.de.com>
JONES Peter	<jonep@dg13.cec.be>
VEKINISPeter	<pve@dg13.cec.be>
	<aitor@mail.internet.com.mx>
BruceRahnWB9ANQ	<brahn@ibm.net>
	<julio@aix1.uottawa.ca>
AlbertoAzagni-I2KBD	<azagni@micronet.it>
'Bob_Walker-N4CU'	<Bob_Walker-EBW004@email.mot.com>
'TimBusch N0CKR'	<busch@cacd.rockwell.com>
DaveJ.Mullen '	<jmullen@facstaff.wisc.edu>
Gerry Creager-N5JXS	<gerry@cs.tamu.edu>
'JohnBoudreau-ve8ev'	<ve8ev@gov.nt.ca>
Ivano Garavaglia	<I.Garavaglia@archivio.it12.bull.it>
John MeltonG0ORX	<j.d.melton.slh0613@oasis.icl.co.uk>
'Laura HallidayVE7LDH'	<lhalliday@creo.bc.ca>

'Jason Suchman'	<suchmj@leland>
Wayne Estes-WD5FFH	<wayne@csg.mot.com>
Walt DuBose-K5YFW	<k5yfw@sat.n5lyt.ampr.org>
'Mark-N0PWZ-names?'	<froggy@southwind.net>
'Kevin Keller-WB9MUP'	<kwk@world.std.com>
'GustavocCarpignano'	<gustavoc@pinos.com>
Rob Whiteley-N3HQX	<robert.whiteley@intelsat.int>
'Jay Sattle-N8JTR'	<JASATTLE@argo.acs.oakland.edu>
Chris Kitts	<kitts@leland>
'Chris-AtGrace'	<cjk6113@grace.rit.edu>
'pat_kilroy wd8laq'	<pat_kilroy@ccmail.gsfc.nasa.gov>
Jay Hackel	<jhackel1@cc.swarthmore.edu>
'Adam O'Donell-N3RCS'	<adam@libertynet.org>
"Robert J. Twiggs"	<btwiggs@best.com>
"Cooksley, John"	<ees2jc@ee.surrey.ac.uk>
Loftur E Jonasson	<loftur.jonasson@simi.is>
	T-GSCHWINDT@nov.mht.bme.hu
Arne Luehrs	<arne@gplarne2.grenoble.hp.com>
Tom_Jennings	<jennings@eng16.rochny.uspra.abb.com>
"PAUL MANNING"	<MANNING_P@wfum.flint.umich.edu>
"Jim White"	<jjwhite@ntsqm1.uswc.uswest.com>
Karen M Garrison	<kmg@kepler.unh.edu>
C. Ratsameenil,HS1GOS	<hs1gos@md2.md.chula.ac.th>
	robs@bconnex.net
David Medley	dmedley@indirect.com
	joehol@microsoft.com
Jim Tissler	jwt@shrine.cyber.ad.jp
Rick Meuse	rickham@ix.netcom.com
Ron Parsons	rparsons@bga.com
Jim Wotus	ka1ryi@ix.netcom.com
Laurent Ferracci	f1jkj@planete.net (F1JKJ)
"Clark, Keith"	<k.clark@surrey.ac.uk>
"Stephen Martin"	<martin4s@CC.IMS.DISA.MIL>
"da Silva Curiel, Alex"	<A.Da-Silva-Curiel@ee.surrey.ac.uk>
Alex Curtis	axcurtis@sae.ssu.umd.edu
Bill Gearhiser	gear@sgifll.lauderdale.sgi.com

MIR:
FIVE YEARS OF A PERMANENT PACKET RADIO SPACE STATION

Gustavo Carpignano, LW2DTZ
P.O.BOX 94
1828 Banfield
Argentina
lw2dtz@amsat.org

This year the first amateur packet radio space station celebrates five years aboard the Russian MIR Orbital complex. Launched on 19 February 1986, MIR replaced the SALYUT space stations series run by the Soviets throughout the '70's and 80's. Since 1991 packet radio was a permanent part of the complex, starting an era of cooperation with other amateur radio organizations.

The Complex

On orbit near 400 km high inclined at 51.6 degrees, the space station is a modular design and has been slowly constructed. The current complex consists of the original MIR module, a cylinder of about 15 x 4.15 m and a mass about 20000 kg, the Kvant-1 astrophysics module docked at the rear axial port, a cylinder of 5.8 x 4.15 m and 11000 kg, launched on 31 March 1987. Kvant-1 has inside X-ray, Gamma-ray, and UV telescopes. Mounted on this module is the Sofora mast structure which is 14 meters long with an attitude thruster maintaining package at the end. For accommodating the arrival of Progress and Soyuz vehicles a docking port to the rear of the Kvant-1 is used. The Progress resupply vehicle is launched every 1 ½ months carrying water, tools, equipment, mail, and fuel. It's capable of a three-day free flight and can stay docked to MIR for up three months. During this period its engine can be used to maintain the space station in the proper orbit. Before the Progress undocks, and prior to the arrival of the next resupply vehicle, the module is loaded with material to be returned, like films. Once the Progress separates to reenter, the main section is consumed during the reentry and the payload module parachutes to a soft landing over Kazakhstan. The Soyuz capsule can deliver three cosmonauts to MIR taking nearly three days to reach the orbital complex. It can stay docked for up six months before returning to Earth. At the other end of the complex are the front axial port and four side ports. On one of the side ports is docked the Kvant-2 module, a cylinder of 12 x 4.4 m and 20000 kg. It carries technical support facilities. On the opposing side port is docked the Kristall module. It's used for semiconductor and biological experiments.

Amateur Radio Activity

The amateur radio operations aboard the Soviet space station MIR started on November 1988. The equipment used was an FT290R YAESU transceiver with 2.5 Watts and a GP antenna specially installed outside the station on the original core MIR module. This was the most significant advantage over the American SAREX counterpart.

From 1988 to 1992 cosmonauts call was U # MIR , where U = USSR , # = cosmonaut number MIR = MIR Complex. U0MIR, as a collective station call, was used.

The following table shows the names of cosmonauts that operated only voice mode, before the digital was installed.

#	CALL	NAME	#CREW	FLIGHT DATE
01	U1MIR	VLADIMIR TITOV	3	21/12/87 - 21/12/88
02	U2MIR	MUSA MANAROV	3	21/12/87 - 21/12/88
03	U3MIR	VALERY POLYAKOV	4	28/08/88 - 27/04/89
04	U4MIR	ALEKSANDR VOLKOV	4	26/11/88 - 27/04/89
05	U5MIR	SERGE KRIKALEV	4	26/11/88 - 27/04/89
06	U6MIR	ALEKSANDR VIKTORENKO	5	06/09/89 - 19/02/90
07	U7MIR	ALEKSANDR SEREBROV	5	06/09/89 - 19/02/90
08	U6MIR	ANATOLY SOLOVEYV	6	11/02/90 - 09/08/90
09	U7MIR	ALEKSANDR BALADIN	6	11/02/90 - 09/08/90
10	U8MIR	GENNADY STREKALOV	7	01/08/90 - 10/12/90
11	U9MIR	GENNADY MANAKOV	7	01/08/90 - 10/12/90

Packet Radio Activity

Ham radio activity has been part of Amateur Radio space communications for almost a decade. Packet radio was on the U.S. space shuttle STS-35 mission. But since January 1991 packet radio was a permanent part of the Russian orbital complex MIR, call sign U2MIR.

The packet equipment was launched to MIR on the Progress M6 resupply space truck on January 14, 1991. It docked with the MIR two days later. The initial reports of packet activity from MIR were made on Sunday, January 20, 1991.

The packet equipment consists of a PacComm Handi Packet and ICOM IC-228A 2 meter FM transceiver together with a laptop computer . Veteran Cosmonaut Musa Manarov, UV3AM, familiarized himself with the equipment at the cosmonaut training facility at Star City near Moscow prior to his launch to orbit. The TNC and radio were donated during the Goodwill Games during the summer of 1990, to facilitate the MIR packet activity. At that time the downlink frequency was 145.550 MHZ.

The Handi Packet TNC on MIR has a built-in Personal Message System that has been using the address U2MIR-1. Immediately the packet radio station converted on the most popular and easy satellite for work for packeters.

On 1 January 1992 the fleet of tracking ships that helped MIR to have a permanent radio contact was taken out of service. This caused a long period in which the MIR crew did not have radio contact. This period can increase to more than nine hours in 24 hours. Of course they often used the Altair geostationary satellites. But, thanks to the amateur radio station, specially to the packet radio rig the crew could establish radio contact with terrestrial stations so in cases of a serious problem or even emergency the crew could relay data via amateur links. This could be realized, thanks the help gave from Leonid Labutin, UA3CR, chief of the club station of the Moscow Adventure Club, RK3KP, and Sergey Samburov, RV3DR. They fought a long struggle to establish notion for radio amateurism in manned space flight on MIR.

The International Cooperation

Since 1991, a wave of cooperation has started with other amateur organization around the word to train cosmonauts in the used of amateur radio equipment, especially digital use, aboard MIR.

Helen Sharman, GB1MIR, of England operated simplex voice contacts during one week on May 1991, and has the honor to be the first foreign woman cosmonaut that visited the complex.

The Austrians on October 1991 with AREMIR (Austrian Amateur Radio Experiment Aboard MIR), operated by cosmonaut Franz Viehbock, OE0MIR. The equipment included a modified Alinco DJ 120 transceiver for 2 meter FM, TNC and CW generator, and a laptop computer (which is part of the DATAMIR experiment). The hardware for AREMIR was made possible by members of the Radio Club for Communication and Wave Propagation in Graz, Austria.

Germany on March 1992 experiment with DVM MKF,(Digital Voice Memory Microphone), operated by Klaus Flade, DP1MIR. The hardware for DVM was made by members of the DARC. The DVM could relay voice messages recorded from the crew to ground stations that could be heard with a simple HT. The DVM was adapted to be operated with the current transceiver in the complex.

French Cosmonaut Michel Tognini, F5MIR operated simplex voice contacts on July 1992 during two weeks.

The following table shows the cosmonauts that operated under the former USSR call signs in packet and voice mode.

#	CALL	NAME	#CREW	FLIGHT DATE
12	U9MIR	VIKTOR AFANASIEV	8	02/12/90-26/05/91
13	U2MIR	MUSA MANAROV	8	02/12/90-26/05/91
14	U7MIR	ANATOLY ARTSEBARSKY	9	18/05/91-10/10/91
15	U5MIR	SERGE KRIKALEV	10	02/10/91-25/03/92
16	GB1MIR	HELEN SHARMAN *	--	08/05/91-26/05/91
17	U4MIR	ALEKSANDR VOLKOV	10	02/10/91-25/03/92
18	OE0MIR	FRANZ VIEHBOECK **	--	02/10/91-10/10/91
19	U6MIR	ALEKSANDR VIKTORENKO	11	17/03/92-10/08/92
20	U8MIR	ALEKSANDR KALERI	11	17/03/92-10/08/92
21	DP1MIR	KLAUS FLADE ***	--	17/03/92-25/03/92
22	U6MIR	ANATOLY SOLOVEYV	12	26/07/92-01/02/93
23	U3MIR	SERGE AVDEYV	12	26/07/92-01/02/93
24	F5MIR	MICHEL TOGNINI ****	--	26/07/92-10/08/92

* England Cosmonaut
** Austrian Cosmonaut
*** German Cosmonaut
**** France Cosmonaut

R0MIR

From the start of 1993 the amateur radio activities continue using the same equipment, but just the policy changes and the vanishing of the USSR the call sign of the complex changed to R#MIR ,(R= Russia , # = Cosmonaut Ham Number ,MIR= Complex Name), R0MIR for call collective station and R0MIR-1 to call PMS. The old series of call U#MIR are still valid.

From 1991-1996 the complex was visited by cosmonauts from Germany, Austria, France, England, and USA.

#	CALL	NAME	#CREW	FLIGHT DATE
25	U9MIR	GENNADY MANAKOV	13	24/01/93-22/07/93
26	R2MIR	ALEKSANDR POLESCHUK	13	24/01/93-22/07/93
27	R0MIR	VASILY ZIBLIEV	14	01/07/93-14/01/94
28	R0MIR	ALEKSANDR SEREBORV	14	01/07/93-14/01/94
29	F6MIR	JEAN PIERRE HAIGNERE *	--	01/07/93-22/07/93
30	U9MIR	VIKTOR AFANASIEV	15	08/01/94-14/07/94
31	R3MIR	YURIJ USACHEV	15	08/01/94-14/07/94
32	U3MIR	VALERIJ POLYAKOV	15/17	08/01/94-22/03/95
33	R0MIR	YURIJ MALENCHENKO	16	01/07/94-02/11/94
34	R0MIR	TALGAT MUSABAEYV	16	01/07/94-02/11/94
35	R0MIR	ALEKSANDR VIKTORENKO	17	03/10/94-22/03/95
36	R0MIR	YELENA KONDAKOVA	17	03/10/94-22/03/95
37	DP0MIR	ULF MERBOLD *	--	03/10/94-02/11/94
38	U6MIR	GENNADY STREKALOV	18	14/03/95-07/07/95
39	R0MIR	VLADIMIR DEZHUROV	18	14/03/95-07/07/95
40	R0MIR	NORMAN THAGARD	18	14/03/95-07/07/95
41	R0MIR	ANATOLY SOLOVEYV	19	27/06/95-11/09/95

42	R0MIR	NIKOLAI BUDARIN	19	27/06/95-11/09/95
43	R0MIR	YURIJ GIDZENKO	20	03/09/95-29/02/96
44	U9MIR	SERGEI AVDEYV	20	03/09/95-29/02/96
45	DP0MIR	THOMAS REITER **	--	03/09/95-29/02/96

* France
** Germany

The most significant chance on the amateur space station started in November 1995 when a new transceiver TM-733 KENWOOD dual bander 2m/70 cm with a dual band antenna and a PacComm 9600 bps were launched to MIR. In May 1996 the PRIRODA module docked to MIR, containing the new SAFEX II equipment. The SAFEX contains the following modes:

Repeater: 437.950 down/ 435.750 up + CTCSS

Packet: 437.975 down /435.775 up

QSO: 437.925 down/435.725 up + CTCSS

SAFEX II will work on 1.2 GHz , 2.4 GHz , SSTV and ATV modes.

FUTURE CALL SIGNS

The following list displays the call list of cosmonauts onboard MIR. Planning for the rest of '96 and '97 is shown in the following table:

#	CALL	NAME	#CREW	FLIGHT DATE
46	R0MIR	YURIJ ONUFRIYENKO	21	21/02/96-30/08/96
47	R3MIR	YURIJ USACHEV	21	21/02/96-30/08/96
48	R0MIR	SHANNON LUCID *	--	STS-76
49	R0MIR	GENNADY MANAKOV	22	14/08/96-22/02/97
50	R0MIR	PAVEL VINOGRADOV	22	14/08/96-22/02/97
51	R0MIR	CLAUDI ANDRE DECHAYS **	--	14/08/96-30/08/96

52	R0MIR	JOHN E. BLAHA *	--	STS-79
53	R0MIR	VASILY TSIBLEYEV	23	02/02/97-15/07/97
54	R0MIR	ALEKSANDR LAZUTKIN	23	02/02/97-15/07/97
55	DP0MIR	H. SCHELEGEL/R.EWALD ***	--	02/02/97-22/02/97
56	R0MIR	JERRI LENENGER *	--	STS-81
57	U8MIR	ALEKSANDR KALERI	--	24/06/97-20/12/97
58	R0MIR	VALERIJ KORZUN	24	24/06/97-20/12/97
59	R0MIR	FRANCE OP ???	--	24/06/97-15/07/97
60	R0MIR	MICHAEL FOALE *	--	STS-84

* USA
** France
*** German

Amateur Radio on the International Space Station

Frank H. Bauer, KA3HDO
AMSAT V.P. for Manned Space Programs
NASA Goddard Space Flight Center
and
Matt Bordelon, KC5BTL
SAREX Principal Investigator
NASA Johnson Space Center

Abstract

The Shuttle Amateur Radio EXperiment (SAREX) is sponsored by the American Radio Relay League (ARRL), the Radio Amateur Satellite Corporation (AMSAT) and the National Aeronautics and Space Administration (NASA). SAREX is a multifaceted program which includes education, experimentation and amateur radio communication between astronauts on the Space Shuttle and ham radio operators and students on the ground. Since 1983, the hundreds of volunteers that make up the SAREX team have worked hard to develop a robust, comprehensive SAREX program on the Space Shuttle. This team, led by the SAREX Working Group, is working in concert with NASA engineers, managers and astronauts to develop a permanent capability on the International Space Station. While not a guarantee, the SAREX team is "cautiously optimistic" that a permanent amateur radio station on the International Space Station will become a reality.

The following represents our visions as we enter into this new phase of SAREX operations.

Nomenclature

AMSAT	Radio Amateur Satellite Corporation
ARRL	American Radio Relay League
BBS	Bulletin Board System
DX	Long Distance Communications
IARU	International Amateur Radio Union
ISS	International Space Station
NASA	National Aeronautics and Space Administration
QSO	Amateur Radio Contact
SAREX	Shuttle Amateur Radio EXperiment
TNC	Packet Radio Terminal Node Controller

Introduction

1995-1996 will most likely be noted as transitional years for the Shuttle Amateur Radio EXperiment (SAREX) program. Over the past 13 years, SAREX has flown 21 times as a secondary payload on all 5 U.S. Space Shuttles. Tables 1 and 2 depict all the SAREX flights flown to date. NASA is currently shifting its manned space activity from short duration missions on U.S. Space Shuttles to long duration continuous presence experimentation on the International Space Station (ISS). As NASA transitions, SAREX is striving to stay in lock-step with NASA's manned space plans. Through these efforts and international coordination with amateur space activities in other countries, the SAREX team hopes to provide a permanent amateur radio presence on human-tended space vehicles.

As was stated in reference 1, the SAREX program has evolved through two major phases in its development cycle. See figure 1. The first phase, the pure experimental phase, introduced new amateur radio hardware and techniques to the Space Shuttle program and accomplished several firsts in manned space history. These include the first communications between astronauts and people on the ground outside of the "official" channels (usually reserved for presidents and heads of state). This occurred on STS-9. Other firsts included the first uplink and downlink of pictures on STS-51F, the first packet computer-to-computer radio link on STS-35 and the first video uplink on STS-37.

SAREX Phase II, which started in 1992, represents the operational frequent-flyer phase. During this phase of SAREX, the paperwork, tools and operational techniques were honed to allow SAREX to fly up to 4-5 times a year on the Space Shuttle. This could only be accomplished through careful development of

Phase I	Phase II	Phase III
Pure Experimental Phase Infrequent Flights (<<1/year) New Techniques New, Untested Hardware Shuttle Based	Operational Phase Frequent Flights (>3/year) Specific Hardware Configurations Multiple Hardware Reflights AMSAT SAREX Operations Team Some Experimentation Shuttle Based	Operational Phase Long Duration Missions Nearly Continuous Ops Permanently Installed Hardware International Facility International Space Station Based
1983-1991	1992-1995	Future

SAREX Development Phases
Figure 1

several specific SAREX configurations which allowed the generation of generic SAREX paperwork to meet Shuttle payload integration requirements. The Crew Training Plan was formalized and made more efficient; generic lessons were developed that could be used for every flight. In addition, a concerted effort was initiated to license the Space Shuttle astronauts. To date, almost half of the U.S. astronauts currently have ham radio licenses. ARRL developed SAREX educational materials to be distributed to the schools. To support SAREX Phase II, AMSAT set up a network of volunteers who prepare the schools for their SAREX contacts. These volunteers, who comprise the AMSAT SAREX Operations Team, provide real-time information bulletins to hams around the world and provide critical mission control support to the SAREX team at the Johnson Space Center.

The beginning of SAREX Phase III is represented by the current transition from short duration, intense, Space Shuttle flights to long duration U.S. presence on the Russian Space Station MIR and finally permanently tended human operations on the ISS. As was required when SAREX transitioned from Phase I to SAREX Phase II, the SAREX team will need to evolve its hardware development, its documentation and its operations techniques to better serve the long duration activities in space during the Phase III era. Since both MIR and ISS represent international facilities, a much closer relationship with our international amateur radio partners is required. School group contact, personal contact and experimental contact scheduling and preparation will also require new techniques and procedures. New hardware and new operating bands will naturally occur with a new facility. While this permanent amateur station will provide some new challenges to the SAREX team, it also promises to open the doors to some very exciting, new capabilities which will significantly enhance the SAREX educational outreach program. In addition, it will also provide hams on the ground more frequent, comprehensive access to space.

International Space Station Plans

After reviewing the future shuttle flights, it becomes increasingly apparent to focus future SAREX activities toward a permanent presence in space. If one were to ponder the probability of using amateur radio in space, one would quickly realize that "permanent presence" means human tended operation on the International Space Station.

NASA will reach a continuous human presence in space in three discrete steps. The first is through joint U.S. Russian missions where U.S. Astronauts will spend extended periods of time (on the order of 90 days) on the Russian Space Station MIR. This activity was initiated in 1995 with Norm Thaggard's visit to MIR and the STS-71 MIR docking mission. This activity will continue until 1997. As the ISS is being assembled, from 1997 to 2002, "human-tended" operations represent the second discrete step in the NASA program. During this phase of the ISS development several week duration operations in the ISS laboratory module with a docked Space Shuttle will become the norm. Finally in 2002 the habitation module will be installed and permanent crew presence on the ISS will begin.

The SAREX team picks flights based on many criteria, but the major variables in the SAREX manifest are the attitude timeline and primary mission of each shuttle flight:

a. Shuttle/MIR docking missions have a busy timeline, many flight maneuvers, minimal school activity (<5 schools), and some random QSO activity. The same goes for "early assembly flights," which will look very similar.

a)

b. Shuttle laboratory flights use a stable shuttle attitude and consistent activity level. These are ideal SAREX conditions. These flights can have more school contacts, more random QSO's, packet operations, and even time for experimentation.

a)

c. U.S. presence on the Space Station MIR provides some unique opportunities to SAREX. First, it will serve as a conduit to help resolve the multi-national licensing and third party issues that need to be permanently fixed prior to ISS. It provides an opportunity to test out and hone our ISS operations procedures. It also gives the SAREX team additional opportunities to allow school students to talk to U.S. astronauts from space.

a)

d. Midway through the assembly flights (at the human tended operations milestone) there will be packet, regularly scheduled school contacts, and random QSO's because of less restrictive timelines. These flights are similar in activity levels with the MIR station.

a)

e. After the habitation module is launched, our permanent presence will facilitate more school contacts, random QSO's, experiments, demonstrations, earth observation downlinks, etc.

Once on-board ISS, SAREX will (1) SERVE as an educational tool, (2) BE an outreach to the general public, (3) ALLOW a method for crews to maintain contact with family and friends while on orbit (to improve psychological factors), (4) PROVIDE an experimental communications testbed, (5) OFFER a back up communications link for emergencies, and (6) PROVIDE public information to the grass-roots public.

SAREX Equipment Strategy

While focusing on the new home for SAREX, we must not forget what got us where we are today. The plan is to gradually phase SAREX operations to a permanent station inside the ISS Habitation module in the year 2002.

The first step SAREX will take is to update/upgrade the equipment currently used onboard shuttle missions. SAREX currently has six different configurations which provide us with 2m frequencies at 2.5 watts, a 1200 baud TNC which counts contact connections, a slow scan television module, a fast scan television (ATV) module, a 2m/70cm cavity antenna, a 70cm loop antenna, and numerous interface cables. Shuttle hardware upgrade plans include a dual band (2m, 70cm) radio; an expanded TNC (PacComm Pico Packet with more memory and BBS); a better, smaller slow scan module; and a battery charger.

At the same time, SAREX will utilize the unique opportunity of having US hams onboard the Russian space station MIR to develop and refine procedures that will also be used aboard the ISS. MIR already has a 2m station onboard, but has plans to add new capabilities to the station in the near future.

Next, SAREX will utilize the upgraded, portable equipment developed for the Shuttle during the early "ISS assembly flights," which start in late 1997. Current, tentative plans include SAREX operations and permanent stowage as early as the second assembly flight. SAREX equipment during this time period has the distinct possibility of operating on both vehicles. Changes in the cavity antenna's adapter plate will be sought to use Earth viewing windows on the partially assembled space station. The equipment will be upgraded to include a radio and TNC capable of higher baud rates.

During later assembly flights (1998), SAREX will explore opportunities to mount a steerable antenna on the ISS truss to provide the capability to work other spacecraft and satellites (i.e., Phase 3D). SAREX will attempt to upgrade the portable equipment one last time before the permanent station is delivered in its module.

Finally in 2002, the habitation module will be delivered. The SAREX team is working hard to ensure that an external Earth viewing antenna; and a rack mounted transceiver capable of many new modes and frequencies will be part of the module with the capability for future expansion.

SAREX Development Strategy

When do we start? The answer is NOW. The SAREX Working Group has prepared paperwork to become Òofficially manifested.Ó The ISS design and its outfitting are maturing at a rapid rate. We must ramp up our effort on the habitation module station design. Work has begun on the ISS interface requirements for the permanent amateur radio station. We must explore the real estate for our steerable antenna. We must design for future expansion. We must make the portable equipment usable on both vehicles. We must use the lessons learned from our past flights.

SAREX will seek to combine efforts with the International Partners who are helping forge the ISS. We must keep SAREX an international venture. We must coordinate amateur activities in European, Japanese, and Russian modules on the ISS. This will enhance the overall ISS amateur ÒpresenceÓ and capability. To this end, a meeting is planned this fall at the NASA Johnson Space Center in Houston, Texas. This meeting will serve to coordinate our efforts with NASA and with our international partners.

From a U.S. perspective, we have initiated the development efforts by assigning a SAREX hardware development lead. This development lead is currently working with members of the SAREX Working Group and the NASA ISS engineers to compile a detailed hardware development plan. The hardware development team will continue to evolve this plan over the next 6 months as each ISS member nation has had an opportunity to review the plan, propose new ideas and define their role as hardware development participants.

Frequency Coordination

The SAREX Working Group is working with AMSAT, the ARRL and members of the IARU to help coordinate SAREX frequencies for the International Space Station. Worldwide frequency coordination for SAREX is extremely difficult due to the lack of frequency coordination for packet radio operations in the U.S. and the diverse frequency allocation plans in countries outside the U.S. Over the past two years, 2m frequency recommendations for ISS and MIR have been discussed and debated in various international forums. It is hoped that the upcoming IARU meeting in Surrey, England will serve as a forum which will solidify the ISS/SAREX/MIR 2-meter frequency plan. In addition, it is hoped that this forum will serve to open a new dialog to select manned space frequencies for the amateur bands above and below 2-meters.

Third Party Restrictions

As the U.S. space program merges its activities with the international community, particularly Russia, the SAREX program is quickly doing the same. Amateur radio has always shared an international camaraderie with our neighbors across the waters. This camaraderie has resulted in international partnerships which have extended to new heights...outer space. The most recent international space station collaboration is resulting in a quick blurring of the separate U.S. and Russian amateur radio activities on the U.S. Space Shuttle and the Russian space station MIR into a single Manned Space activity. These changes have brought new challenges to the SAREX team; that of ensuring a strong, well balanced program on an evolving manned platform while maintaining and adapting the international regulations regarding international amateur communications. The 3rd party restrictions between Russia, the U.S. and other countries have been a problem for the SAREX and MIR teams this past year. As more countries become active partners in the international space station, this issue will get even more complicated. Unfortunately, these restrictions curtail the amateur community's ability to spark student's interest in amateur radio by not allowing some astronauts (on international space carriers) and some foreign space participants to talk to students while in space.

The SAREX team is actively working with our international partners, particularly Russia in an attempt to get a permanent waiver of third party traffic restrictions to manned space vehicles. This would go a long way in improving international participation in amateur radio.

Conclusions

Human operated ham radio in space appears to be transitioning from short, intense bursts of activity (analogous to a DXpedition) to permanent (nearly continuous) operations. Multiband, multi-mode operation and regularly scheduled school group contacts will be the norm in this scenario. While "cautiously optimistic" in an era of government budget cuts, the SAREX team will put forth its best efforts to ensure these dreams will become a reality for terrestrial based radio amateurs and ham radio operators in space.

While it continually maintains an eye towards the future, the SAREX team strives to improve the on-going Shuttle-based SAREX activities. SAREX is an outstanding, low cost outreach program for amateur radio, NASA and science and technology. It could only be accomplished through the superb support from the hundreds of volunteers from around the world and the support, interest and encouragement from NASA, particularly the Astronaut Office and Division of Education at NASA Headquarters. The authors extend their deepest thanks to all these volunteers for their tremendous support to bring space-borne astronauts literally into the schools and living rooms of the general public.

References

1. Bauer, F. and McFadin, L., "SAREX Hardware Configurations and Flight Operations Support", Proceedings of the AMSAT-NA Tenth Space Symposium, October, 1992.

2. Bauer, F., White, R. and Jones, T., "Shuttle Amateur Radio Experiment Status Report", Dayton Hamvention Presentation, April 1993.

1. Bauer, F., "Another Banner Year Planned for the Shuttle Amateur Radio Experiment", The AMSAT Journal, January/February 1993.

a)
2. Bauer, F., "The Shuttle Amateur Radio Experiment Current Status and Future Visions", Proceedings of the AMSAT-NA Eleventh Space Symposium, October 1993.

1. Bauer, F. and Bordelon, M., "Shuttle Amateur Radio Experiment (SAREX) Status 1995", Proceedings of the AMSAT-NA Thirteenth Space Symposium, October, 1995.

Flight	Date	Ham Crew	Modes
STS-9 Columbia	November, 1983	Owen Garriott, W5LFL	Voice
STS-51F Challenger	July, 1985	Tony England, W0ORE John-David Bartoe, W4NYZ	Voice, SSTV
STS-35 Columbia	December 1990	Ron Parise, WA4SIR	Voice, Packet
STS-37 Atlantis	April 1991	Ken Cameron, KB5AWP Jay Apt, N5QWL Linda Godwin, N5RAX Steve Nagel, N5RAW Jerry Ross, N5SCW	Voice, Packet, SSTV, ATV Uplink
STS-45 Atlantis	March 1992	Dave Leestma, N5WQC Brian Duffy, N5WQW Dirk Frimout, ON1AFD Kathy Sullivan, N5YYV	Voice
STS-50 Columbia	June 1992	Dick Richards, KB5SIW Ellen Baker, KB5SIX	Voice, Packet SSTV, ATV Uplink
STS-47 Endeavour	September 1992	Jay Apt, N5QWL Mamoru Mohri, 7L2NJY	Voice, Packet
STS-56 Discovery	April 1993	Ken Cameron, KB5AWP Ken Cockrell, KB5UAH Mike Foale, KB5UAC Ellen Ochoa, KB5TZZ Steve Oswald, KB5YSR	Voice, Packet SSTV, ATV Uplink
STS-55 Columbia	April 1993	Steve Nagel, N5RAW Jerry Ross, N5SCW Charlie Precourt, KB5YSQ Hans Schlegel, DG1KIH Ulrich Walter, DG1KIM	Voice, Packet
STS-57 Endeavour	June 1993	Brian Duffy, N5WQW Janice Voss, KC5BTK	Voice, Packet
STS-58 Columbia	October 1993	Bill McArthur, KC5ACR Marty Fettman, KC5AXA Rick Searfoss, KC5CKM	Voice, Packet

SAREX Missions Flown to Date 1983-1993
Table 1

Flight	Date	Ham Crew	Modes
STS-60 Discovery	February, 1994	Charlie Bolden, KE4IQB Ron Sega, KC5ETH Sergei Krikalev, U5MIR	Voice, Packet
STS-59 Endeavour	April, 1994	Jay Apt, N5QWL Linda Godwin, N5RAX	Voice, Packet
STS-65 Columbia	July 1994	Don Thomas, KC5FVF Bob Cabana, KC5HBV	Voice, Packet
STS-64 Discovery	September 1994	Dick Richards, KB5SIW Blaine Hammond, KC5HBS Jerry Linenger, KC5HBR	Voice, Packet,
STS-67 Endeavour	March 1995	Steve Oswald, KB5YSR Bill Gregory, KC5MGA Wendy Lawrence, KC5KII Tammy Jernigan, KC5MGF Sam Durance, N3TQA Ron Parise, WA4SIR	Voice, Packet
STS-71 Atlantis	June-July 1995	Charlie Precourt, KB5YSQ Ellen Baker, KB5SIX	Voice
STS-70 Discovery	July 1995	Don Thomas, KC5FVF Nancy Curie, KC5OZX	Voice, Packet
STS-74 Atlantis	November 1995	Ken Cameron, KB5AWP Jim Halsell, KC5RNI Bill McArthur, KC5ACR, MS Jerry Ross, N5SCW, MS Chris Hadfield, KC5RNJ, VA3OOG	Voice
STS-76	March 1996	Kevin P. Chilton, KC5TEU, CDR Richard Searfoss, KC5CKM, PLT Linda Godwin, N5RAX, MS Ron Sega, KC5ETH, MS	Voice
STS-78	June-July 1996	Susan Helms, KC7NHZ, MS Charles Brady, N4BQW, MS Robert Thirsk, VA3CSA, MS	Voice, Packet

SAREX Missions Flown to Date 1994-1996
Table 2

APRS SAREX EXPERIMENT ON MISSION STS-78

Bob Bruninga
wb4apr@amsat.org

During mission STS-78 the SAREX team authorized an experiment for packet ground stations to relay their geographical position coordinates via the SAREX digipeater instead of attempting the usual connection to the SAREX Robot. Not only does the automatic plotting of these position reports on a map display enhance the appeal to participating student groups, it also has the potential for improving the overall SAREX packet success rate. The objective of using these short position reports instead of the simple serial number robot messages was to reduce the number of packets required for success from the current five to only one. This was actually the second space test of the APRS (Automatic Position Reporting System) formats. In January 1996, the SPRE experiment built by students at the University of Maryland also flew on the shuttle and relayed APRS position reports for over 18 hours during the deployment of the Spartan Payload. Using the APRtrak software all ground stations would instantly display these positions on the world map on receipt of a single digipeated packet.

Word of the test was spread on the AMSAT-BB and APRSSIG Internet Special Interest Groups. Reports indicate about 39 stations participated in the special test using APRS formatted packets. Of these, twenty stations successfully reported their position and were copied by other ground stations. All stations reported very weak signals and many of the APRS stations heard nothing at all on any pass. This was due to the disadvantageous shuttle orientation during most of the mission. These reports imply that the signals were so weak, that only a few dB of extra station loss was enough to cause a station to completely miss all packets. Almost all successful stations were using beam antennas and high power. The special APRS space format compresses the position report in to only 6 characters (grid square) and a few other characters, making the length of the packet very short to minimize QRM.

Over the whole mission, amateur radio enjoyed 15 days of SAREX activity, with 11 School, 9 personal, and 20 general voice passes, plus 25 packet passes. That leaves only about 23 passes where no activity was detected. A fantastic effort on the part of the STS-78 crew!

The positions of the following 18 stations were successfully reported via SAREX as part of the APRtrak/APRS experiment: K1HJC, WB6LLO, KE6AFE, WB4LTF, N8DEU, KE4EER(WA8INZ), KB0UZQ, KC5EJK, KG0DW, N1JDU, KD1SM, N6HNY, WA4HEI, AD4BL, WB3JNZ, N2NRD, KC7CO, and VA3HOI. Two others reported STATUS, but no POSIT. A total of 65 APRS packets were received.

It appears that about 10 APRS stations were making a serious effort and trying every pass: WA8INZ, WB6LLO, KB0UZQ, KD4EMI, N2THO, WB4APR, KC5EJK, AD4BL, KC4ZQ, WB4PAN.

Many other stations operated on passes when they could: N3MNT, N3IVO, N8EDU, N2QAE, WA1LOU, KC7CO, N1CPE, WB5QLD, K1HJC, KE6AFE, KU0G, WB4LTF,

N5RKN, KC4NHB, AB5GE, KG0DW, KD1SM, N1JDU, KF4DYS, KK6IB, N6HNY, WA4HEI, KC4ZGQ, KI5VM, WB3JNZ, N2NRD, VA3HOI, AD4BL, and W4NMK. Interestingly, WB3JNZ tried only twice and got successes both times.

In analyzing the results of the experiment the largest unknown was the total number of stations causing congestion on the uplink. Within the APRS experiment, the number of reporting stations was known to be about 39 because of reports on the Internet, but the total number of other stations attempting conventional SAREX Robot contacts was completely unknown. To get a rough estimate, we compared the APRS success rate of 20 pkts for the total of 39 APRS stations participating to the total number of stations heard by the SAREX Robot according to the 1350 QSO numbers. Using a similar ratio could imply a lower bound of 2700 or an upper bound of 5400 total packet stations on frequency adding QRM to the APRS test. Presumably if all stations had used the APRS formats instead of attempted to connect with the robot, many more stations would have been plotted on the APRtrak maps.

This SAREX mission was a real test of your overall station sensitivity. With the shuttle orientation often sending the SAREX signals out into space away from earth, you had to have minimum receive losses and/or use a beam. Ending with SAREX QSO#'s in the 1300's is down by a factor of 3 or so compared to shorter missions scoring into the 3000's. Also, contacting the SAREX robot using dumb terminal technology the same way we have been doing it for 10 years is getting a little old and fewer stations are making the effort. That is part of the appeal of using APRS position packets to show the locations of all successful stations in real time.

Table 1 is a pass-by-pass summary that provides information on the use of SAREX during the mission. It is not assumed to be 100 percent accurate but it does represent the perspective observed here on the east coast and gleaned from the Internet reports. This summary is provided here for possible analysis and comparison with other observations currently unknown to the author.

CONCLUSION: Despite the small numbers of stations participating in the APRS SAREX experiment, we believe that the test demonstrated the application of mobile position reporting via amateur radio satellite. In any case, the use of APRS formatted position reports by approximately 1% of the amateur radio community had no adverse impact on the normal SAREX packet activity and should be encouraged on all future SAREX packet experiments.

TABLE 1. This table is a log of SAREX activity for mission STS-78 during the last week of June and first week of July. It represent conditions as monitored from the East Coast and of reports copied from participants on the Internet.

DAY	EDT	ZULU	COMMENTS
-------	-----	-------------	
21	1745	2145z	Voice KO4HD Fl Keys
21		2238z	Voice WB6LLO San DIego, and W5GEL Texas
22	0915	1315z	through 1400 on 23 June nothing heard on 9 passes
22	1225	1625z	SAREX test pass with Houston. (nothing heard on 55)
23	1535	1935z	voice heard in S. Fla (school pass San Antonio)
23		2110z	Voice heard in Calif
24	0740	1140z	nothing heard on 4 passes
24	1355	1755z	voice reported in Texas END FIELD DAY
24	1530	1930z	nothing heard on 2 passes
25	0902	1302z	School pass Grapevine TX
25	1045	1445z	I missed the pass (Any reports of activity?)
25	1230	1620z	Voice over usa. They said Packet soon!
25	1400	1750z	Voice over USA
26	0730	1130z	Packet reported fm Alabama
26	0904	1304z	Packet reported in Texas & East. QSO#'s 104 to 130
		1313?	QSO#123. K1HJC>FN43HB,W5RRR-1*>APRS 0.5 on line
26	1040	1440z	School pass Delmar NY
26	1210	1610z	QSO#141
26	1356	1756z	QSO#189-214 (the 189 is not certain) (School at 1745z)
26	1500	1900z ?	(I missed it. Anyone else have a report?)
27	0725	1125z	nothing heard
27	0900	1300z	School pass Kingsville TX
27	1035	1435z	voice heard on this and 1610z, and 1745z passes
27	1510	1910z	Personal contact for crew
28	0725	1125z	QSO#346-355. 22 packets copied in Maryland
28	0900	1300z	27 pkts reported in MO and AL by KB0UZQ and KE4EER
28	1036	1436z	voice heard
28	1440	1740z	School pass, Santa Barbara, CA
28		1915z	packets heard in Calif. WB6LLO gets APRS SUCCESS message
29	0730	1130z	voice heard
29	0900	1300z	nothing heard
29	1027	1427z	QSO#519-529. & KE6AFE>CM86XX,W5RRR-1*:Hi de Cap
	10??	14??z	WB6LLO gets 2nd APRS SUCCESS msg in CA. (Anyone see it?)
	1033	1433z	WB4LTF>EL98IP,W5RRR-1*:Orlando FL
	1036	1436z	N8DEU>EM64QS,W5RRR-1*:[GS]Tim at Huntsville, AL (TNC only)
29	1200	1600z	School pass, Anacortes WA and Orlando, FL
29	1346	1746z	Voice reported in FL
29		1911z	WB6LLO gets 3rd APRS SUCESS msg in CA. (Anyone see it?)

		1920z	Voice reported in Honduras
30	0545	0945z	QSO#672. & KE4EER>EM64SX,W5RRR-1*:Bill, Hazel Green
AL V7.6e			
30	0720	1120z	QSO#729.
30	0850	1250z	9 weak pkts heard in MD. Weak pkts hrd in SoCAL
30	1023	1423z	nothing heard in SoCAL
30	1157	1557z	voice on west coast and in AL
30		1732z	nothing heard in Calif
30		1906z	WB6LLO gets 4th APRS SUCCESS msg
01	0405	0805z	Strong voice reported
01	0540	0950z	KE4EER reports strong voice in AL
01	0720	1120z	Voice heard in MD working Michigan
01	0850	1250z	someone reported weak pkt? School Pass Santa Rosa,CA
01	1025	1425z	nothing. Weak pkts then voice reported in Salt Lake City
01	1200	1600z	nothing
02	0422	0822z	no packets detected in MD (Anyone hear voice or data?)
02	0540	0940z	no packets detected in MD (ditto)
02	0722	1122z	no packets detected in MD (ditto)
02	0842	1242z	nothing
02	1013	1413z	Voice full quieting over Utah
02	1147	1547z	
		WA8INZ>W5RRR-1*>EM64SX:@021000/3458.49N/08629.87WyBillsLaptop	
	1148	1548z	WA8INZ>W5RRR-1*>EM64SX:Bill, Hazel Green, AL v76
		1726z	nothing heard (weak packets heard in Utah and Honduras)
03	0532	0932z	21 pkts hrd in Dallas, 26 in MD. QSO#888-914. And 2 APRS
	0532	0932z	KB0UZQ>W5RRR-1*>EM29QJ: (four)
	0532	0932z	KC5EJK>W5RRR-1*>APRS:[EM12OU]
	0533	0933z	KG0DW>W5RRR-1*>EN31CO:Hello Columbia fm Steve in DesMoines
	0537	0937z	N1JDU>W5RRR-1*>FN42LK:APRS 0.5 on line (two)
	0537	0937z	KD1SM>W5RRR-1*>FN42DO:APRS 0.5 on line (two)
03	0707	1107z	6 Pkts heard in MD. QSO#971-975
	0711	1111z	KD1SM>W5RRR-1*>FN42DO:APRS 0.5 on line
	07??	11??z	KB0UZQ>EM22QJ,W5RRR-1*:
03	0838	1238z	QSO#1010-1035. 39 pkts heard in Dallas, 3 in MD, 34 in FL.
	0838	1238z	WB6LLO 030540 /261214/3247.03N/11711.35WSdm12js0 (three!)
	0838	1238z	N6HNY>DM04RK,W5RRR-1*:DM04RK
	08??	12??z	KC5EJK>W5RRR-1*>APRS:[EM12OU]
	0844	1244z	WA8INZ>W5RRR-1*>EM64SX:Bill, Hazel Green, AL v76d (two)
	0847	1247z	WB4LTF>W5RRR-1*>EL98IP:Casselberry Fl (six)
03	1020	1420z	Weak voice (canadian) heard in MD for 1st half of pass
03	1150	1550z	KO4HD reports carrier bursts near end but no audio

03		1720z	out of view of east coast
04	0355	0755z	N4ZQ>W5RRR-1*>QST:CQ this is radio N4ZQ, Keith in Florida
04	0528	0928z	QSO#s1108-1125
	0528	0928z	KC5EJK>W5RRR-1*>APRS:[EM12OU]
	0530	0930z	WB4LTF>W5RRR-1*>EL98IP:Casselberry FL (eight)
	0533	0933z	WA4HEI>W5RRR-1*>EN65UX:@EN65ux]^C2
04	0700	1100z	QSO#s1152-1180
	0703	1103z	KC5EJK>W5RRR-1*>APRS:[EM12OU]
	0703	1103z	WA8INZ>W5RRR-1*>EM64SX:Bill, Hazel Green, AL v76d (five)
	0705	1105z	AD4BL>w5RRR-1*>EM70DF:AD4BL EM70
	0705	1105z	WA4HEI>W5RRR-1*>EN65UX:@EN65ux]^C2
04	0834	1235z	Voice copied in the midwest
04	1000	1400z	Voice heard in CA and midwest
04	1145	1545z	School pass Kingsville, TX
05	0347	0747z	QSO#1256-1258. WA8INZ gets APRS SUCCESS (anyone see it?)
	0347	0747z	WB3JNZ>FN10RS,W5RRR-1*: (sent with just TNC & PROCOMM)
05	0521	0921z	QSO#1288-1297. 25 packets copied in NJ
	0525	0925z	WB3JNZ>FN10RS,W5RRR-1*: (ditto)
	052?	092?z	KD1SM>FN42DO,W5RRR-1*:73 de Ralph
05	0658	1058z	QSO#1320-1343. 42 packets copied in NJ
	0658	1058z	KC7CO gets APRS SUCCESS msg (Anyone see it?)
	0658	1058z	KB0UZQ gets congrats (anyone see it?)
	0702	1102z	N2NRD>FM29LQ,W5RRR-1*: (three)
	0702	1102z	VA3HOI>FN05IE,W5RRR-1*:]-[Greetings/FN05
	0704	1104z	KD1SM>FN42DO,W5RRR-1*:73 de Ralph
	0705	1105z	N1PPP>DAVE,W5RRR-1*:
05	0835	1235z	Voice
05	1008	1408z	Voice
06	0350	0750z	Nothing heard
06		2034z	Sarex Stowed

Reply mail addr: wb4apr@amsat.org
javAPRS WEBPAGE: http://web.usna.navy.mil/~bruninga/aprs.html

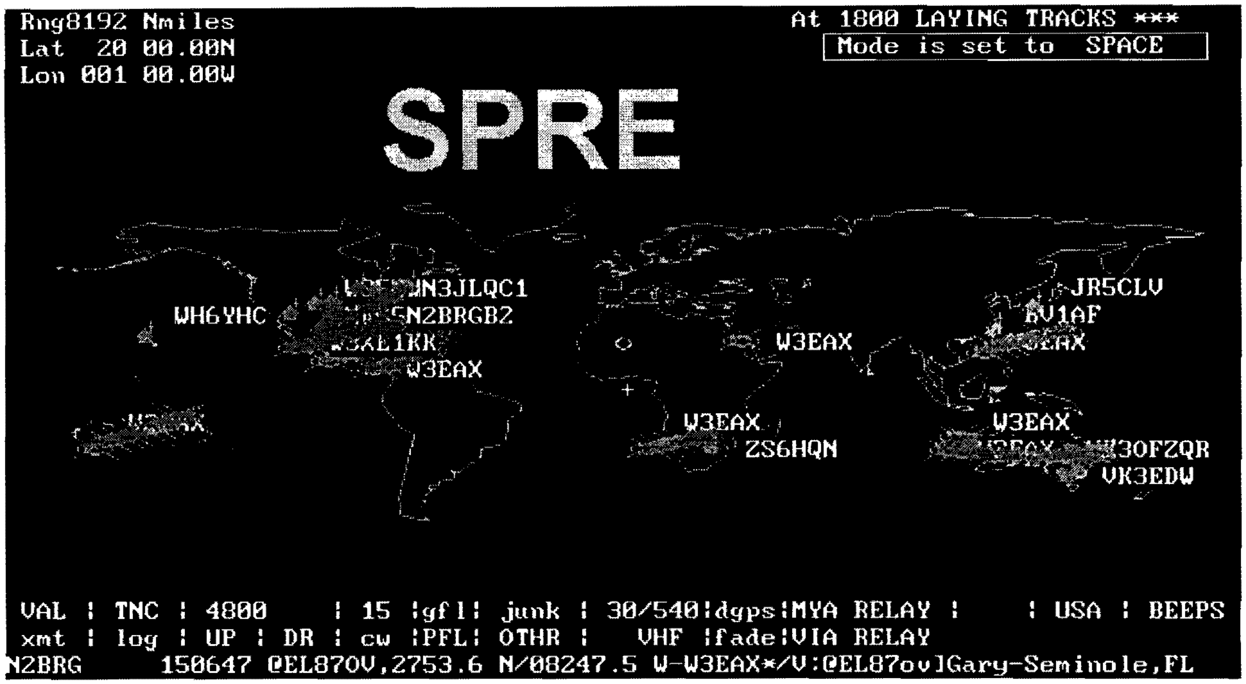


Figure 1

Figure 1. This APRS screen capture shows all of the data captured during the SPRE mission on STS-74 in January 1996. The SPRE payload not only relayed APRS position reports between ground stations, but also reported its own position from an on-board GPS. The spacecraft position only shows on APRS where ground stations were available to receive the packet position reports.

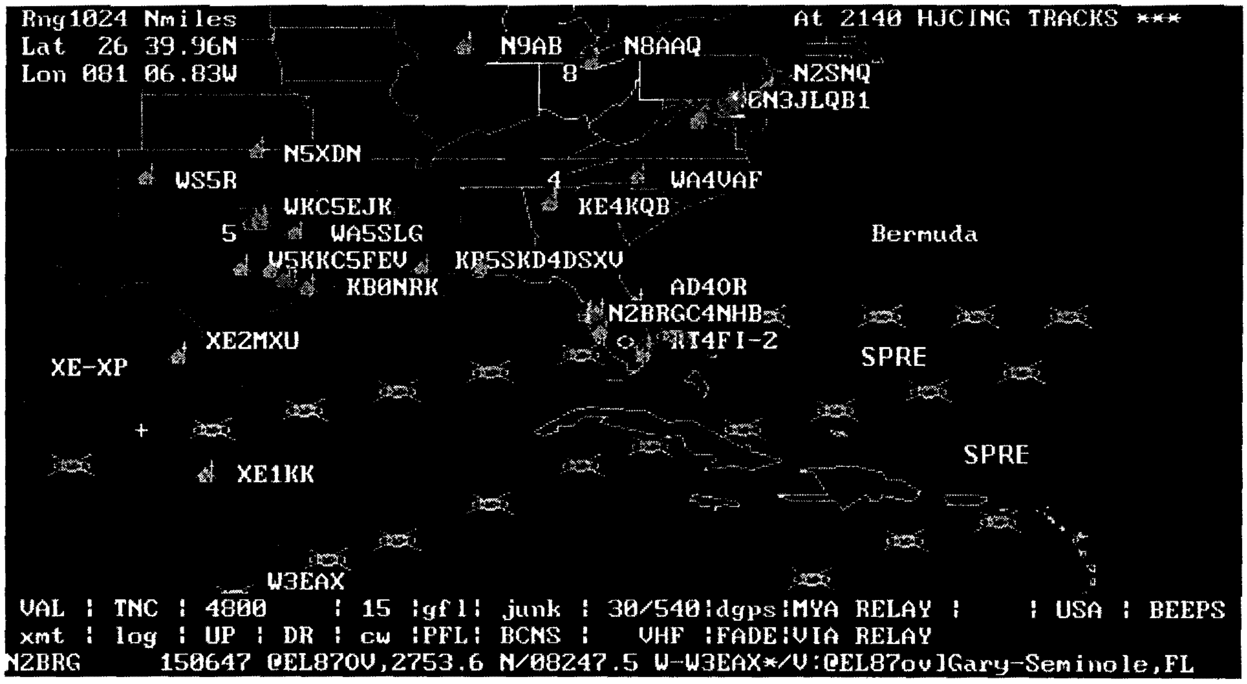


Figure 2

Figure 2. This APRS screen is zoomed in to the 1024 mile range over the east coast to show the APRS position reports that were plotted on the three successive passes between about 2300 and 0300 EDT. About 66 successful APRS position reports were relayed by SPRE.

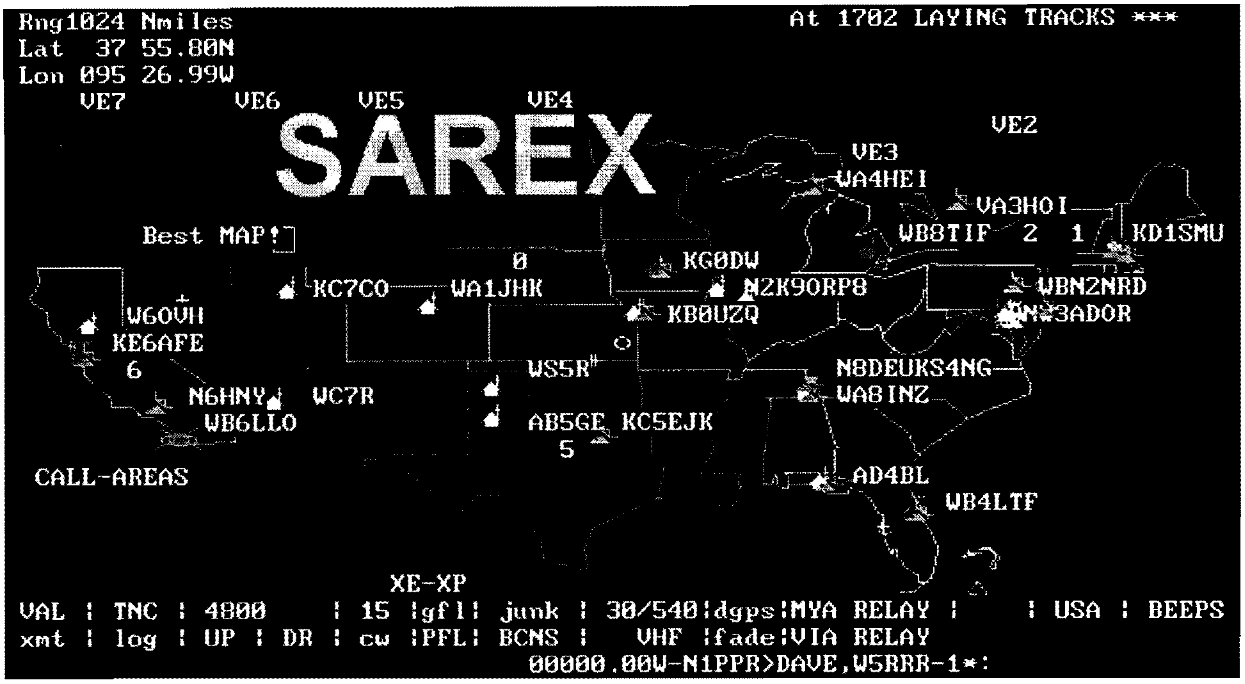


Figure 3

Figure 3. This APRS screen displays the APRS position reports relayed by SAREX during mission STS-78. It is a composite image of all position reports heard during the entire mission. Currently SAREX does not transmit its own GPS position so the path of the orbiter is not shown.

AMSAT Satellites and ESA Launches

Gould Smith
8008 Chesterfield Dr.
Knoxville, TN 37909
wa4sxm@amsat.org

AMSAT and the European Space Agency (ESA) have longed maintained an excellent working relationship. ESA has offered AMSAT launches at reduced cost to no cost for many years. In return, AMSAT has proven the feasibility of microsats and provided additional standard integration hardware to ESA. This paper will discuss the history of ESA, ESA/AMSAT launches and ESA rockets. Descriptions of the physical site at Kourou and some of the innovative methods of attaching an amateur satellites to the main payload will also be covered.

What is ESA?

Many of the European countries were interested in creating a presence in space as far back as the early 60's. Six of these nations (Belgium, France, Germany, Italy, the Netherlands and the United Kingdom) banded together and were joined by Australia in 1962 to form ELDO, the European Launcher Development Organization. Their purpose was to develop and build a launcher system known as Europa. Concurrently, the European ELDO countries along with Denmark, Spain, Sweden and Switzerland formed ESRO, the European Space Research Organization, to create a satellite program. About ten years later, these ten countries met to create a new organization by merging the ELDO and ESRO groups. The Convention creating ESA took place in May 1975 with Ireland also joining the group that year. On 30 October 1980 the Convention was ratified and ESA became a legal entity. With the addition of four more countries the current membership of ESA is now composed of thirteen full members (Austria, Belgium, Denmark, France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom), one Associate Member(Finland) and one External Member (Canada).

esa

Figure 1. The ESA logo

ESA programs are divided into two categories - Mandatory and Optional. All member nations support the Mandatory program in proportion to their GNP (Gross National Product) (see Table 1). These programs support the basic activities of ESA such as technology research, shared technical investment, studies for future programs, information systems, scientific satellites and training programs. Participation in other programs are Optional for any member nation. Each nation can decide what level of support to provide to any of the Optional programs. The Optional programs include areas such as Earth observation, telecommunications, space transportation(Ariane), the space station, microgravity research and manned spaceflight. The 1995 budget saw 22% of the expenditures devoted to mandatory activities and 76% to the Optional programs. See Table 2 for a comparison of the 1993 and 1995 budgets.

ESA has a very innovative process in place called the "fair return rule". To carry out its programs, ESA spends the bulk of its budget on contracts awarded to industry in its member states. So, for each ESA accounting unit (roughly equal to the EURO dollar) paid by a member state into the agency, that state should get that money by the agency awarding industrial contracts within that country. As a result, ninety percent of the 1995 budget flowed back into the member counties. In addition the countries also receive the technological benefits of producing space related products. France, Germany and Italy provide about 72% of the operating budget for ESA. France, having initiated the space transport system, still directs the major portion of its contribution to this area. The UK has provided support for the telecommunications area, but Italy is taking over in this area. Germany's main interest has been in the Space Station systems. See Table 2 for a comparison list of the general expenditures of ESA in 1993 and in 1995.

Table 1. 1993 ESA General Budget based upon GNP of Member Countries

Austria	1.07%	Spain	4.24%
Belgium	4.93%	Sweden	2.25%
Denmark	0.92%	Switzerland	2.29%
France	29.22%	United Kingdom	6.30%
Germany	22.46%		
Ireland	0.19%	Canada	0.80%
Italy	16.96%	Finland	0.34%
Netherlands	2.71%	not yet covered	4.56%
Norway	0.76%		

The amount of money spent on a particular area by ESA depends upon the contributions of the countries interested in that project. In Table 2 notice the reduction in the amount spent on launchers (Space Transport System) between 1993 and 1995. This is because the Ariane-5 program was nearing completion and startup expenditures were less. ESA also spent more on earth observation activities utilizing their ERS-1 and ERS-2 observation satellites. The 1995 ESA Annual Report shows that ESA spent only 7% of its 1995 budget for manpower, demonstrating a very efficient operation.

ESA Organization

The main governing body of ESA is the ESA Council. The ESA headquarters building is located in Paris, France. There are five major operating units in ESA known as establishments. They are ESTEC, ESOC, ESRIN, EAC and Kourou.

Table 2. 1993/1995 ESA Budget Expenditures

	1993	1995
General Budget	9%	9%
Space Transport System	42%	30%
Space Stations and Platforms	14%	13%
Telecommunications	11%	10%
Microgravity	3%	2%
Earth Observation	12%	18%
Science	9%	12%
Other	1%	2%

ESTEC - the European Space Research and Technology Center is located in Noodwijk, Netherlands and is the largest of the establishments. This center is responsible for the technical preparation and management of ESA space projects. In addition to the technical support for ESA's satellites and manned space projects, ESTEC has laboratories facilities in all major technical space disciplines. The environmental test facilities at ESTEC are among the largest and best performing in the world. They can permit testing of spacecraft up to the Ariane-4 and Ariane-5 class spacecraft (4000-6000 kg/6 tons).

ESOC - the European Space Operations Center in Darmstadt, Germany ensures the smooth operation of the satellites in orbit. Here the satellites signals are received and processed. ESA has satellites conducting scientific experiments, collecting weather information, images of the Earth and communication links. ESOC also operates nine ground stations around the world to assist in satellite control and data reception. These nine stations are located in Redu, Belgium; Fucino, Italy; Maspalomas, Canary Islands; Oldenwald, Germany; Kiruna, Sweden; Villafranca, Spain; Kourou, French Guiana; Malindi, Kenya; and Perth, Australia.

ESRIN - ESA's Earth Observation Mission Exploitation Centre is in Frascati, Italy. Although a major part of the operation at ESRIN is Earth observation activities, this establishment is taking on the role of ESA's information source to the external world. Their on-line catalogs, help and publication activities, workshop organization and training classes all provide a plethora of information to the external world. One of the most useful and visible products of ESRIN is their comprehensive and up to date WWW site they maintain for ESA . (**http://www.esrin.esa.it**)

EAC - the European Astronaut Center at Cologne, Germany is the latest of the ESA establishments. This group has the job of selecting and training the men and women who will be participating in missions aboard the International Space Station, the U.S. Space Shuttle and the Soviet Mir spacestation.

Kourou - ESA's spaceport is located on the NE coast of South America in Kourou, French Guinea. This site was chosen because it is on the coast and it is close to the Equator. Supplies and launcher assemblies can be shipped there easily and because. It also is just ashore of the former French penal colony Devil's Island made famous by the book/movie "Papillion". See Figure 2 for a map of the Kourou launch complex.

The French Space Agency, CNES, fired its first Diamant rocket from here in 1970. The ELDO group used this site known as the Centre Spatial Guyanais(CSG) for its Europa launcher program. In 1975, ESA took over the facilities at CSG and built ELA-1 [Ensemble de Lancement Ariane - the Ariane launch complex 1]. ELA-1 was used for the Ariane-1, Ariane-2 and Ariane-3 rockets. When the launch rate was increased for the Ariane-4 program, a new launch site was constructed and named ELA-2. This second site allowed construction of another launcher to take place before the preceding one was launched. The new design of the Ariane-5 launcher necessitated a new launch area, so ELA-3 was started in 1988. This new site is very flexible, easier to use, and safer than the previous launch sites. The entire spaceport covers 96,000 hectares (237,000 acres) and employs a work force of 1300 people. The new ELA-3 launch area for the Ariane-5 rocket has new fueling plants (liquid Oxygen (LOX), liquid Hydrogen (LH2), a solid propellant plant and a solid-propellant booster test stand) in addition to a launcher integration building, a final assembly building and the ELA-3 launch zone all on 5200 acres. These can be found in Figure 2.

The EPCU is the payload preparation area for Ariane-4, used to assemble the payloads into the fairing structure. See Figure 7 for a sample P3D fairing arrangement. Building 53A contains the cleanroom where the satellites are kept until they are mounted onto the payload in the EPCU. Last minute changes to the satellites also take place in the cleanroom.

Arianespace, an international company that markets the Ariane launches, is often mentioned in regard to Kourou or ESA. The first eight launches from Kourou were handled by CNES (the French Space Agency) and ESA. Beginning with launch number nine Arianespace took over the marketing of the launches and management of the CSG complex. Arianespace currently has orders for 60% of the world market for launches. ESA is seeing increased competition for launches with the Russians and Chinese entering the business.

AMSAT and ESA

ESA and AMSAT have similar mission statements and complimentary goals. They were destined to work together. AMSAT flew on the second Ariane launch. During a time when launch opportunities were becoming difficult to find for the types of satellites AMSAT envisioned, ESA was formed and offered exactly what AMSAT needed - available and reasonably priced rides into space.

The ESA task - *" to provide for and to promote, for exclusively peaceful purposes, cooperation among European States in space research and technology and their space applications, with a view to their being used for scientific purposes and operational space applications systems."*

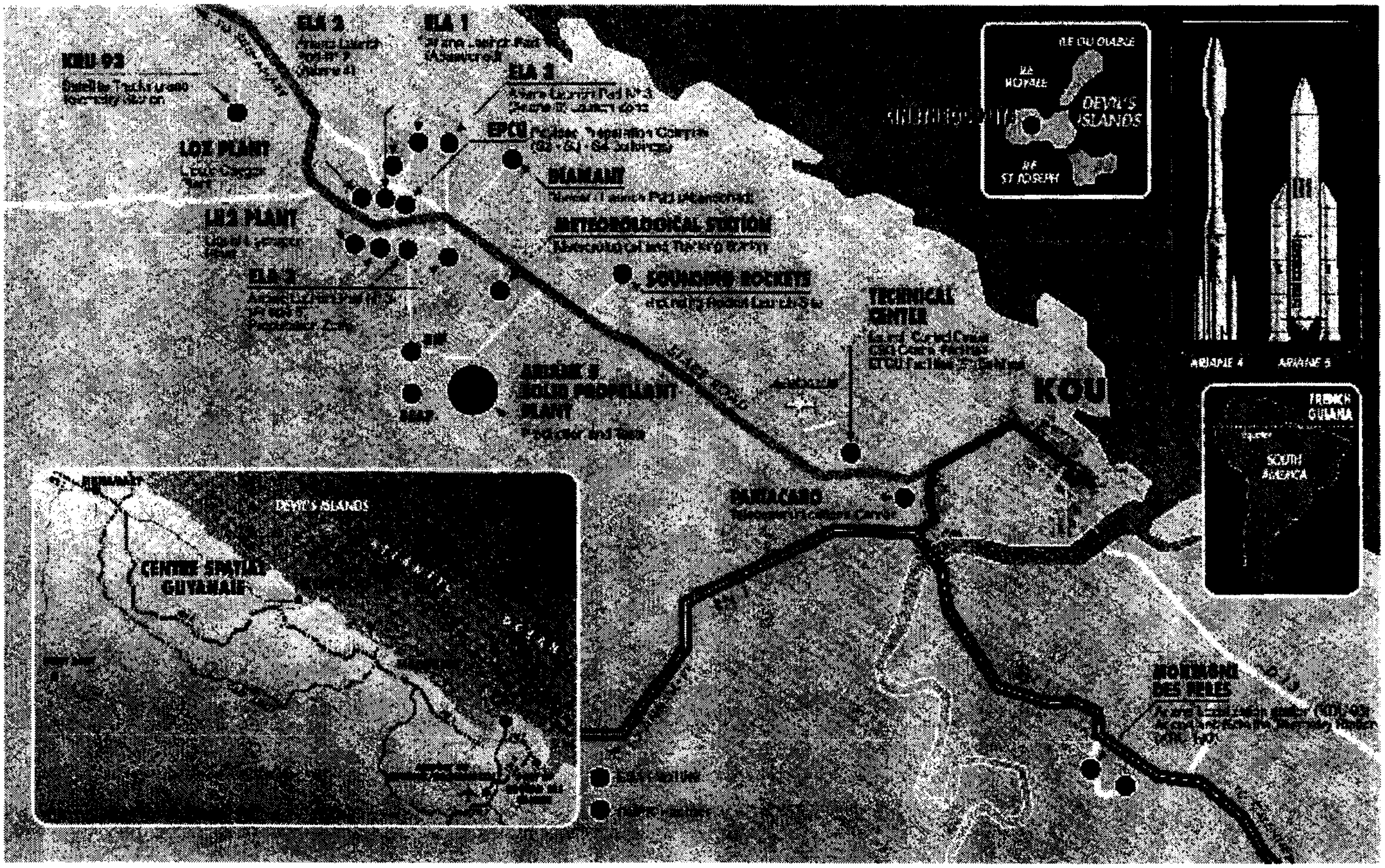


Figure 2. Map of Kourou launch site, from the ESA WWW site.

In the first issue of the AMSAT Newsletter, June 1969, the purposes and objectives of the Radio Amateur Satellite Corporation, AMSAT are listed.

A. *Providing satellites that can be used for amateur radio communication and to conduct experiments by suitably equipped amateur radio stations throughout the world on a non-discriminatory basis.*
B. *Encouraging development of skills and the advancement of specialized knowledge in the art and practice of amateur radio communications and space sciences.*
C. *Fostering international goodwill and cooperation through joint experimentation and study, and through the wide participation in these activities on a noncommerical basis by radio amateurs of the world.*
D. *Facilitating communications by amateur satellites in times of emergency.*
E. *Encouraging the more effective and expanded use of the higher frequency amateur bands.*
F. *Disseminating scientific and technical information derived from such communications and experimentation, and encouraging publication of this information in treatises, theses, technical journals or other public means*

AMSAT launch history with ESA

Of the 44 or so amateur satellites that are orbiting or have orbited the earth, ESA has taken 16 of them into space on nine launches. These amateur satellites, placed into orbit by ESA, constitute 16 of the last 24 (66%) amateur satellites launched. See Table 3 for a comprehensive list of ESA launched amateur satellites.

By August 1996, ESA had conducted 87 launches carrying more than 150 satellites with only eight failures involving 15 satellites. This is a low failure rate by international standards. ESA currently has a waiting list of 45 launches. Arianespace has maintained a aggressive schedule averaging seven launches a year since 1989.

The Loss of Flight 501

On 4 June 1996 the first flight of an Ariane-5 launcher took place. This qualification flight of the Ariane-5 rocket abruptly ended 37 seconds into the flight. Preliminary information on the cause of the failure was that the inertial guidance system malfunctioned. Tests led to the conclusion that the inertial reference system was undergoing a routine aliment function before lift-off. Apparently this alignment test was not shutoff during liftoff. As a result the inertial guidance system received faulty inflight information causing flight 501 to veer off the flight path and was destroyed by the ground control station. At one time during the development of P3D, the AMSAT P3D satellite was slated to be launched on the 501 flight. Now that the problem seems to be identified, solutions are in progress. ESA has announced that P3D will fly aboard Flight 502 (still a qualification flight) in the first six months of 1997.

AMSAT Satellite Launch Insurance

Launch insurance typically costs about 20% of the insured value of the satellite. This insurance is only available for satellites on reliable, tested launch vehicles. To insure a $4 million dollar satellite costs about $800,000. The fact that P3D will be on a qualification flight of the Ariane 5 means that there is little chance of purchasing insurance even if AMSAT had the money to buy it. Again, the volunteer effort to design, build and test the satellite cannot be estimated or AMSAT afford to purchase. The reason that AMSAT only had to pay the equivalent of 1 million U.S. dollars for the launch was because it will be an experimental flight.

Table 3. AMSAT satellites launched by ESA (see also Figure 4)

Flight number	Launch Date	Launcher	AMSAT payload
L02* (q)	12/24/79	Ar 1	P3A
L6 (p)	6/16/83	Ar 1	P3B (AO-10)
V22 (f)	6/15/88	Ar 44LP	P3C (AO-13)
V35 (g)	1/22/90	Ar 40	UoSat 3 (UO-14)
			UoSat 4 (UO-15)
			AO-16
			DO-17
			WO-18
			LO-19
V44 (s)	7/17/91	Ar 40	UoSat 5 (UO-22)
V52	8/10/92	Ar 4	KO-23
V56	5/11/93	Ar 4	Arsene?
V59	9/29/93	Ar 4	KO-25
			IO-26
			AO-27
			PoSat
V?? (q)	before 7/97	Ar 5	P3D

*launch failure, second ESA launch

f first Ariane-4 (44LP) flight
g first Ariane-4 (40) flight
s second Ariane-4 (40) flight

p promotional flight
V Commercial flight
q qualification flight

AMSAT Providing Standard Integration Hardware to ESA

Nearly every ESA launch of an AMSAT satellite poses an interesting challenge for AMSAT to provide a unique device to attach the amateur satellite to some part of the payload structure. In the case of the ill-fated P3A the satellite was stuck on the side of the payload. Figure 3 shows the P3A attachment to the Application Technology Capsule. The canisters above P3A were called Firewheel, the primary payload of flight L01.

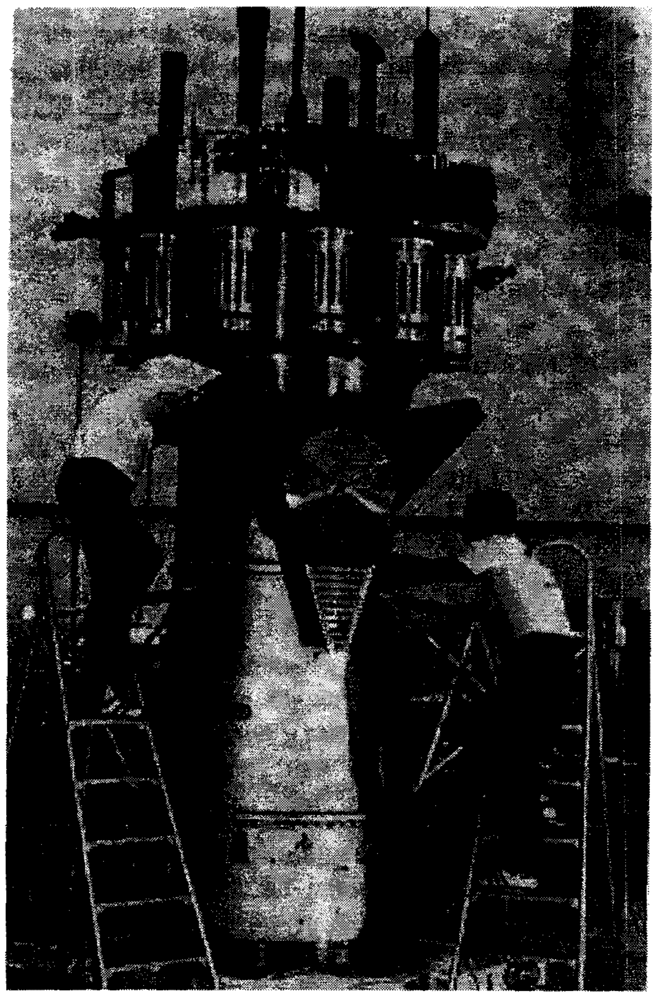


Figure 3. AMSAT P3A satellite attachment (AMSAT-DL photo)

Other launches have provided AMSAT an opportunity to design an interface that could be used again. AMSAT has provided ESA with two pieces of satellite interface hardware that can be used commercially for other launches. The first is the Ariane Structure for Auxiliary Payloads (ASAP) adapter ring that was used on the upper stage of the Ariane 4 to take advantage of unused space there. Figure 4 shows this ring and the six amateur satellites (4 Microsats and 2 UoSats) attached to it. This structure has since been used by ESA to carry other small payloads into space, many of them carrying derivatives of the same digital "store- and-forward" satellite communications technology pioneered by AMSAT.

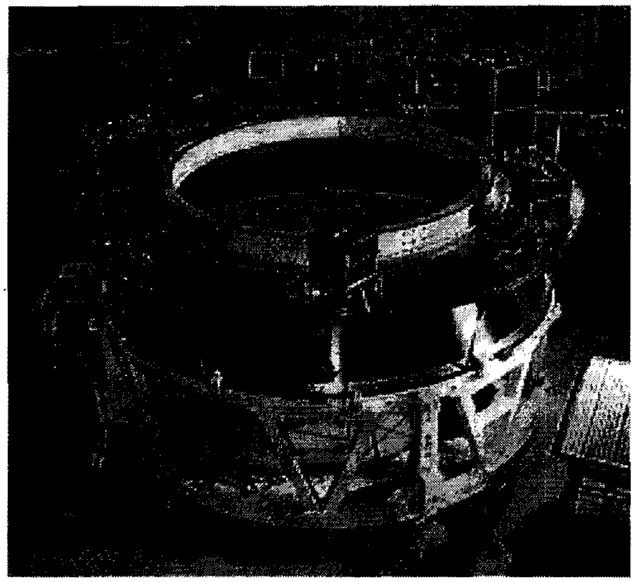
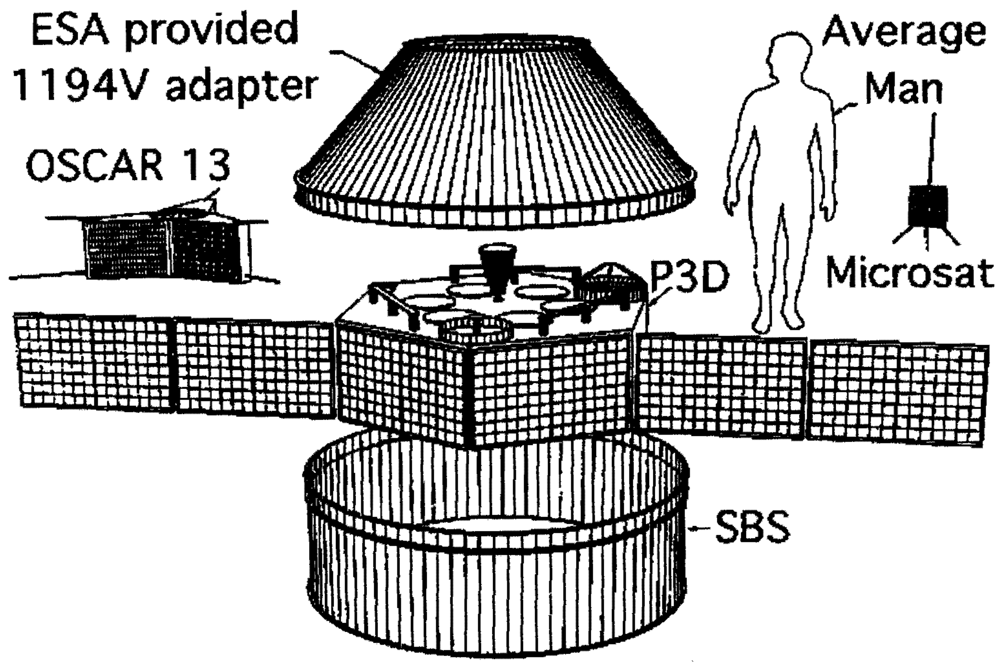


Figure 4. Photograph of the ASAP unit holding the Microsats and UoSats

The second piece of AMSAT supplied hardware used by ESA is the SBS (Specific Bearing Structure) ring used to allow P3D to fit under the standard ESA conical 1194V Adapter. This adapter interfaces between the 2624mm (103.3inches) diameter bolt circle on the Ariane upper stage to a 1194mm clamp-band used for major payloads. In addition to housing P3D, this ring must be able to withstand the load forces imposed by a 4.7 T [4.7 metric ton, (10,350 lb.)] satellite load.



Phase 3-D size comparison

Figure 5. AMSAT designed SBS adapter ring for P3D (Dick Jansson, WD4FAB)

In order to assure ourselves and ESA that our design is capable of handling such a load, extensive structural Finite Element Analysis (FEA) work has been performed by computer. Two of these SBS units were completed in Utah, mainly at Weber State University. These were made from the highest quality ring-forged aircraft aluminum. These frames were mounted to a precision steel table, holding flatness and roundness values to less than 0.05mm (0.002in.), far better than ESA requires. Tests have also been conducted at Weber State University to verify that the mechanism to separate the spacecraft from the SBS and the launch vehicle will work. To test this operation, a 500kg Mass Mockup Unit (MMU) was constructed of concrete and steel to take the place of the P3D satellite. See the story in the Nov/Dec 1995 AMSAT Journal article "Launch Contract for Phase 3D Finalized". If for some reason the P3D satellite can not go, the MMU and SBS will fly on the Ariane, since their weight has been budgeted. The separation nut units were operated using nitrogen gas, rather than the pyrotechnically generated gas sources that will be used in flight.. All went well over quite a number of tests, with the satellite separation from the three nuts being within 3ms (0.003 second) of each other. Dick Jannson reported that witnessing the rapid exit of a 500kg object from the SBS was quite impressive. Figure 5 shows the SBS, P3D and the ESA supplied conical adapter.

ESA Launchers

The first European Ariane rocket successfully lifted off on 24 December 1979. These Ariane-1 rockets were used consistently until 1984 when the first Ariane-3 rocket launched. As the mass of the satellites began to grow, Ariane-1 gave way to the Ariane-3 and Ariane-2 rockets. From the beginning these rockets were designed specifically to allow satellites to get into geostationary transfer orbit (GTO). The two best assets of a launch site are to be close to the equator and on the coast. Launching a rocket due East takes full advantage of the "boost" provided by the earth's rotational velocity. At Kourou this boost amounts to 460 m/sec. The latitude of the launch site is also important because it requires a great deal of energy to place a satellite into an orbit that has a lower inclination. Launching due East from Kourou is optimum for a GTO.

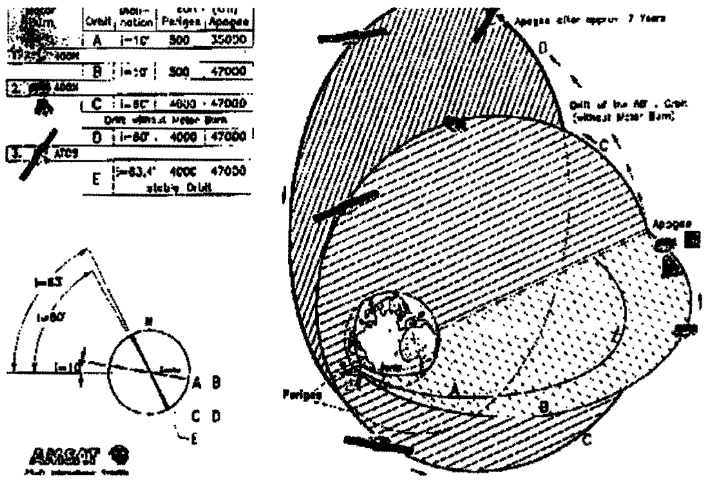


Figure 7. The process P3D will undergo from GTO to an inclined orbit

In addition to the optimal latitude at Kourou, the ability to launch a rocket over the ocean is also a plus. Here the area down range is very sparsely populated. In case there are any problems there is much less chance to cause harm to a population. The area to the North of Kourou is also ocean, so launches for satellites in polar or sun-synchronous orbits that go North are also safe. Once in GTO the satellite will fire an on-board engine to move the satellite inclination to 60 degrees. See the article, "Phase 3D Orbit Estimation and Characteristics", by Ken Ernandes, N2WWD in the March/April 1996 issue of the AMSAT Journal for additional information.

The early ESA launched satellites were mainly for communication and meteorology. ESA has lowered the cost of placing satellites in space by routinely launching two satellites on one rocket. 1988 saw the arrival of the workhorse of the European Space program, Ariane-4. See Figure 6 for an ESA drawing of the Ariane family. The -4 series of rockets is available in six configurations depending upon the mass of the payload to be launched. These consist of a basic rocket and 2 or 4 solid or liquid strap-on boosters. The 40 version is a the basic rocket similar to Ariane-2. There are two types of the 42 version, the 42P with two solid boosters and the 42L with two liquid boosters. The liquid boosters are larger than the solid ones, supply less lifting power, but burn three times as long. The four booster versions available come with four solid boosters (44P), with two solid and two liquid boosters (44LP) and with four hefty liquid boosters (44L) . The 44L will lift more than two and a half times that of the Ariane-1. ESA realized very early that even the series -4 would not keep them competitive in the next decade. So in 1985 the Agency decided to begin designing a new rocket that was not a mere follow-on to the three stage Ariane-4, but one that was more powerful, more reliable and more economical - the Ariane-5. By the end of 1994 Ariane rockets had lifted a total of 134 satellites into orbit, ensuring European credibility in the space market.

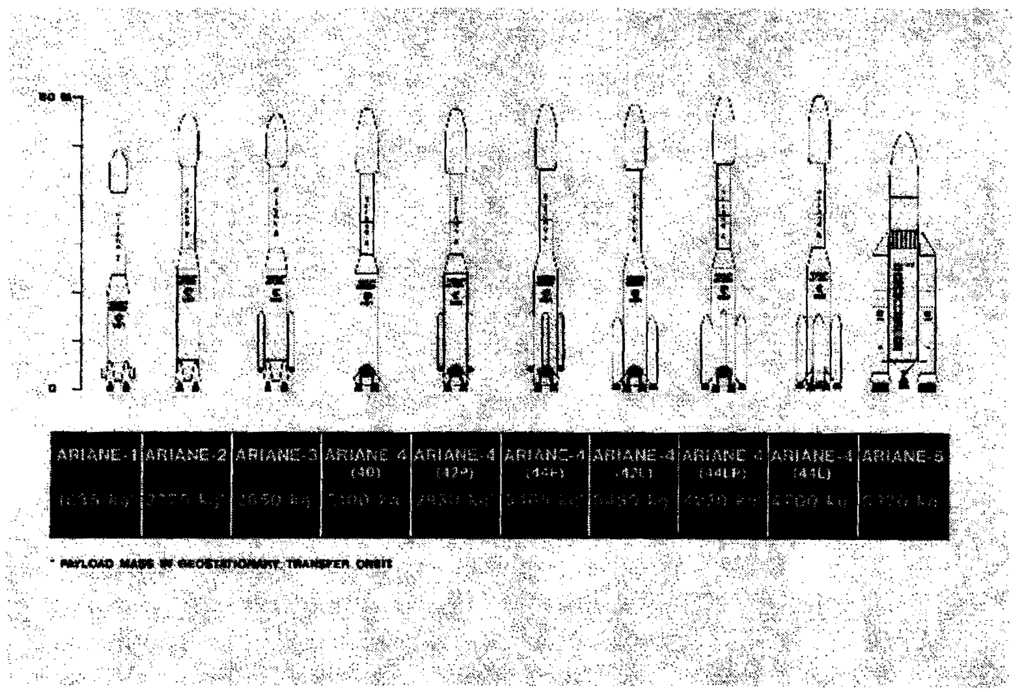


Figure 6. Drawings of the Ariane launcher family from the ESA Web site

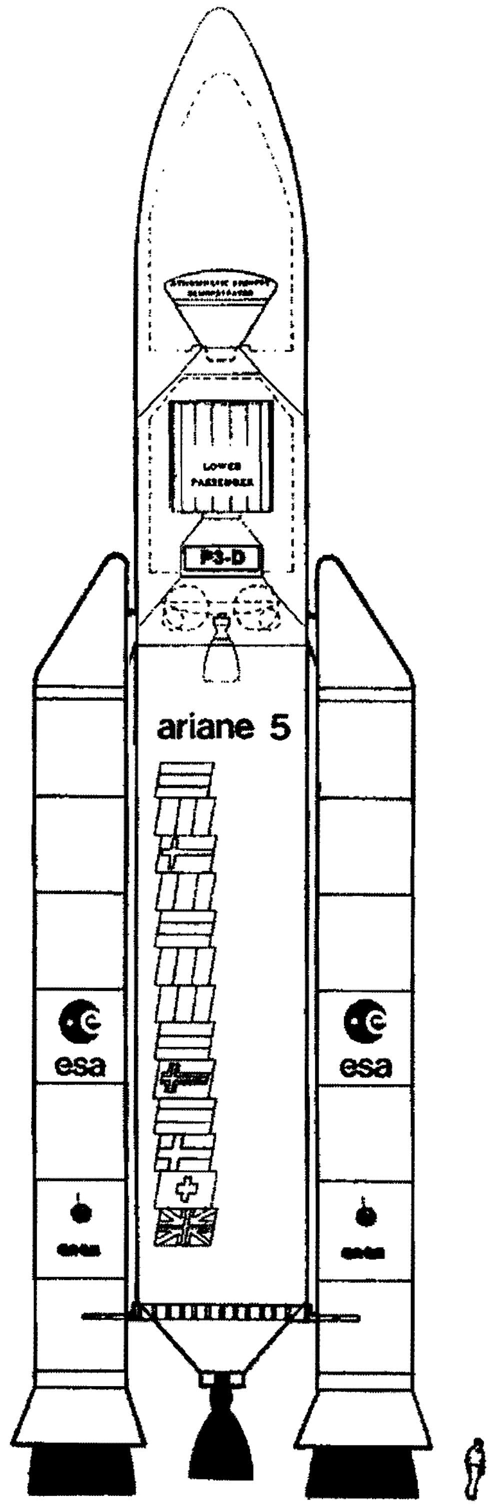


Figure 7. The Ariane-5 rocket with a possible P3D configuration.

Ariane-5 rocket

This new rocket that will take AMSAT's P3D satellite into Geostationary Transfer Orbit ushers in a new era for ESA. The powerful Ariane-5 rocket has launch engines that are ten times as powerful as the Ariane-4 rocket and will be able to carry multiple, large satellites. The electronic control system is 100 times more powerful than on previous boosters. The Ariane-5 is a two stage rocket, with a huge cryogenic stage of liquid hydrogen and liquid oxygen. This stage is flanked by two solid propellant boosters. This rocket was designed with enough power to carry one, two or three satellites weighting up to seven tons into GTO or 23 tons into low earth orbit. The upper composite structure will carry ten tons of propellant. In process is the design of the ATV (Automated Transfer Vehicle) that will transport a manned module to the International Space Station.

Glossary

CNES - The French Space Agency

CSG - Centre Spatial Guyanais, the Guiana Space Center in Kourou, French Guiana

EAC - European Astronaut Centre in Cologne, Germany is in charge of selecting and training the men and women taking part in missions aboard the International Space Station.

ELDO - European Launcher Development Organization, formed in 1962 one of the precursors to ESA.

ESA - European Space Agency, headquartered in Paris oversees the establishments of ESTEC, ESOC, ESRIN, EAC and the launch base in Kourou,

ESOC - European Space Operations Centre in Darmstadt, Germany ensures the smooth working of the satellites in orbit. It also controls nine ground stations around the world

ESRO - European Space Research Organization, founded in 1962, precursor of ESA.

ESRIN - ESA's Earth Observation Mission Exploitation Centre is located in Frascati near Rome, Italy and provides corporate information, publications, workshops and training.

ESTEC - European Space Research and Technology Centre in Noordwijk, the Netherlands is responsible for the technical preparation and management of ESA space projects.

GTO - Geostationary Transfer Orbit, a temporary orbit around the equator from which an onboard satellite motor will propel the satellite into an elliptical or geostationary orbit.

Kourou - ESA launch site in Kourou, French Guiana, South America

References

AMSAT Bulletin 96-05 July 30, 1996 "Phase 3-D Will Launch on Ariane 502"

Chien, Philip, "Ariane 5 A Bid for the Future", Satellite Times, Grove Enterprises, July/August 1996

Davidoff, Martin, "The Satellite Experimenter's Handbook", ARRL, 1990
editor, The AMSAT Journal, "Launch Contract for Phase 3D Finalized", Nov/Dec 1995

Ernandes, Ken, N2WWD, "Phase 3D Orbit Estimation and Characteristics, The AMSAT Journal, March/April 1996

ESA Press Release, Nr 03-96-Paris, 11 January 1996 "Europe opens new Control Centre and Space Museum in French Guiana"

ESA Press Release, Nr 20-96-Paris, 6 June 1996, "Flight 501 Failure - First Information"

Hine, Greg, WT0M, 'Reflections of a Microsat Lab Volunteer", QST, August 1991

http://www.amsat.org

http://esapub.esrin.esa.it, ESA ESRIN web site

http://mosaic.ifs.univie.ac.at, ESA Launcher Program

http://www.airspacemag.com/10th/F1979.html, "1979: The French Succession"

http://www.esoc.esa.de, ESA ESOC web site

http://www.esrin.esa.it, main ESA ESRIN web site

http://www.estec.esa.nl, ESA ESTEC web site

http://www.ifs.univie.ac.at/~jstb/esno4-1.html, "50 Ariane Launches "

Jansson, Dick, WD4FAB, "New Agreement with the European Space Agency on Phase 3D Design", The AMSAT Journal, Jan/Feb 1993

Maurer, Richard, "Junk in Space", Simon and Schuster, 1989

Amateur Radio Satellites on the Internet

Eric Cottrell, WB1HBU

Background

The popularity of the internet has exploded within the last couple of years. This paper will give examples of internet services helpful for radio amateurs involved in space communications. This paper is limited to a general overview due to the many different configurations and types of services available. The configuration and available services depend mainly on the user's computer and the internet provider. I have found the Internet very helpful in many aspects of computers and Amateur Radio.

What is The Internet?

The internet started in the United States as a way to connect research facilities together. The original network, usually called the (Big I) Internet, is only a part of the current internet network. It is not quite world-wide with North America and Europe having the most sites. Each site is individually owned. Although there is no central control, each site belongs to a network and follows the network's guidelines. The networks cooperate and interconnect with each other via various means. It is similar to how the Amateur Packet Radio BBS Network, and the Pacsat BBS Network operate. The network uses a common suite of communication protocols called TCP/IP. The same protocols are used on amateur radio packet networks.

Due to it's origins as a research network, a lot of technical information is available on the internet. Commercial use of the internet is a recent development and is still limited. It is mostly used for marketing of products and customer support. Sales are limited due to the network lacking a common secure method of doing money transactions.

In the United States not quite 40 percent of people access to a computer. Ten percent of computer users have used the internet and five percent have seen a World Wide Web Page. Even with these small percentages, more companies are getting on the internet every day. It is common to see internet addresses shown during television programming and commercials. Operating systems, like OS/2 Warp and Windows 95, now have internet capability.

Government and the news media are not only using the internet, but are discussing what the internet is, and what it will become. It can be confusing as the internet is perceived or described as; the "Information Superhighway" where everyone in the world can access information quickly; the extension of "the neighborhood" where small groups of people will chat over the electronic "backyard fence"; the "American Wild West" because there is no "Marshal" so lawlessness reigns; the haven of all sorts of "Fringe Groups". No one item can totally describe the whole internet.

Even with it's shortcomings, the internet is very useful. All sorts of information, software, and technical support are available. Almost anyone with the proper tools and resources can provide information and files on the internet. Radio Amateur groups, computer groups, and commercial companies have provided gigabytes of information. Because all types of people has access, some of the information has to, as they say, "be taken with a grain of salt". Just because information is on a computer does not mean that it is accurate or true.

Types of Access

The common method of accessing the internet is by using a modem to connect via an internet service provider (ISP) or an educational institution. I will use the term host computer to refer to the provider. I will use the term home computer to refer to the user's computer. Internet services are implemented by having a client program that requests a service and a server program on the same or remote host computer provides the service. The two common types of access are through a Shell Account or Serial Line Protocols.

Shell Account

This is the simplest method of connecting to the internet. A regular communications program is used to access the host computer. The home computer is used as terminal emulator and all the internet programs run on the host computer. The user interface is limited to a text based interface. The user has to learn the commands of the host computer, most likely using a UNIX operating system. Files and graphical information can be transferred via a file transfer protocol, but it is a two stage process with the file being stored temporarily on the host computer.

Serial Line Protocols

This method can be more difficult to setup correctly, but can have an better graphical user interface. The internet gets "extended" from the host computer to your home computer. The host computer routes the information directly between you and the internet. It also acts like a "Post Office", gathering your mail and delivering it when you connect. Special software is required because your home computer must be able to send and receive the TCP/IP protocols. Experience with setting up a Pacsat station is useful as a special protocol is also used. Experience with setting up a ham TCP/IP packet station is even more helpful because the same protocols are used.

Serial Line Internet Protocol (SLIP)

Information is transferred on the internet via internet protocol (IP). It is a 8 bit binary protocol. Not all serial lines can pass 8-bit binary data so SLIP was developed to solve the problem. The KISS protocol used in packet TNCs is based on this protocol.

Point-to-Point Protocol (PPP)

This is an improved serial line protocol that eliminates some of the shortcomings of SLIP. Some parameters are negotiated at connect time or automatically set so the user does not have to configure them. Header information is compressed resulting in slightly better data transfer rates.

Slip Emulators (TIA and similar programs)

These protocols simulate a SLIP connection if the user only has a shell account. Special programs are run on both the host computer and the home computer.

Description of Services

Email

This is a basic service provided by almost every site. It allows text messages to be sent to individual users on any computer that is connected to the internet. There are also methods to reach other non-internet computers via various gateways. The sender must know that exact address of the party he is sending mail to. Incoming mail is stored on the host computer until the home computer connects to it. Shell accounts require you to remain connected to the host computer to read and send mail because the mail program on the host computer is used. Serial line protocol accounts allow a mail program on the home computer to send and receive all messages when connected to the host and allows the user to read and compose mail when not connected to the host computer.

If other services discussed below are not available, it is possible to use a service that gets the information and mails it to your account. This can be slow as each step that can be a quick sequence using the real service involves sending Email and waiting for a reply. If the information is in a binary form, like a program, it cannot be sent without converting it to ASCII characters that will pass through the mail system. The two common methods are to use a uuencode/uudecode program or a mine capable mail program. The mine method is the easiest as the mail program can convert and save the binary information to a file. The uudecode method involves saving the text messages to a file and running the uudecode program on the text file to convert it.

Mailing lists

A mailing list is regular Email sent to multiple users about a particular topic of interest. The user sending a message to the mailing list uses a special address and the message is remailed to everyone on the list. A mailing list program on a host computer is used to control the list and to do the remailing. Some lists are moderated, which means that one or more persons look over incoming messages before sending them out to the list. Another Email address is used to send administrative requests, like subscribing and unsubscribing.

If your internet provider has a mail limit or charges by the message, then mailing lists can present some problems. Some active mailing lists can send 30 or more messages a day. The amount of unrelated postings (called noise) on mailing lists are low, but you still get every message sent. Other internet services have lower signal to noise ratios, but the user has more selection on the items he wants to receive.

Telnet

This is a method of remote terminal emulation so a user can logon to another computer. It is possible to access your shell account on your host computer remotely through another host computer. If you are using a serial line protocol the remote computer can be your home computer. Some host computers have accounts set up similar to a telephone bulletin board system (RBBS).

IRC

This is the internet party line. It is usually very crowded and very uncontrolled. There are some discussion groups that get together by prearranged schedule to interactively discuss various topics.

Usenet

This service started between two universities as a way to provide updated bulletins of events at the other university. It quickly grew to over 5600 topics call newsgroups. The newsgroups are in hierarchical order. It is similar to a mailing list, but messages are sent to the host computer instead of individual users and a newsreader program is used to access the newsgroups. Any group available on the host computer is available to any user having Usenet access. Shell accounts have to read messages while on-line. Serial line protocol accounts have the option to download all the messages in groups the user has a interest in, but this can take alot of disk space on the home computer. It is more common for the newsreader program on the home computer to download header information for all messages in a newsgroup. The user then selects messages to be read.

FTP

This is the basic method of sending and receiving files. The user logs on to a remote host computer where you have a account or a remote host computer that provides what is called anonymous FTP. It is called anonymous FTP because you use anonymous as the user name and your Email address as the password. Due to the way the end-of-line is handled, FTP has two modes, ASCII and image (binary). Not setting the right mode can lead to unreadable text or corrupted binary files. Some sites are known as mirror sites. They receive uploaded files from a another host computer site. This spreads the load on busy host computers or provides a closer location for users to download files.

Gopher

This service was developed at the University of Minnesota as a better way to organize data. It organizes information via hierarchical menus. Selecting a menu item can display a document, or go to another menu. The new menu can be on the same host computer or on another host computer. The user can start at any Gopher site as there is no "top" page. It is possible to use a keyword search to find information using Veronica.

World Wide Web (WWW)

It was not invented by Netscape, but developed at CERN, Switzerland. This is one of the fastest growing services on internet. Some observers claim that web pages will be the pet rock of the 1990's (Twenty years later users will be ashamed they had one).

It is similar to Gopher but uses links that are embedded in the displayed document, called a web page. This method, called hypertext, is also used in Windows Help. The original work done at CERN was extended to handle graphics, sound, movies, and other multimedia information. A program called a web browser is used to access and display the web pages. Web browsers can handle other types of internet services, like FTP, Gopher, and Usenet. They can also call other programs to handle the various multimedia formats. If the user selects a link on a web page, it moves the user to another web page with related information. The newly displayed web page can be on another host computer accessible via the internet.

If the user has a shell account or is only using DOS on the home computer, only the text portions of the web page are displayed with limited text formatting. Sometimes this can be advantageous as some web page creators overdo it with the graphics and it takes some time to load the page. Web browsers handling graphics also have a option not to load the graphics.

Information Sources and Other Tips

Besides the documentation that comes with the internet software, there are numerous books about the internet that are helpful. The internet provider should have on-line information via the man command, the help command, or web pages about the particular services and programs available. Some services also have host computers with helpful files and other documentation about their service as well as others. Some companies supplying internet software also have host computers on internet to provide customer support..

Site information in this paper for FTP, Usenet, Gopher and World Wide Web services are given in the URL form used by web browsers. See the FTP, Usenet, and Gopher subsections below for information on how to convert a URL into a form appropriate for other programs.

Mailing Lists

When you subscribe to a mailing list, a message is sent to you detailing how to unsubscribe and other commands and addresses to use. It is important to keep this message for future reference.

FTP

To enter a URL into a FTP program, connect to the host computer indicated in the host name (from after the double slash to the single slash), and use the change directory command with the path (the portion after the host name) as the parameter. Remember that the case of the characters in the path can be significant on some computers.

Usenet

I use the * character in the newsgroups tables as a wild card to denote one or more newsgroups with one or more lower levels in the hierarchy. Newsreaders cannot handle the * character so refer to a list of newsgroups for available names. Most newsreaders have a list of all available groups. This is usually stored in a file called newsrc. Not every hierarchical level is a valid group. Rec.radio.amateur, for example, is not a group and general questions about amateur radio should be posted to rec.radio.amateur.misc. If you are using a shell account it is best to unsubscribe to all groups and then subscribe to the ones you are interested in. To enter a URL into a newsreader program, use the newsgroup name (the part after news:) only.

Newsgroups	Description
news:news.*	Newsgroups dealing with Usenet
news:news.answers	Periodic postings from various newsgroups
news:news.announce.important	Important announcements about Usenet
news:news.announce.newusers	Useful information from "What is Usenet" to "FAQ about FAQs (Frequently Asked Questions)" (This should be the first group read)
news:news.newusers.questions	Answers to questions about Usenet not covered by another group but it does seem to have alot of noise (off-topic postings)

Gopher

The host computer's Gopher page will contain documentation on Gopher and other internet services. Most Gopher programs have a bookmark to University of Minnesota Gopher server which has alot of information about Gopher.

To enter a URL into a Gopher program, enter the host name (from after the double slash to the single slash), the type (number), and the path (the portion after the number) into the proper entry fields. The number 11 should be entered as type 1.

World Wide Web

The host computer's web page(s) will contain links to other web information. Some web pages may also provide help on other services.

Web Server	Description
http://www.w3.org	World Wide Web Consortium - Information on WWW and Virtual Library (a WWW catalog by subject)

Search Engines

This is a very important service on the internet as information can change by the second.

FTP

The Archie program allows the user to search a database of files on various anonymous FTP sites. Because of the large number of sites, files uploaded within the past 30 days or so may not be listed. There are Archie programs available for home computers when serial line protocols are used, a program on the host computer may be available, or the user can Telnet to a host computer providing Archie. Archie services are also available via Gopher. Searches are limited to file names.

Gopher

The user can use a Gopher program to access either Archie or Veronica search servers. Archie was discussed under the FTP section. Veronica does keyword searches of Gopher sites.

Gopher Item	Description
gopher://veronica.scs.unr.edu/11/veronica	Veronica searches

World Wide Web

Several web pages provide keyword searches of web sites. Subject lists are also available and can be better for finding sites dealing with major categories.

Web Site	Description
http://www.intac.com/~kgs/subject.html	Subject guides and search engines
http://www.interpath.net/home/search.html	Links to internet and web search engines
http://www.via.net/~kse/Telecom/text/Search.html	Links to web search engines
http://www.altavista.digital.com	Search engine (Can search Usenet newsgroups as well)
http://www.mckinley.com	Search engine
http://www.yahoo.com	Search engine
http://slacvx.slac.stanford.edu/misc/internet-services.html	Yanoff's Internet Services List

Sites of Interest

This is not a extensive list and I am sure I missed a few sites. Gopher and World Wide Web sites usually have links to other related sites.

Email

AMSAT.ORG provides a mail alias service. Mail sent to your_call@amsat.org (like **wb1hbu@amsat.org**) will get redirected to your real Email address. This allows people to send Email to a easy- to-remember address.

Mailing List

The following lists are provided by AMSAT. To subscribe to one or more of the following lists, send a message to listserv@amsat.org with your callsign (if any), your Email address, and the names of the lists you want to receive. The request is processed manually at the present time so delays are likely. See **http://www.amsat.org** for more information.

Mailing List Name	Description
ANS	Official AMSAT-NA news releases suitable for packet radio
AMSAT-BB	General discussion of AMSAT and Satellite topics
KEPS	Official AMSAT-NA Keplerian Element postings suitable for packet radio
SAREX	Information and press releases pertaining to SAREX missions

Usenet

Newsgroup	Description
news:alt.*	Unofficial newsgroups almost anyone can create (Not all internet providers carry these)
news:alt.radio.*	Unofficial newsgroups about radio
news:aus.*	Australian regional newsgroups
news:aus.radio.*	Australian regional newsgroups about radio
news:aus.radio.amateur.*	Australian regional newsgroups about amateur radio
news:rec.*	Newsgroups about recreational activities
news:rec.radio.*	Newsgroups about radio
news:rec.radio.amateur.*	Newsgroups about amateur radio
news:rec.radio.amateur.space	Newsgroup about radio amateur space operations
news:sci.*	Newsgroups about science
news:sci.space.*	Newsgroups about space
news:sci.geo.satellite-nav	Newsgroup about satellite-based navigation systems like GPS
news:uk.*	UK regional newsgroups
news:uk.radio.*	UK regional newsgroups about radio
news:uk.radio.amateur	UK regional newsgroup about amateur radio

Telnet

Host Computer	Description
telnet:oig1.gsfc.nasa.gov	NASA OIG Raid RBBS - Keplerian elements and other information (Login as oig - Password is goddard1)

FTP

FTP Site	Description
ftp://ftp.cs.buffalo.edu/pub/ham-radio	Amateur radio information
ftp://ftp.ucsd.edu/hamradio	Amateur radio information and files (Includes satellite files)
ftp://grivel.une.edu.au/pub/ham-radio	Australia mirror site for buffalo and ucsd as well as Australian radio information
ftp://nic.funet.fi/pub/ham	Lots of ham radio information (Includes satellite files) as well as being a mirror site for several systems
ftp://oak.oakland.edu/pub/hamradio	Boston ARC - ARRL files, amateur radio information and files (Includes satellite files)
ftp://ftp.tapr.org/tapr	TAPR - Various information files and software about TAPR products and packet (Includes Satellite information)

ftp://ftp.cdrom.com	Walnut Creek (Producer of software collection CDROMs including Amateur Radio)

Gopher

Gopher Item	Description
gopher://gopher.up.ac.za/11/faq/recreation/faq-radio/amateur	Amateur radio information
gopher://micros.hensa.ac.uk	Microcomputer programs (Also has ham satellite stuff)
gopher://spacelink.msfc.nasa.gov	NASA SpaceLink
gopher://java.lerc.nasa.gov	NASA Lewis server
gopher://sspp.gsfc.nasa.gov	NASA shuttle small payloads (Also has other shuttle info)

World Wide Web

Web Site	**Description**
http://www.amsat.org	AMSAT-NA
http://www.mcc.ac.uk/AMSAT/main.html	AMSAT-UK
http://serpiente.dgsca.unam.mx/unamsat/unameng.htm	UNAMSAT Satellite
http://www.technion.ac.il/~asronen/techsat	TechSat Satellite
http://www.micronet.it/english/itamsat/itamsathome.html	ITANSAT (IO-26) Satellite
http://www.aball.de/~pg/amsat/	AMSAT-DL (German with English in future)
http://ourworld.compuserve.com/homepages/AMSAT_F/	AMSAT France
http://www.deustnet.es/amsat/	AMSAT-URE (Spanish)
http://satrec.kaist.ac.kr	KAIST Remote Sensing Center (Kitsat Satellites)
http://www.mcc.ac.uk/RADIO	University of Manchester Amateur Radio Club (Callbooks and other links)
http://www.acs.ncsu.edu/HamRadio/	General amateur radio information, files, and alot of links to other sites
http://www.tapr.org	Tucson Amateur Packet Radio
http://www.mvangel.com/aea/	AEA
http://www.icomamerica.com	Icom (US)
http://www.kenwood.net	Kenwood
http://www.yaesu.com	Yaesu
http://www.hamradio.com	Ham Radio Outlet (U.S . Ham Radio Dealer)
http://www.arrl.org	American Radio Relay League

http://www.rsgb.org/contents.htm	Radio Society of Great Britain

World Wide Web (Continued)

Web Site	**Description**
http://www.grove.net/~tkelso	Celestial WWW (Keplerian elements from T. S. Kelso)
http://www.ee.surrey.ac.uk/EE/CSER	University of Surrey (Spacecraft Engineering and UoSat satellite)
http://www.esrin.esa.it/	European Space Agency (Includes launch and Arianne 5 information)
http://www.nasa.gov	NASA (Main page with lots of links to all over NASA)
http://oigsysop.atsc.allied.com/	NASA OIG Raid BBS (Keplerian elements and other information)
http://spacelink.msfc.nasa.gov/	NASA news and information (Some interesting software on science and satellites)
http://www.grove.net	Grove Enterprises (Satellite Times)
http://www.cdrom.com	Walnut Creek (CD-ROM)

SETI Sensitivity: Calibrating on a Wow! Signal

by Dr. H. Paul Shuch, N6TX
Executive Director, The SETI League, Inc. [1]

rev. August 21, 1996

Abstract

The Ohio State University SETI program is the longest continuously running electromagnetic Search for Extra-Terrestrial Intelligence to date. In 1977 that sky survey detected a signal which seemed to fit all the characteristics anticipated for communications of intelligent extra-terrestrial origin. The so-called Wow! signal is interesting in its own right, and we analyze it here, applying time-honored reverse engineering principles in trying to ascertain its nature. But it is also important as a possible benchmark, in defining the signal characteristics for which future SETI projects might be searching. Microwave antenna, receiver and digital signal processing technologies have all advanced significantly in the two decades since the detection of the Wow! signal. If we take it as being typical of the types of signals which we are seeking, we can use it to calibrate the effectiveness of future generations of SETI receiving stations. We see that the amateur state-of-the-art is today easily capable of detecting any future Wow! signals which happen our way.

Introduction -- Is Amateur SETI Practical?

The ambitious NASA SETI (Search for Extra-Terrestrial Intelligence) program, modestly funded at five cents per American per year, was terminated by Congress in October of 1993, reducing the Federal deficit by 0.0006%. Several organizations arose to privatize the research, including the membership-supported, non-profit SETI League, Inc. The SETI League differs from other space advocacy organizations in that it is a grassroots movement, composed mainly of radio amateurs, which encourages its individual members to build and operate their own modest SETI receivers. A tax-exempt educational and scientific corporation, we are modeled in large part after the amateur

[1] PO Box 555, Little Ferry NJ 07643. (201) 641-1770. Email n6tx@setileague.org.

communications satellite organizations, AMSAT and Project OSCAR.

The professional radioastronomy community has voiced an understandable skepticism as to the contributions to science which might be made by a handful of amateurs, funded at a small fraction of the former NASA SETI budget. The late SETI pioneer Dr. Bernard M. Oliver articulated this skepticism well. Barney Oliver's credentials are impressive. Longtime vice-president of engineering for the Hewlett-Packard Company, he served as president of the IEEE, and was principle author of NASA's ambitious 1971 *Project Cyclops* design study for detecting intelligent extra-terrestrial life. [2] He said of amateur SETI, "If your system wouldn't detect the strongest signal the ETI might radiate, then years of listening, or thousands doing it, won't improve the chance of success. To cross the Golden Gate, we need a bridge about 10,000 feet long. Ten thousand bridges ... one foot long won't hack it." [3]

Barney made a good point, even if he was something of a dinosaur. The burden of proof falls to us in the amateur SETI community to demonstrate that our systems are indeed capable of detecting, at the very least, that *strongest* signal which an extra-terrestrial civilization might generate. We do so through the following analysis of the Ohio State "Wow!" signal. As for the Golden Gate analogy, it would be valid only if SETI proved a serial process. I suggest that it is more of a parallel enterprise, and hope to show in this paper that 10,000 volunteers can, if properly coordinated, accomplish something which Barney Oliver had never contemplated. For we seek to cross not just the Golden Gate, but the gulfs of space, in all directions at once, in real time.

Review of the "Wow!" Signal

Modern SETI was born in 1959, with the publication in Nature of a short paper by Cocconi and Morrison [4] proposing a search of nearby Sun-like stars, near the 1420 MHz

---

2 The *Project Cyclops* study has recently been republished as ISBN 0-9650707-0-0, available for a $20 US contribution ($24 postpaid overseas) to The SETI League, Inc.

3 Oliver, Bernard M., private correspondence with the author, March 1995.

4 Cocconi, G., and Philip Morrison, *Searching for Interstellar Communications*. Nature 184 (4690): 844 - 846, Sept. 19, 1959.

neutral hydrogen frequency, for artificially generated signals. Unbeknownst to the authors, even as they wrote their paper Frank Drake was preparing to perform the very experiment which they were proposing. *Project Ozma* searched only two stars, at that single frequency, for two months during the summer of 1960. During the succeeding years, several dozen other SETI experiments have been performed, many still concentrating on the hydrogen line as a likely frequency for interstellar communications.

The longest running of these is the Ohio State sky survey, which has been continuously operational since 1973. It was the Ohio State Radio Observatory which on August 15, 1977 detected the most tantalizing and promising candidate signal to date, the so-called "Wow!" signal. The computer printout of this historic signal is shown below in **Figure 1**.

The "Wow! received its name from the marginal note on the computer printout, penned by SETI volunteer Dr. Jerry Ehman. "I came across the strangest signal I had ever seen, and immediately scribbled 'Wow!' next to it," Ehman explained. "At first, I thought it was an earth signal reflected from space debris, but after I studied it further, I found that couldn't be the case." [5]

The letters and numbers in the printout are today widely misinterpreted as a message. "What does the progression 6EQUJ5 actually stand for?" asked one SETI enthusiast. "A sequence in need of completion? A matrix in need of expanding? A computer malfunction? The ASCII equivalent to a binary code?" [6]

Let me emphasize that the "Wow!" sequence itself is ***not* a message**. What was received appeared to be a CW (unmodulated) signal. The numbers and letters in the much-reproduced computer printout are merely a time-series representation of the signal amplitude, as received at the Big Ear radiotelescope. Specifically, the symbols represent the number of standard deviations by which the received signal exceeded average background noise, on a scale of 0 to 35. So a 0 means no stronger than background noise, 1 is one sigma above noise, 9 means nine sigma above noise, an A would be ten units, and U (the strongest peak of the actual signal) is 30 standard deviations above the mean background

---

5 Ehman, J., cited in "Wow!" by Greg Gillespie, The Institute, August 1996.

6 "Ask Dr. SETI" column, reproduced from The SETI League, Inc. World Wide Web site, URL http://www.setileague.org/admin/askdr.htm.

noise in the receiver. If you graph the sequence as amplitude values over time you get roughly a Gaussian distribution, consistent with the antenna pattern of the Big Ear in drift-scan mode. The data set depicts signal amplitude over both frequency and time.

Figure 2 shows just such a graph of the output of the Ohio State 50-channel receiver during the transit through the antenna pattern of the "Wow!" source. Time is plotted horizontally, amplitude vertically, and frequency in the depth axis. The time increments are twelve seconds per sample. Each of the channels is 10 kHz wide; thus, a half MHz surrounding the hydrogen line is depicted. Note that the signal rises almost 15 dB above the background noise, in a single channel, then falls back into the noise, its amplitude pattern exactly coinciding with the known beamwidth pattern of the dish (including its feed-induced skew, and coma sidelobes).

From the "Wow!" signal's temporal correspondence to the antenna pattern, we know that its source was moving with the background stars. From its Doppler shift signature (the local oscillator of the receiver was being chirped at a rate which corresponds to the Earth's motion with respect to the Galactic center of rest) we can eliminate terrestrial interference, aircraft or spacecraft from consideration. The antenna coordinates indicated that the signal was coming from no known nearby sun-like star, though at any time, in any direction, the antenna pattern encompasses on average about half a dozen distant stars. Most significantly, though over a hundred follow-on studies of the same region of the sky were performed, from several different radio observatories, the signal never repeated. [7]

Of course, it should not have. Consider that the Big Ear radiotelescope at the Ohio State Radio Observatory is extremely narrow in beamwidth, viewing just one part in a million of the sky at a given time. That means if you are listening on exactly the right frequency, at exactly the instant when The Call arrives, there's still a 99.9999% chance you'll be pointed the wrong way. And if we imagine that the "Wow!" signal emanated from a similar high gain antenna, which (let us assume) illuminates only one millionth of the sky, what are the chances the two antennas will be pointed *at each other at the same*

[7] Extensive follow-on studies of what has become known as the "Wow! region" were performed by Dr. Paul Horowitz, W1HFA, with a most advanced META (Mega-channel Extra-Terrestrial Assay) receiver on an 83-foot diameter radiotelescope at Harvard MA. He heard nothing. I performed a more modest study with a single channel receiver, and a 40-foot diameter radiotelescope, at the National Radio Astronomy Observatory (NRAO), Green Bank WV, during the summer of 1995. I also heard nothing, proving that my simple equipment is no less effective than META!

time? That's easy, says the statistician: 10^{-6} squared equals 10^{-12}.

But wait, if we know the direction from which the signal emanated, and concentrate our antennas there, we've removed one factor of 10^{-6}, and we're back to million-to-one odds. Even still, we've only looked in that direction for a total of a few tens of hours. Not only have we not yet scratched the surface, we haven't even felt the itch.

Quantifying the "Wow!"

If the "Wow!" signal is typical of the type of evidence which SETI seeks (and we have no reason to assume otherwise), then we can expect valid SETI hits to be extremely strong, highly intermittent signals which appear once (as the transmit beam sweeps past Earth), and never repeat on human time scales. Thus we do not expect to again encounter the "Wow!" Yet there may be countless other signals, similarly strong and intermittent, falling on our heads even now. In order to determine whether our receivers are up to the task of detecting these future "Wow!" events, let us quantify the amplitude of our only known specimen. If we can show that amateur SETI is capable of detecting such signals, then Oliver's first objection is overcome.

We know a great deal about the status of the Ohio State Radio Observatory at the moment of the "Wow!" detection. It exhibited, for example, a 100 Kelvin overall noise temperature, and had channels 10 kHz wide. From the above, we use Boltzmann's Law to compute the noise threshold of the receiver:

$$P_n = kTB = 1.4\text{ e-}17\text{ W} = -138.6\text{ dBm}$$

From its reflector area and feed illumination, we determine that the antenna exhibited a gain of +55.3 dBi. Combining this figure with noise threshold, we find the incident isotropic power threshold of the radiotelescope to be:

$$\text{Thresh} = P_n\text{ (dBm)} - G_{an}t\text{ (dBi)} = -193.9\text{ dBm}$$

But actual sensitivity improves with the square root of integration time, and integrating a CW signal for ten seconds, within a 10 kHz bandwidth, improves things by 25 dB. So the actual system sensitivity is:

$$\text{TSS} = \text{Thresh} - \text{Integration Gain} = -218.9\text{ dBm}$$

Finally, the received Signal-to-Noise Ratio (SNR) was +14.9 dB. This suggests that, to detect a "Wow!" twin, a radiotelescope needs to provide us with an ultimate sensitivity of:

$$\textbf{Required Sens} = \textbf{TSS} + \textbf{SNR} = \textbf{-204 dBm}$$

Thus, any radiotelescope with an overall sensitivity of -204 dBm would, in theory, be able to detect a "Wow!" type signal, if tuned to the right frequency, and pointed in the right direction, at the right time.

Sensitivity of an Amateur SETI Station

During the Spring of 1996, I had the pleasure of designing and assembling a demonstration amateur SETI station at SETI League headquarters in New Jersey. The design objective of this proof-of-concept station was the capability of detecting rf events of "Wow!" amplitude. **Figure 3** depicts the simplified block diagram of the resulting prototype system, which employs a mix of commercial and home-brew elements.

The antenna chosen for the prototype is a Paraclipse Classic 12 commercial satellite TV antenna of 3.7 meter diameter, on a modified horizon-to-horizon mount. The antenna feed is a monopole-fed cylindrical waveguide feedhorn from Radio Astronomy Supplies, Atlanta GA. The front end is a Hewlett-Packard GaAs MMIC preamp from Down East Microwave, Frenchtown NJ. An Icom 7000 microwave scanning receiver is employed; it drives a TI 560 CDT laptop Pentium computer for digital signal processing. Construction details of the station can be found in the SETI League Technical Manual. [8]

We analyze the sensitivity of the amateur SETI station in much the same manner as we previously quantified the Ohio State Radio Observatory. Digital Signal Processing gives us a 10 Hz bandwidth, significantly improving sensitivity over the 1977 state-of-the-art. Overall noise temperature is a modest 200 Kelvin. Boltzmann's Law thus gives us the noise threshold of the receiver:

$$P_n = kTB = 2.8\text{ e-}20\text{ W} = -165.6\text{ dBm}$$

---

[8] SETI League Technical Manual, ISBN 0-9650707-2-7, H. Paul Shuch, Editor. Available for a $10 US contribution ($12 postpaid overseas) to The SETI League, Inc.

The 12 foot reflector is poorly illuminated by the simple feedhorn, and thus achieves only about 50% efficiency. At the hydrogen line frequency, this corresponds to a gain of +31.8 dBi. Combining this figure with noise threshold, we find the incident isotropic power threshold of the amateur system to be:

$$\textbf{Thresh} = \textbf{P}_{\textbf{n}}\ \textbf{(dBm)} - \textbf{G}_{\textbf{an}}\textbf{t}\ \textbf{(dBi)} = \textbf{-197.4 dBm}$$

which is slightly better than that achieved at Big Ear, circa 1977. But our integration gain offers us significantly less improvement, since we are starting with a channel a thousand times narrower than the bandwidth then employed at Ohio State. Still, we achieve a 10 dB improvement by integrating for ten seconds, for an ultimate sensitivity of:

$$\textbf{TSS} = \textbf{Thresh - Integration Gain} = \textbf{-207.4 dBm}$$

Comparing our Tangential Signal Sensitivity to the Incident Isotropic Power of the "Wow!" signal, we see that this station would have achieved about a +3.4 dB SNR, had it been available to intercept the "Wow!" This is not dissimilar to the amplitude experienced by radio amateurs bouncing their signals off the surface of the moon. We can classify our sensitivity as "+3.4 dBW!" (3.4 dB more sensitive than the "Wow!" amplitude).

The above result may appear to violate the conventional wisdom. The Big Ear radiotelescope is, after all, a LARGE antenna. The amateur station we've just described uses a small one. And everyone knows there's no substitute for capture area.

Or is there? One substitute, which amateur SETI employs to good advantage, is Digital Signal Processing.

Introducing the Project Argus Network

Recall that a chief limitation of the Big Ear radiotelescope is that it can "see" only perhaps a millionth of the 4π steradians of space at any given time. If "Wow!" type signals are as highly intermittent as we suppose, then the odds are rather good that we'll miss the next one which comes along. It would be highly desirable to see in all directions at once. We could do so by building a global network of a million Big Ear type telescopes. But at a cost of fifty to one hundred million dollars apiece, we would very quickly exceed the gross planetary product.

There is another way, and it has been described above. Consider that at the 21 cm neutral hydrogen line, a three- to five-meter diameter parabolic antenna (such as is commonly used for satellite TV reception) will have a power gain perhaps 200 times less than that of a "real" radio telescope such as Big Ear. The reduced capture area would also imply that such an antenna would enjoy 200 times the sky coverage, so a mere 5,000 such antennas could, if properly situated, "see" the whole sky at once. And such a global array of small telescopes could be constructed at a cost far less than that of a single Big Ear.

Unfortunately, this increase in angular coverage afforded by smaller antennas was accomplished by a reduction in their capture area, hence gain. Thus, as compared to our Big Ear example, these smaller antennas will experience a reduction in their effective communications range by that same factor of 200, all else being equal. A signal which could be detected by Big Ear at a range of, say, 20,000 LY, would be detectable to our smaller antennas at a distance of only 100 LY. Since for uniform distribution of candidate stars, the number of targets varies roughly with the cube of distance, this sacrifice in sensitivity significantly reduces (perhaps by a factor of several million) the number of suitable stars which might be within range of our sky survey.

Nevertheless, for surveying the entire sky in real time, there's no better resource than the world's radio amateurs. On April 21, 1996, The SETI League launched its *Project Argus* all-sky survey. Over the coming years, we can envision our small network growing to perhaps 5,000 stations worldwide, operating in a coordinated manner, covering the whole sky with our modest receiving beams. Perhaps we won't cross the Golden Gate, but amateur radio has a very real opportunity to cross the gulfs of space and time.

Conclusions

Within the past half-century, SETI has finally emerged out of the realm of science fiction, and into the scientific mainstream. Every month we read about the discovery of yet another planetary system in space. Thanks to microbes detected in meteorites, we are beginning to learn about how life might have developed on other worlds. And we have completed the Copernican Revolution, finally realizing that we are not the center of all creation. Yet SETI programs continue to yield negative results. Our most promising candidate signal was detected nearly two decades ago. It may well take many more spades digging in the sands of space before we can expect to uncover another gem. But we have demonstrated here that suitable spades are readily available to any interested prospector.

The non-profit, membership-supported SETI League has launched its search on

Earth Day, and flies the Flag of Earth, because SETI is an enterprise which belongs not just to one country, government or organization, but to all humankind. Like Argus, the guard-beast of Greek mythology who had a hundred eyes, we seek to see in all directions at once, that we might capture those photons from distant worlds which may well be falling on our heads even now.

Project Argus started with a mere five stations. This small step for humanity represents a humble beginning for what will ultimately be a global effort. We can foresee 500 participants within two years, and perhaps five thousand by the year 2001. When we reach that level, there will be no direction in the sky which evades our gaze. Then we can hope to find the answer to a fundamental question which has haunted humankind since first we realized that the points of light in the night sky are other suns: Are We Alone?

And when Project Argus grows
To full strength, we will show
That the suns shall never set on SETI. [9]

[9] From "The Suns Shall Never Set on SETI," in Sing a Song of SETI, ISBN 0-9650707-1-9, copyright (c) 1996 by H. Paul Shuch, available for a $10 US contribution ($12 postpaid overseas) to The SETI League, Inc.

Figure 1
A small portion of the "Wow!" computer printout, as annotated by Jerry Ehman on August 15, 1977.

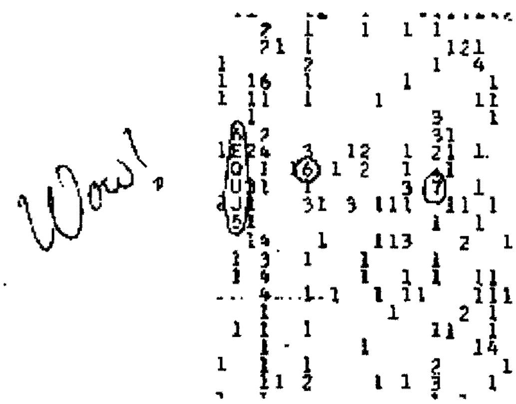


Figure 2
The "Wow!" signal plotted as amplitude and frequency vs. time

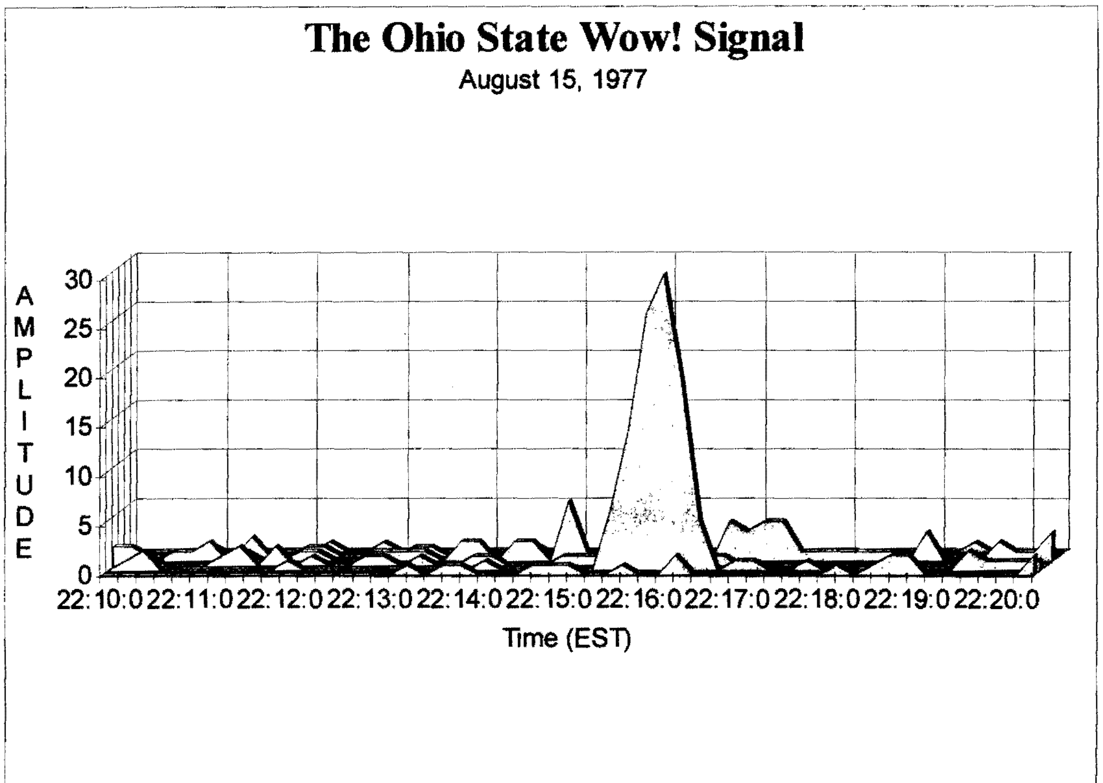
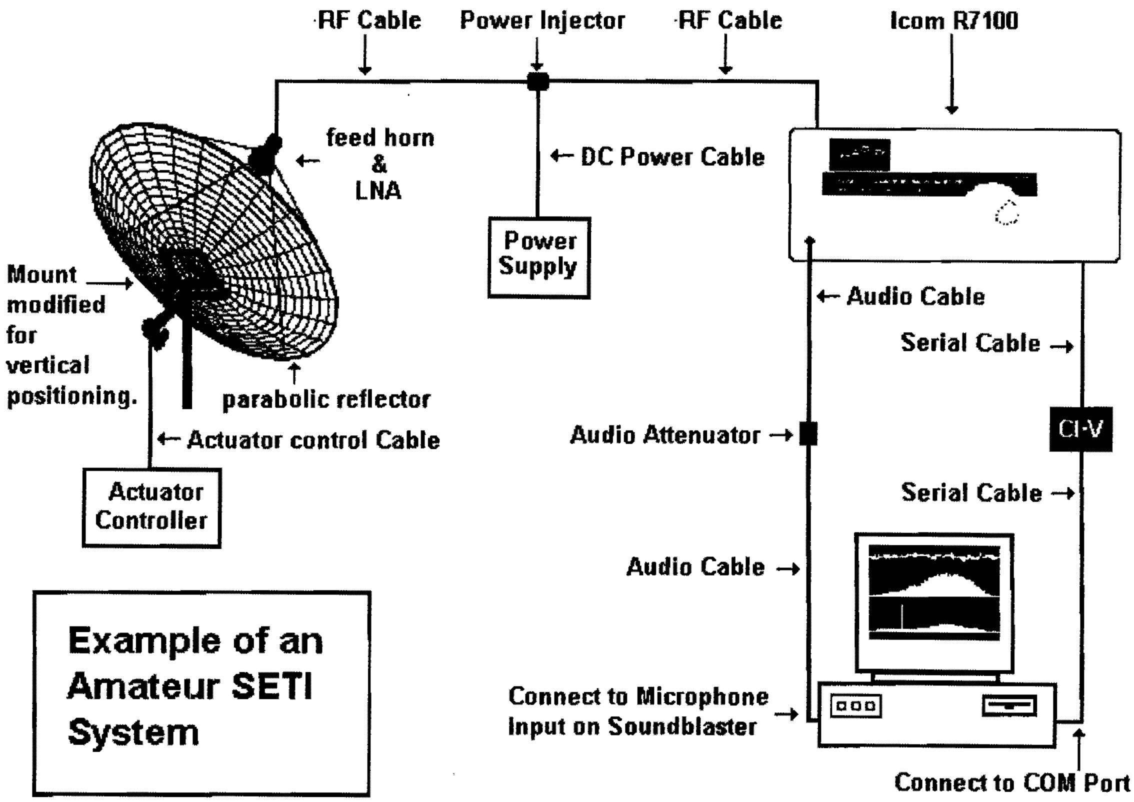

The Ohio State Wow! Signal
August 15, 1977
AMPLITUDE
30
25
20
15
10
5
0
22:10:0 22:11:0 22:12:0 22:13:0 22:14:0 22:15:0 22:16:0 22:17:0 22:18:0 22:19:0 22:20:0
Time (EST)

Figure 3
Block Diagram of Prototype Amateur SETI Station
(Courtesy of Daniel Fox, KF9ET)



The Mars Global Surveyor Project

Presented by:
Cliff Buttschardt, K7RR

Mars Relay Flight Test Workshop

Objective

To Verify, while en route to Mars, the Two-Way Functionality of the Mars Relay on board the NASA Mars Global Surveyor and Russian Mars'96 Spacecraft.

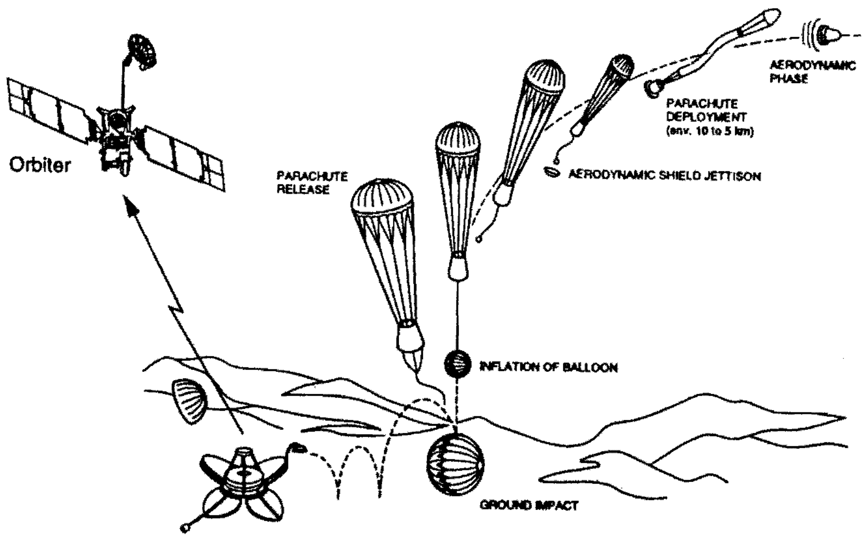
Approach

Enlist the UHF-Capable Assistance of the World-Wide Radio Amateur Community in carrying out this Flight Test of the Mars Relay shortly after Launch.

JPL

Russian Mars'96

Small Station Landing



Mars Relay Flight Test Workshop

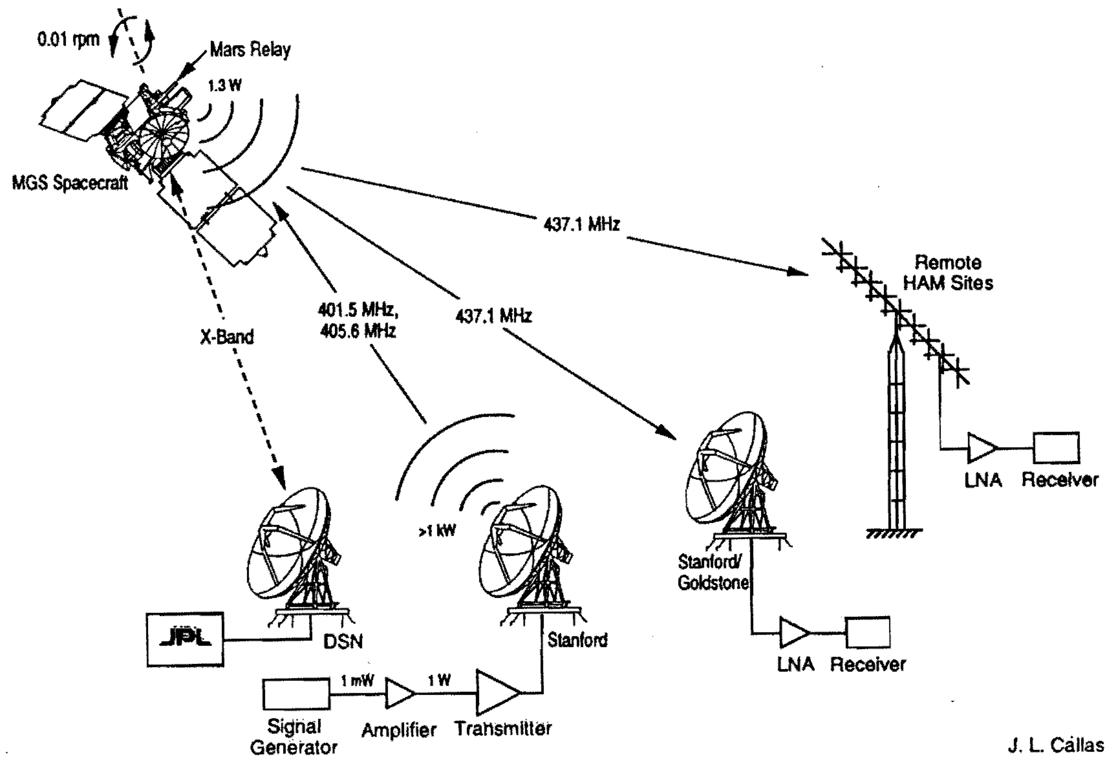
Test Objectives

- **Verify Mars Relay Operational Modes**
  - Observe Beacon Subcarriers (RC1, RC2, RC3 and TC)
- **Confirm Far-Field Antenna Pattern**
  - Measure Beacon Signal Strength vs. Spacecraft Rotation
- **Verify Receiver Functionality**
  - Radiate Simulated Small Station Signal
  - Observe Mars Relay TC Signal Lock-Up
  - Measure Bit Error Rate (BER) as a Function of Signal Level

J. L. Callas

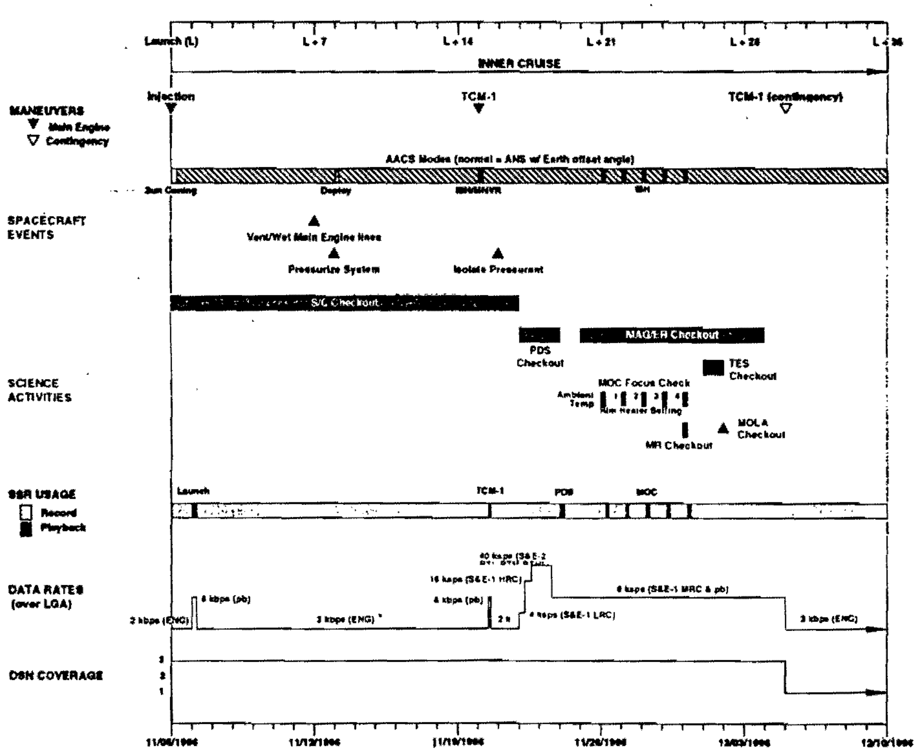
Mars Global Surveyor Project

Mars Relay Flight Test



J. L. Callas

MGS Inner Cruise Timeline



JPL

Earth-based Uplink to the Mars Relay

Frequency	401.5275 MHz
Wavelength	0.747 m
Symbol Rate	8003 bits/s
Signal Polarization	RCP
Signal Modulation	FM

Mars Relay Receiver System		
MR Antenna Gain	0.0 dBi	
MR Effective Area	0.0444 m2	
Polarization Losses	-1.23 dB	
Feeder Losses	-1.0 dB	
Receiver Losses	-1.8 dB	
Modulation Index	60 °	
Data Power/Total Power	0.75	
System Temperature	457 K	
Noise Spectral Density	-172.0 dB/Hz	
Threshold Eb/No	5.6 dB	(for BER of 1E-5)
Signal Threshold	-122.1 dBm	

Free Space Losses	
Earth-Spacecraft Distance	1.0E+10 m
One-Way Light Time	33.4 s
Atmospheric Losses	-0.05 dB
Required Isotropic Power	1.77E+7 W
Required EIRP	102.5 dBm

Earth Transmitting Antenna	Stanford	Goldstone
Antenna Diameter [m]	46	34
Antenna Gain [dBi]	45.7	43.1
Antenna System Efficiency	0.4	0.4
Margin [dB]	3.0	3.0
Minimum Transmit Power [W]	2360.7	4321.1

JPL

Downlink from the Mars Relay

MR Beacon Parameters		
Beacon Frequency	437.1000 MHz	
Beacon Wavelength	0.686 m	
Beacon Transmit Power	1.3 W	
MR Antenna Gain	1.0 dBi	
Effective Isotropic Rad Power	1.64 W	32.1 dBm

Signal Polarization	RCP		
Signal Modulation	CW or FM		Modulaion Index
FM Subcarriers	RC1	1484.06 Hz	2.90
	RC2	1137.78 Hz	3.78
	RC3	1028.11 Hz	4.18
	TC	1376.34 Hz	3.12
Peak Frequency Deviation	Δf	4300 Hz	

Earth-Probe Distance	1.0E+10 m
Total Received Carrier Flux	1.30E-21 W/m2

Earth Receiving Antenna	Goldstone	Goldstone	Stanford	Stanford	Algonquin	Ham Site
Antenna Diameter [m]	70	34	46	18	46	
Antenna Gain [dBi]	50.1	43.8	46.5	38.3	46.5	21.5
Half Power Beam Width [degrees]	0.56	1.16	0.85	2.18	0.85	15.15
Antenna System Efficiency	0.40	0.40	0.40	0.40	0.50	0.50
Antenna Effective Area [m2]	1539.4	363.2	664.8	101.8	831.0	2.6
System Temperature [K]	150	150	125	125	85	100
Noise Spectral Density [dBm/Hz]	-176.8	-176.8	-177.6	-177.6	-179.3	-178.6
Search Bandwidth [Hz]	0.3	0.3	0.1	0.1	2.0	1.0
Coherence Loss	0.95	0.95	0.37	0.37	0.95	0.95
Misc Loss	0.95	0.95	0.95	0.95	0.95	0.95
Received Signal [dBm]	-147.4	-153.7	-155.2	-163.3	-150.1	-175.1
CW Signal-to-Noise Ratio (linear)	2912.2	687.1	1763.3	270.0	416.1	2.3
CW Signal-to-Noise Ratio [dB]	34.6	28.4	32.5	24.3	26.2	3.5

1996-07-08 J. L. Callas

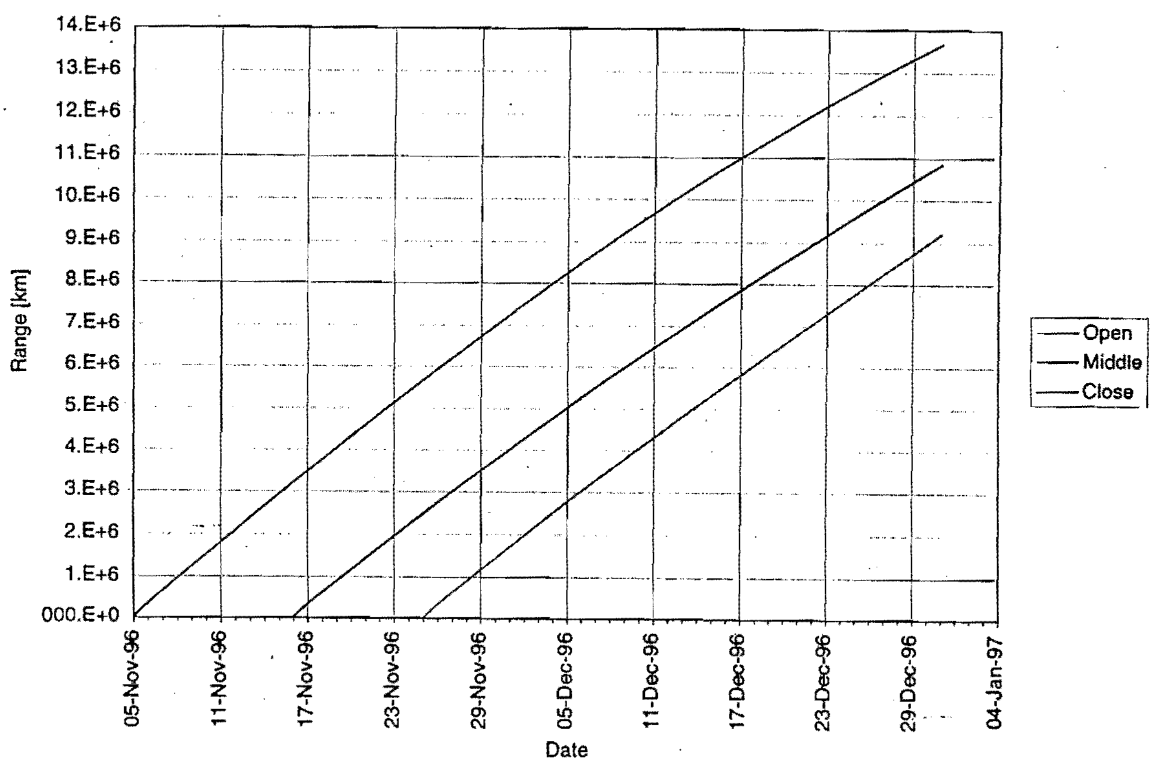
Beacon Spectral Components

- **Spectral Components of the Mars Relay Beacon when Frequency Modulated (FM) by the corresponding Subcarrier Modes (RC1, RC2, RC3 and TC):**

Subcarrier Mode	Carrier (f_c)	First Sideband ($f_c \pm f_m$)
CW	0.0 dB	n/a
RC1	-13.0 dB	-8.5 dB
RC2	-7.9 dB	-33.1 dB
RC3	-8.5 dB	-17.7 dB
TC	-10.6 dB	-10.4 dB

JPL

MGS-Earth Range



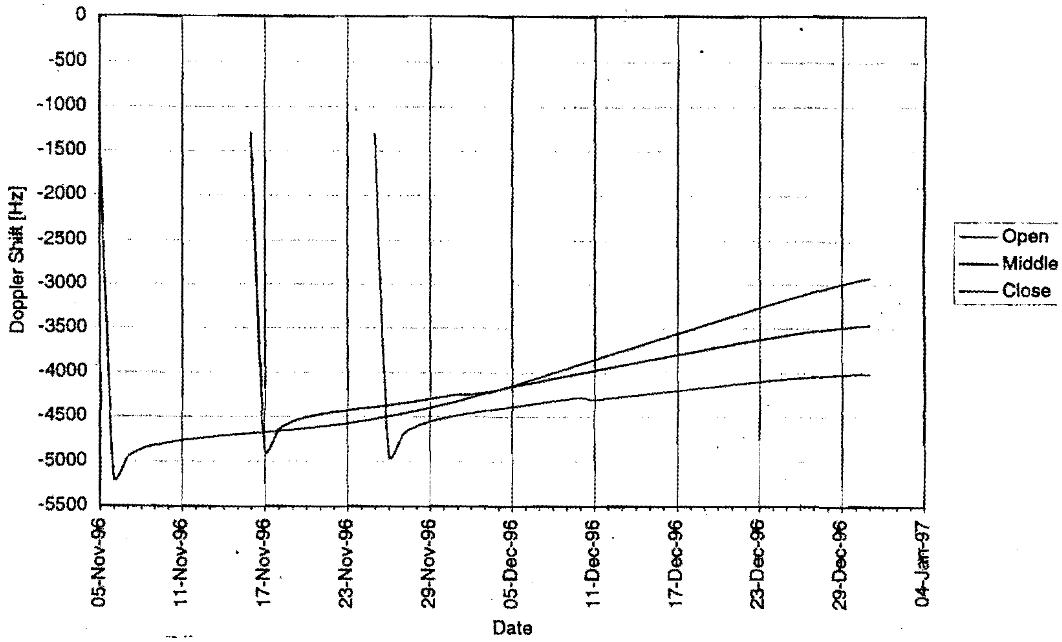
For the Open, Middle and Close
of the MGS Launch Period

1996-05-28 J. L. Callas

JPL

Geocentric Doppler Shift

For 437.1 MHz



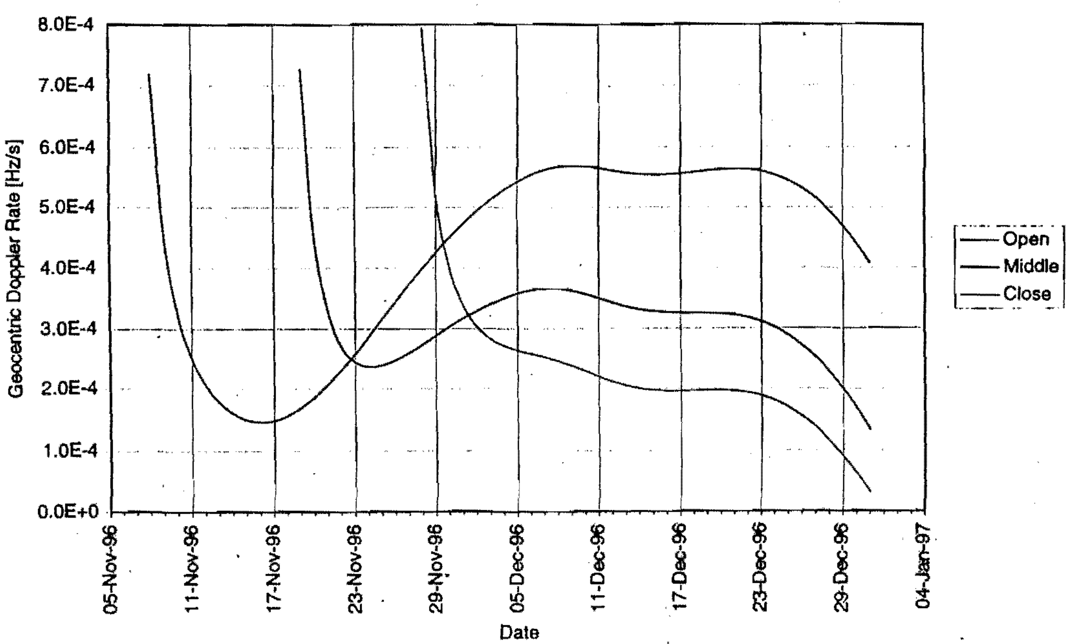
For the Open, Middle and Close
of the MGS Launch Period

1996-05-28 J. L. Callas

JPL

Geocentric Doppler Rate

For 437.1 MHz

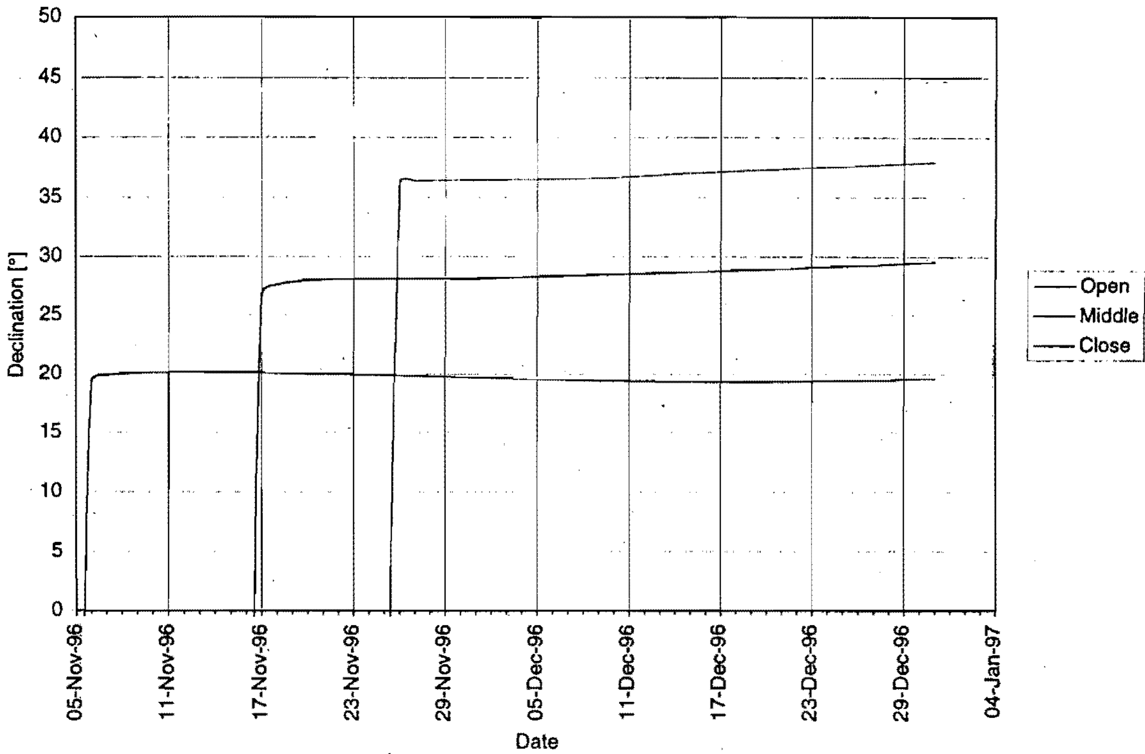


For the Open, Middle and Close
of the MGS Launch Period

1996-05-28 J. L. Callas

JPL

MGS Declination



For the Open, Middle and Close
of the MGS Launch Period

1996-05-28 J. L. Callas

MGS can expect long-distance call from radio amateurs

By DIANE AINSWORTH

About 20 days after launch, Mars Global Surveyor can expect a long-distance call from "Planet Earth" .... just checking in, mind you ... to make sure the spacecraft's UHF radio relay system is operating while it is still within earshot of radio amateurs back home.

Ham radio enthusiasts from across the country gathered recently at JPL to plan a strategy for conducting the Mars Relay Flight Test in late November. Led by Dr. John Callas, JPL scientist and experiment representative for Mars Global Surveyor, the workshop included radio amateurs from the United States, Canada and the French Space Agency, Centre National d'Etudes Spatiales (CNES), which has furnished the UHF Mars Relay system onboard MGS.

MGS will use many frequencies onboard to communicate, said Glenn Cunningham, manager of the Mars Global Surveyor Project at JPL. The spacecraft uses the X-band frequencies, around 8 GHz, for primary spacecraft communications with the Deep Space Network, to send commands to the spacecraft, return telemetry from the spacecraft and to provide navigation and tracking of the spacecraft.

The Ka band, at approximately 32 Ghz, will be used in an experiment onboard MGS to test this band for future deep-space telecommunications use.

Finally, there is the UHF Mars Relay, to be used for relay operations at Mars between MGS and small stations and landers placed on the planet's surface.

The spacecraft's Mars Relay system is a UHF transponder designed to provide a communication link between MGS and landers placed on Mars by other missions. Designed and built by CNES, the Mars Relay uses a 1.3 watt beacon at 437.1 MHz to alert ground stations that the spacecraft is within view. The relay then uses two receive frequencies at 401.5 and 405.6 MHz to collect ground telemetry at either 8 kilobits or 128 kilobits per second. The relay system uses the memory of the MGS camera to buffer the received Mars surface station data into the MGS telemetry system for playback to Earth.

"The objective of the Mars Relay Flight Test will be to verify, while en route to Mars, the functionality of the Mars relay onboard MGS and the Russian Mars '96 spacecraft," Callas said. "The approach we plan to take is to enlist the UHF-capable assistance of the worldwide radio amateur community in carrying out this flight test of the Mars relay shortly after launch."

Detection of the Mars relay beacon has been tried before, MGS team members pointed out. Earth-based detection of the Mars Balloon Relay was attempted during the search for Mars Observer, after contact was lost with the spacecraft in August 1993. Several large antenna facilities around the world supported the search. Unfortunately, after several attempts over many months, no signal from Mars Observer was ever detected.

MGS's new French-built relay system will be tested while the spacecraft is still within range of amateur listening stations on Earth. Specific objectives of the test will be:

- To verify the Mars relay operational modes by observing at Earth the beacon subcarriers;
- To confirm the far-field antenna pattern with Earth-based measurement of the beacon signal strength as a function of spacecraft rotation;
- To verify the Mars relay receiver functionality with a radiated Earth-based UHF signal, and a measurement of bit error rate as a function of signal level.

The Mars Relay Flight Test is currently being scheduled for approximately 20 to 30 days after launch and possibly will be performed a second time with the Russian Mars '96 spacecraft sometime soon after the test with MGS. At 20 days after launch, MGS is approximately 6 million kilometers (3.7 million miles) from Earth, making this test a distance record for radio amateur deep space communication.

"At these distances, the 1.3 watt beacon signal from the Mars relay is of sufficient signal level for detection by radio amateurs with large antenna systems of gain greater than 21 dBi," Callas said.

The test will have three parts. The first part will be to activate the Mars Relay in the beacon pure carrier mode. This mode broadcasts the 1.3W beacon as a pure tone at exactly 437.1 MHz. This will maximize the amount of power in a single carrier frequency. The mode will be active for a period of at least 24 hours.

"While en route to Mars, the MGS spacecraft rotates about its X-axis once every 100 minutes," Callas said. "In addition, the X-axis is pointed off the Earth by approximately 30 degrees. The combination of these two effects is to produce a beacon signal that modulates in strength with the spacecraft rotation. This feature provides an opportunity to observe different parts of the relay's antenna pattern as the spacecraft rotates."

After completion of that part of the test, the second part will be to activate different modes of the relay. Each mode will be active for at least 100 minutes to allow the spacecraft to complete one full rotation. With the activation of these modes the relay signal will drop significantly as the beacon is frequency modulated (FM) with one of four subcarriers. Only those radio operators with the largest antennas will be able to detect these signals from MGS.

The Mars relay onboard the Russian Mars '96 spacecraft has 16 times more gain than the relay on MGS, according to Callas, making the signal from Mars '96 more easily detectable by radio amateurs with smaller antennas, even during this phase of the test.

The third part of the Mars Relay Flight Test will be an active uplink from the 46-meter antenna at Stanford University. The Stanford antenna will be instrumented with equipment to simulate a signal from a Mars lander. The signal will be radiated with sufficient power (about 2.5 kW) to match the expected signal levels received from landers on Mars by the relay.

"The radiate signal will contain a pseudo-random number sequence as the transmitted data," Callas said. "This data can then be analyzed to determine bite error rate after the received data is returned to Earth, via the spacecraft's X-band downlink to the Deep Space Network in the case of Surveyor, or via the Russian ground stations in the case of Mars '96."

Additionally, those radio operators with large antennas will be able to observe the change in subcarrier modulation in the beacon, signifying the relay receiver lock-up on the radiate signal from Stanford.

The flight test will be coordinated from JPL. Flight controllers will control the operation of the MGS spacecraft and will provide instruction to Stanford for the operation of the radiate uplink. JPL will coordinate with the Russians as to the operation of the Russian Mars '96 spacecraft.

The MGS navigation team will generate and distribute the spacecraft position and range information, and Doppler shifts and rates to aid the radio amateurs in tracking MGS. The same information from the Russians will be necessary to support testing of the Mars '96 mission.

JPL will serve as the collection site for observations provided by radio amateurs around the world. The received Mars relay telemetry from MGS will be analyzed at JPL and at CNES in France. The relay data collected aboard the Russian Mars '96 spacecraft will likely be analyzed by the Russians and CNES.

Several sites with large antennas are currently planning on supporting these tests, Callas said. Stanford's 46-meter antenna will be the only site radiating a signal to the Mars relay on either spacecraft. Simultaneously, Stanford will also be receiving the downlink signals from the Mars relay. The Apple Valley, Calif., Science and Technology Center is working with JPL to re-instrument the Goldstone 34-meter standard antenna (DSS-12) to receive the relay signals. The Algonquin 46-meter antenna in Canada, with help from radio amateurs, is also planning to support the relay tests.

Continually updated information on the Mars Relay Flight Test can be found on the Mars Global Surveyor home page at http://mgs-www.jpl.nasa.gov/. ☐

K7RR 7/18/96

A Time Code Reader/Display for Russian Tsikada Satellites

by

John M. Franke WA4WDL

23 Parkwood Drive, Apt. 201

Yorktown, Virginia 23693

One of the easiest groups of satellites to receive is the Russian low Earth orbit navigation satellites more commonly known as Tsikada (pronounced Cicada, like the insect) and their relatives the Nadezhda, Musson, and Parus satellites. The satellites have an orbital period of approximately 105 minutes and an inclination of approximately 83 degrees. Their orbits are nearly circular with an average altitude of 1000 km. They are primarily used by ocean vessels. As you would expect, for navigation satellites, they can be received from any location on Earth. They transmit on several discrete frequency pairs around 150 MHz and 400 MHz and can be detected with a narrowband frequency modulation (NBFM) demodulator. The frequencies around 150 MHz carry the telemetry signal whereas the 400 MHz frequencies are unmodulated to enhance Doppler measurements. The satellites are powerful enough to be heard with a scanner type receiver using an indoor antenna. I presently use an indoor mounted Radio Shack broadband discone antenna and an Advanced Receiver Research model P144VDA preamplifier with a Realistic Patrolman scanning receiver. However, the ideal receiver would have a wider bandpass than most scanners to allow for Doppler shift. Merely set your receiver to 150.000, 149.970 or 149.940 MHz and wait. The tone shift keying with one second tick marks is easily recognized. Additional signals can be heard less often on 150.030 and 149.910 MHz. 150.000 MHz is assumed to form the civilian portion of the system and the other frequencies serve the military. I find no difference in the time signals with either group of satellites.

After casually listening to these birds for several years, I decided to try to decode the time words from their telemetry stream. Several papers were very instrumental in my success although in the beginning I did not have access to them all. Since I was interested in just the telemetry signals, I worked only with the 150 MHz frequency transmissions. One caution; whereas the time and time intervals are very precise at the satellite, they are not as precise as received if for no other reason than the fact that the satellite is moving and therefore the time for the signals to reach you is changing. The second ticks are closer together as the satellite approaches and are further apart as the satellite recedes. This same problem shows up on low Earth orbit weather satellite images if you use a local timing standard to trigger each image line rather than derive the trigger from the sync signals or the 2400 Hz subcarrier. The images will be slightly bowed. However, the maximum error is at worst but a small fraction of a second.

The telemetry consists of three tones; 7, 5, and 3 kHz. Only one tone is present at any one time. All tone duration's or pulse lengths are multiples of 20 milliseconds. The 7 kHz tone is used as a marker tone. The leading edges of the 7 kHz pulses are exactly one second apart. The length of the 7 kHz pulse is dependent on the time on the satellite clock. The pulse can be from a minimum of 20 to greater than 360 milliseconds long. Between leading edges of the 7 kHz pulses, there are 50 time slots of 20 milliseconds each. Hence, the data rate is 50 Hz. For decoding the three time words, we are only concerned with the first 360 milliseconds or 18 time slots following the start of the 7 kHz pulse. The remaining 32 time slots contain other data such as satellite identification number and orbital parameters. The three time words are hours, minutes and seconds in that order. The hours are in Standard Moscow Time or GMT plus 3. Each time word is 6 time slots or 6 bits long. Six bits can represent 64 unique numbers which is more than adequate for 0-59 for the seconds or minutes. Since the marker pulse occupies at least one of the hours word bits, at most only 5 bits are available for the hours word but that is sufficient for 32 unique numbers, which is more than adequate for 0-24 hours.

Following the 7 kHz pulse, the data is encoded in a form of audio frequency shift keying, AFSK. The two audio frequencies are 3 and 5 kHz. Neither tone uniquely represents a logic 1 or 0. Instead, the data is presented in a non return to zero, NRZ, format. Basically, a bit to bit transition from 3 to 5 or from 5 to 3 kHz represents a logic 1 and no transition or frequency change from one time slot to the next represents a logic 0.

Starting before I had this base information, the development of my time decoder was an interesting challenge. The first task was to demodulate or detect the 7 kHz pulses. A simple tone detector was wired up using a XR-2211 integrated circuit, see Figure 1. The first thing I noticed was that the pulses were much longer than the 20 or 40 millisecond length noted initially by Perry and Wood (ref. 1). Mine were 60 milliseconds long! Another pass yielded marker pulses 100 milliseconds long and a third yielded pulses 80 milliseconds long! Had things changed since the Perry and Wood paper? As it turns out, not really.

I embarked on a program of trying to record, on a cassette recorder, at least one pass during every hour of the day and list out the 7 kHz or timing marker pulse lengths and the 3 kHz data up to and including bit 6 to see what fell out. Table 1 shows data from passes for 10 different hours. The traces are restricted to 3 kHz data streams which go high immediately following the marker pulse. More on this later, a number of areas of this work were carried out in parallel. The data yields the satellite time and the difference between local time and the satellite time indicates that the satellite time is indeed Standard Moscow Time. For example, the data for the pass at 16 EDT has transitions at the end of bits 1, 3, 4 and 5. Summing the transitional values at the bottom of the chart, it is seen that the satellite time is 16 + 4 + 2 + 1 or 23 hours. These early results pointed out the error. Additional results, after several months of monitoring, helped form Table 2 which lists the marker pulse length for each and every one of the 24 hours of the day. Perry and Wood's data was slid back and forth until it matched mine. Several interesting things were seen. First, the satellite time is in Standard Moscow Time not GMT minus 5 as stated in their paper. Second, if you monitored the satellites in England between 5 a.m. and 8 p.m. GMT, the marker pulse length would have been either 20 or 40 milliseconds long. Subsequent papers by Perry et. al. give the satellite time as Standard Moscow Time and verify the range in marker pulse length. It feels good to sort out a piece of the puzzle yourself even though you later find out that others had already done so. Third, the marker pulse for any given hour except 00 satellite time stays constant during the hour. However, the marker pulse for 00 hours varies from initially being at least 18 bits to a minimum of 120 milliseconds or 6 bits long. Since the marker pulse is on until the first logical 1, at the time 00:00:00, the marker pulse extends through all 18 bits. As time advances, the marker pulse length is determined by the first logical 1 appearing in the seconds word and then later by the first logical one in the minutes word. For all other hours, there is a logical 1 in the hours word itself which both limits the length of the marker pulse and of course does not change during the hour. The more one gets into this system, the more interesting it becomes.

Next was to wire up a frequency shift detector tuned to the 3 and 5 kHz tones. While the circuit worked well, the result was a disaster. Scope traces of the output when using recorded passes were not repeatable. So, I took the recordings, marker tone detector and AFSK detector in to work and set them up on a audio frequency spectrum analyzer. Using the output from the marker pulse detector to trigger an oscilloscope I was able to look at the 3 kHz and 5 kHz tones detected by the spectrum analyzer. Several things became apparent. First, as noted by Perry and Wood, all three tones are mutually exclusive. At any one time, only one tone is present. This would explain the problems with the AFSK detector. During the marker pulse neither the 3 or 5 kHz tone is present so the detector output is random. Second, again as noted by Perry and Wood, the 3 and 5 kHz tones are occasionally reversed. By that I mean that the tone immediately following the end of the marker pulse could be either 3 or 5 kHz and the sequence of tones would accordingly be reversed. For example, one time the sequence could be 35533353553... and the next might be 53355535335... . As previously mentioned, the data is encoded in NRZ. If the 50th bit changed, it would reverse the sequence or tone polarity of the next data stream. I did not want to have to keep track of the 50th data bit so I compromised. It turns out that the data bit following the end of the marker pulse is always a 1 whether it is represented by 3 kHz or 5 kHz. The presence of the marker pulse always represents a logical 0.

At this point I decided to start packaging up the system before tackling the data handling. I decided to replace the AFSK detector with another tone detector similar to the marker pulse detector but tuned to 3 kHz. There would be no detector for the 5 kHz tone since it was simply the inverse of the 3 kHz signal. An active audio bandpass filter was added in front of each of the tone detectors to improve the signal to noise ratios and reduce false triggering. Each of the filters had a bandwidth of 500 Hz, see Figure 2. The active filters and tone detectors were all consolidated on to a single circuit card, as shown in Figure 3. I now had all the essential data in digital form. I tried to use a COSMAC 1802 microprocessor to do all the digital decoding and data display. I was able to write machine language programs to do such things as measure and display the marker pulse length and even decode and display the hour word. But, I was not able to keep the rest of the program within the 256 byte limit I had imposed so I abandoned the microprocessor route and went back to straight hardware. If I was to start again, I would probably try to use one of the PIC 16Cxx units.

The first step in building the hardware version was to build a sampling generator which would generate 18 sampling pulses exactly 20 milliseconds apart. The sample pulses would each be about 1 millisecond long and occur near the middle of each time slot. The sampling generator would need to be triggered by the leading edge of the marker pulse. The initial thought was to build a couple of analog circuits, but I wanted as few adjustments as possible. So, I built a crystal controlled sample pulse generator shown in Figure 4 on a single circuit card shown in Figure 5.

U1 is a packaged 1.000 MHz TTL oscillator. The first half of U2 is configured to divide the output frequency from U1 by 2, producing 500 kHz. U3 through U6 are resetable decade dividers with decimal outputs. If allowed to free run, the output from U6 would be 50 Hz, the satellite data rate. But, the counters are held in a reset condition. The leading edge of a 7 kHz pulse triggers U10, resulting in a 1 millisecond pulse which sets a set-reset flip flop formed by the second half of U2. Once set, U2 drops the reset line to the decade counters allowing them to start counting. U7 counts the number of pulses from the divider chain. When U7 reaches a count of 18, U9 is triggered which resets the set-reset flip flop. The decade counters are reset and the circuit awaits the next 7 kHz trigger pulse. U11 is used to buffer the output sampling pulses from U6. The output from U6 is taken from the count 5 position which means that the output sample pulse will be near the middle of the time slot. Using a lower count output moves the sample time closer to the beginning of the time slot and using a higher count output moves the sample point towards the end of the time slot.

Next I built a what I called, for lack of a better term, the digital board or circuit card, Figures 6 and 7, to remove the tone reversals. The result is that the data stream output during the marker pulse would be a logical 0 and the data stream following the end of the marker pulse would be unchanged or inverted such that the bit immediately following the end of the marker pulse would always be a logical 1.

Portions of U1 serve as buffers and inverters for the 3 and 7 kHz data streams. The 7 kHz marker pulse triggers two dual monostable pulse delay circuits, U2 and U3. U2 produces a

1 millisecond pulse approximately 400 milliseconds after the leading edge of the 7 kHz marker pulse. The output from U2 is used for two functions. First, the inverted output is used as a latch command for the display board. Second, the noninverted output from U2 is used to reset the digital board itself to get ready for the next 7 kHz marker pulse. U3 produces a 1 millisecond pulse approximately 1 millisecond after the end of the 7 kHz marker pulse. This pulse is AND'ed with the 3 kHz data stream. If the 3 kHz data is high immediately following the marker pulse, U5 a set-reset flip flop is set and the data is considered normal. Hence, a logical 0 is exclusively OR'ed with the 3 kHz data stream, which has no effect on the 3 kHz data. If the 3 kHz data is low immediately following the marker pulse, U5 remains reset and the data is considered inverted. A logical 1 is exclusively OR'ed with the 3 kHz data stream, converting it to a normal state. The final step is to remove the 7 kHz marker pulse from the output by exclusively OR'ing it with the corrected data stream using the second half of U6. Whatever the state of U5, it will be reset about 40 milliseconds after the end of the seconds word by the pulse from U2. A LED indicator was added for diagnostic purposes to show the state of U5. When lit, the input data is normal.

The filters/tone detectors card, sampling generator card and so called digital card fill a small compact card rack. The following 2 cards are physically larger and are mounted in a separate display rack. This arrangement, shown in the photograph, was driven by the availability of circuit cards and provided the greatest flexibility for experimentation.

At this point I had a corrected NRZ data stream and a set of 18 sample pulses. On to data capture and decoding. Data capture is done using a shift register and data decoding is done using a combination of exclusive OR gates and read only memories (ROM's), see Figures 8 and 9. The shift register actually has 24 stages. It was formed from three CD4015 8 stage shift registers. The 6 extra stages are simply ignored. The corrected NRZ data stream is fed to the shift register data input and the sampling pulses are used to clock the shift register. Data is not cleared between data bursts. It is merely allowed to continue on to oblivion as new data is clocked in. For diagnostic and aesthetic reasons I added a linear array of light emitting diodes (LED's) to indicate the content of the 18 shift register stages. Using two ten LED arrays with the 7th and 14th LED painted over, the result is an array of 18 LED's in groups of 6 separated by single blanked out LED's. It is interesting to see the bits slide in from the right, stop and then see the time change on the digital display.

Once the data is captured in the shift register, one more transformation must be done before actually reading and displaying the data. The shift register data is encoded as NRZ. This must be converted to binary and then to duo-decimal binary coded decimal. Perry and Wood provide a table for converting from NRZ to dual decimal. But, what is needed is dual BCD. For example, NRZ 111000 is equivalent to binary 100100 which is decimal 36, but since we are using two decimal digits, 100100 must be first converted to two digit binary coded decimal (BCD) 0011 and 0110 before finally being decoded and displayed. I chose to do this all in a single step. The 6 bits of NRZ data is used as an address to a 2716 ROM which outputs the tens and units BCD through its 8 data output lines. The higher order data lines 4-7 are used for the tens digit and the lower order data lines 0-3 are used for the units digit. This done, another problem becomes apparent which forces you look at the last bit of the preceding word. For example, the NRZ bits in the seconds word are considered to be normal if the last bit in the minutes word is a logical 0. If the last bit in the minutes word was a logical 1, all of the bits in the seconds word would be inverted. This could be handled two ways. First, the easy way, is to use the last bit in the preceding word as part of the ROM address and include both inverted and normal data in the ROM. Second, the way I did it, the data from each word could be exclusively OR'ed with the last bit of the preceding word. Note that with either method this last correction only has to be done with the minutes and seconds, the hours was corrected by the action of the so called digital board. After I had completed this board, I thought that it might have been more practical to eliminate the digital board and do the hours correction the same way as was done for minutes and seconds. But, it is not that simple. When the 3 kHz data is inverted, you do not see the end of the marker pulse in the 3 kHz data stream because the end of the marker pulse is not followed by a logical 1 in the 3 kHz data stream but instead by a logical 0 which is the same state the 3 kHz data stream was in during the 7 kHz marker pulse. So, some sort of test must still be performed at the end of the 7 kHz marker pulse. Therefore, the price of ignoring the state of data bit 50 is the requirement of having the digital board. Of course if you were to convert the data stream from NRZ to binary on the fly, the result might be simpler. Oh well, on to the last board, the actual display board.

The display board, Figures 10 and 11, is very straight forward. Each of the 3 pair of displays has two CD4511 driver/decoder//latches. The CD4511's are fed from 2716 ROM's programmed to convert the 6 bit NRZ data to 8 bit dual digit BCD as discussed before. The latch command for the CD4511's comes from the digital board 400 milliseconds after the start of the marker pulse. The CD4511's drive common cathode, low current seven segment displays through 270 ohm current limiting resistors. The displays are mounted on special right angle sockets which enable them to be easily seen when the display card is inserted in the display card rack. One change I might yet incorporate is to add switches to unused address bits on the hours 2716 ROM and store different codes at the higher addresses to decode and display the hours as GMT or EST.

This has been a most interesting project. Where does one go from here? I guess the next step is to interface the decoder with a infrared LED source and use the system to update the clock on your VCR every time a Russian navigation satellite passes over.

References:

1. G.E. Perry and C.D. Wood; Identification of a Navigation Satellite System Within the Cosmos Programme, *Journal of the British Interplanetary Society*, Vol. 29 (1976), pp. 307-316.

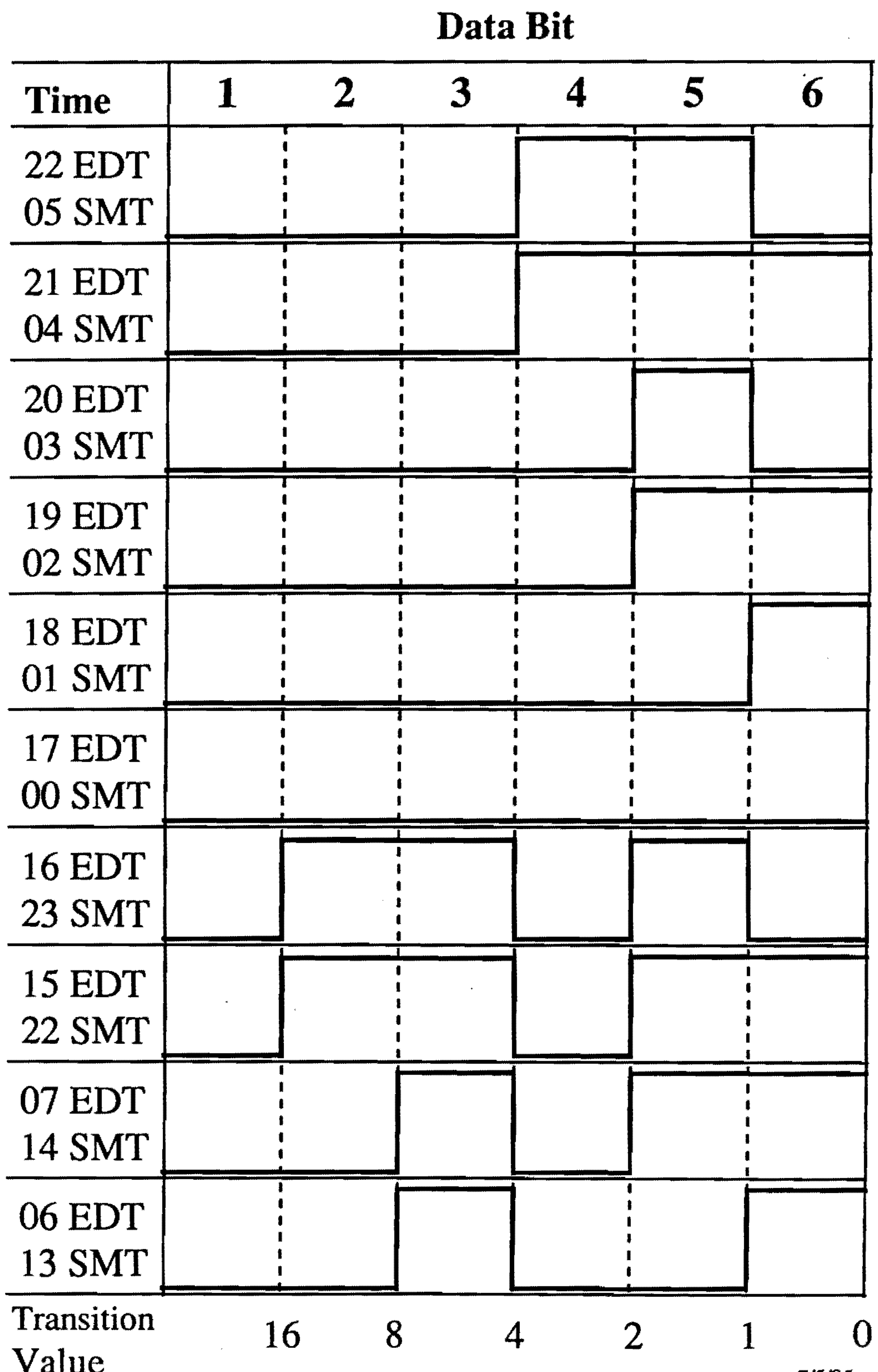
2. C.D. Wood and G.E. Perry; The Russian Satellite Navigation System, *Philosophical Transactions of the Royal Society of London, Series A*, Vol. 294 (1980), pp. 307-315.

3. P. Daly and G.E. Perry; Recent developments with the Soviet Union's VHF satellite navigation system, *Space Communication and Broadcasting*, Vol. 4, No.1, March 1986, pp. 51-61.

4. P. Daly; Cosmos Revisited: the USSR VHF satellite navigation system, *Space Communication and Broadcasting*, Vol. 2 (1984), pp.129-142.

5. Gordon J. Deboo; An RC Active Filter Design Handbook, NASA SP-5104, Technology Utilization Office, National Aeronautics and Space Administration, Washington D.C., 1977.

Table 1: Tsikada Hour Word Decode Check

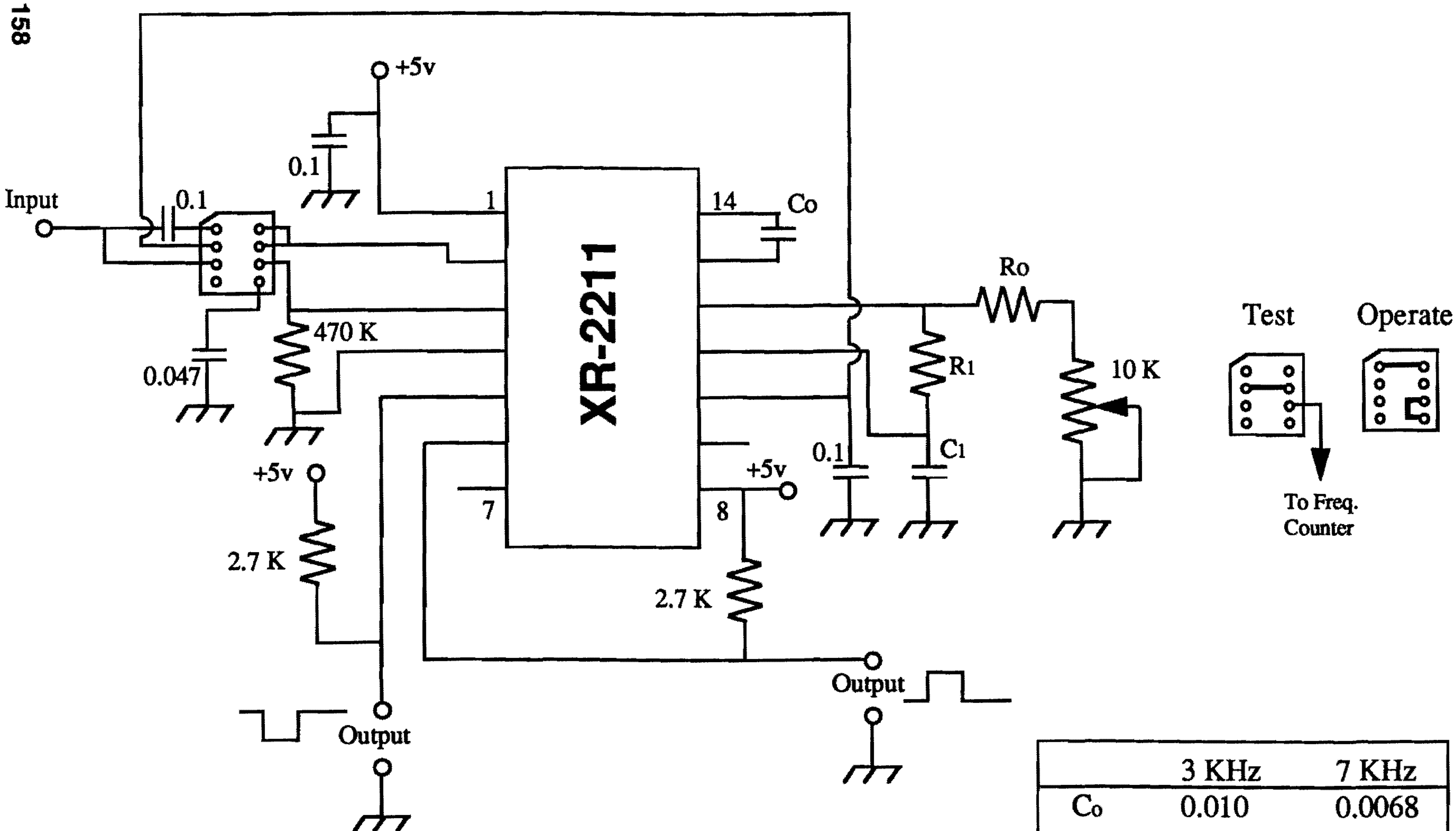


7/5/95

Table 2: Measured 7 kHz Marker Pulse Durations

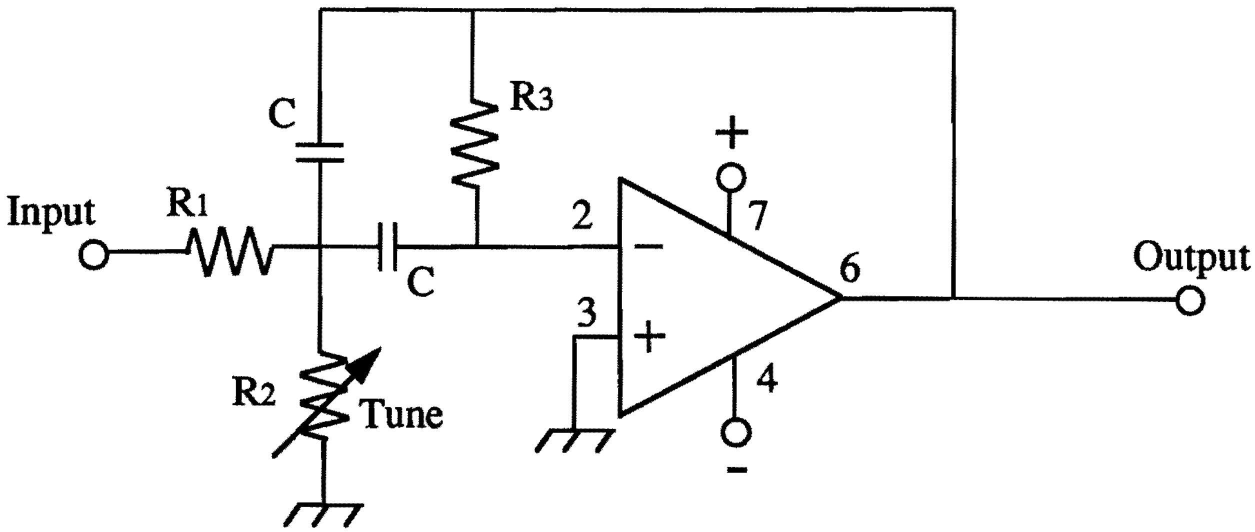
GMT (UK)	EST	EDT	SMT (Moscow)	T(ms) measured	T(ms)-Perry and Wood (Corrected to Moscow Time)
0	19	20	3	80	80
1	20	21	4	60	60
2	21	22	5	60	60
3	22	23	6	60	60
4	23	0	7	60	60
5	0	1	8	40	40
6	1	2	9	40	40
7	2	3	10	40	40
8	3	4	11	40	40
9	4	5	12	40	40
10	5	6	13	40	40
11	6	7	14	40	40
12	7	8	15	40	40
13	8	9	16	20	20
14	9	10	17	20	20
15	10	11	18	20	20
16	11	12	19	20	20
17	12	13	20	20	20
18	13	14	21	20	20
19	14	15	22	20	20
20	15	16	23	20	20
21	16	17	0	*Full	*Full
22	17	18	1	100	100
23	18	19	2	80	80

* $120 \leq T$



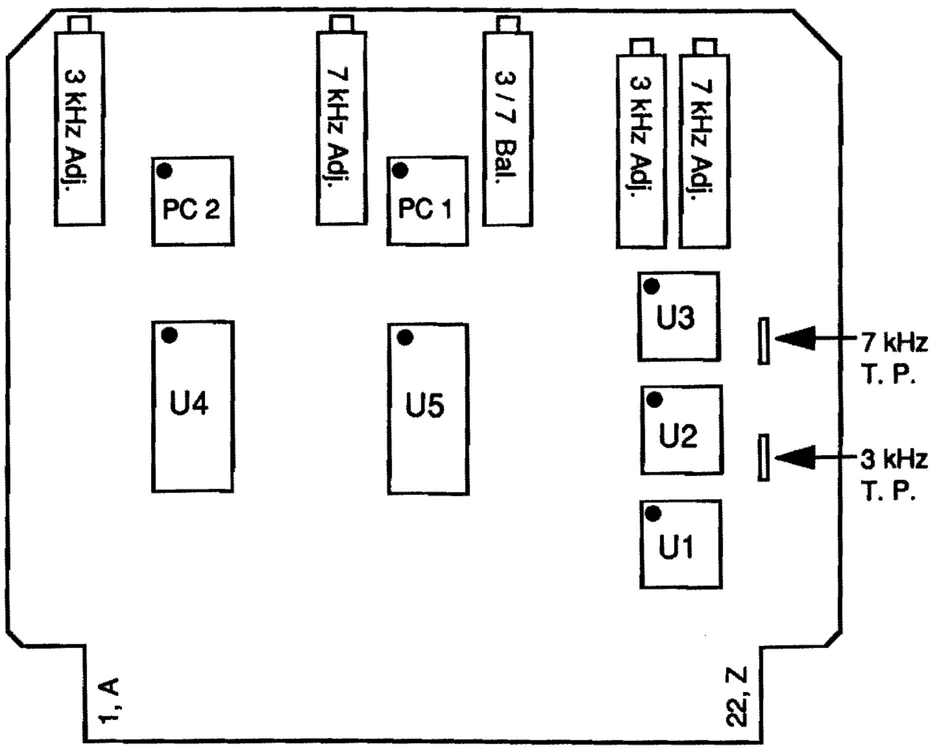
	3 KHz	7 KHz
C_o	0.010	0.0068
C_1	0.0022	0.0022
R_o	27 K	18 K
R_1	120 K	150 K

Figure 1: Tone Detector Schematic



	3 KHz	7 KHz
C	0.1	0.01
R_1	3.3 K	33 K
R_2	44.8	81.4
R_3	6.8 K	68 K

Figure 2: Operational Amplifier Bandpass Filters



U1, U2, U3: 741 or CA3140
U4, U5: XR-2211

Pin	Function
1, A	
2, B	
3, C	
4, D	
5, E	
6, F	3 kHz Det. Output
7, H	
8, J	7 kHz Det. Output
9, K	
10, L	+ 5 Volt Supply
11, M	
12, N	
13, P	
14, R	
15, S	
16, T	
17, U	
18, V	
19, W	-15 Volt Supply
20, X	+15 Volt Supply
21, Y	Signal Input
22, Z	Ground

Figure 3: Filter and Tone Detector Board Layout

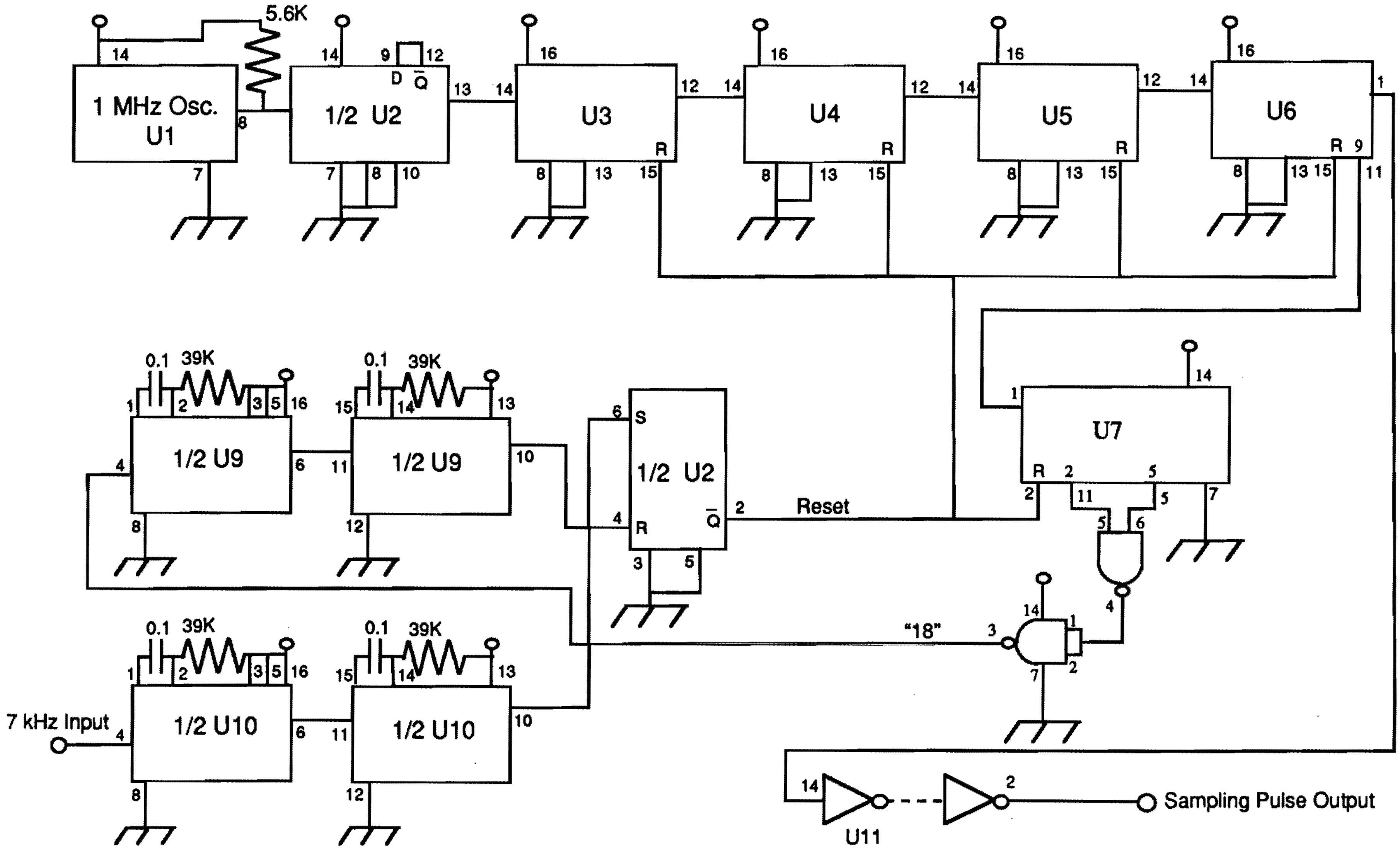
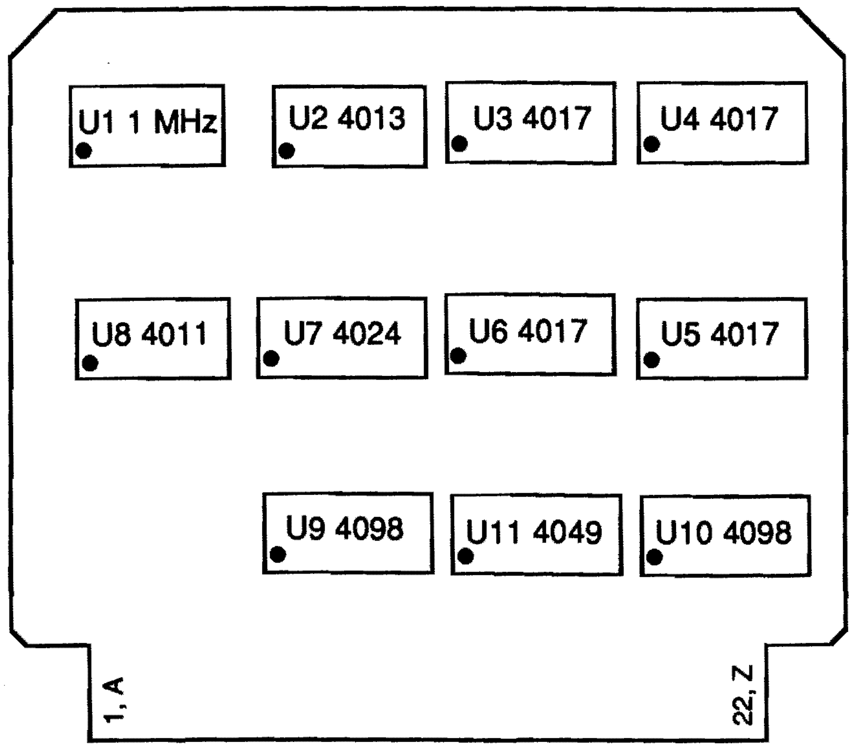


Figure 4: Sampling Pulse Generator Schematic



Pin	Function
1, A	
2, B	
3, C	
4, D	
5, E	
6, F	
7, H	
8, J	
9, K	
10, L	+ 5 Volt Supply
11, M	
12, N	
13, P	Output
14, R	
15, S	
16, T	
17, U	
18, V	
19, W	
20, X	Input Trigger
21, Y	
22, Z	Ground

Figure 5: Sampling Pulse Generator Board Layout

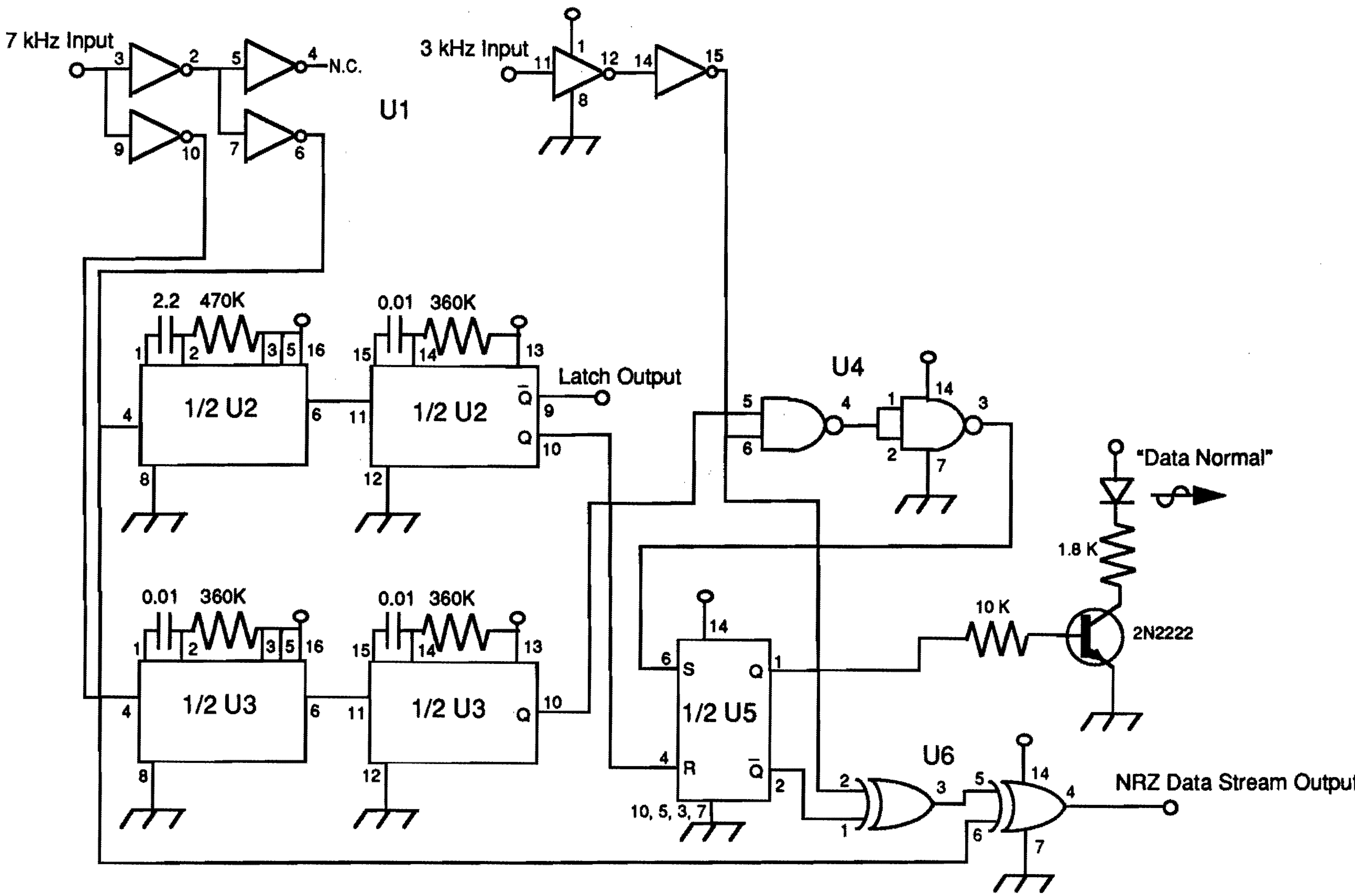
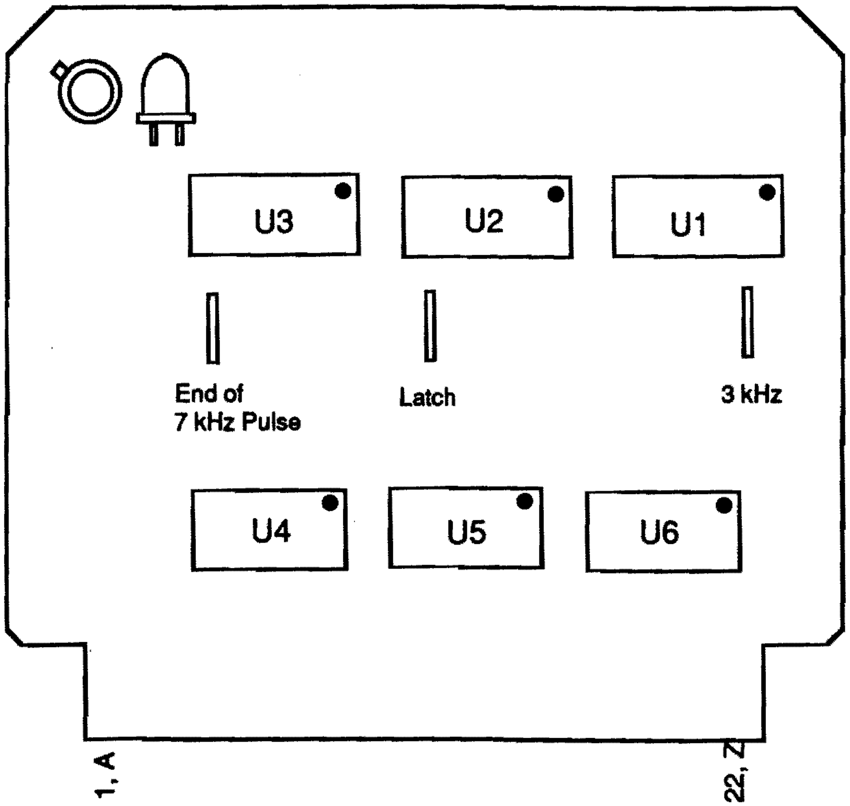


Figure 6: Digital Board Schematic



U1 = CD4049
U4 = CD4011
U6 = CD4070

U2, U3 = CD4098
U5 = CD4013

Pin	Function
1, A	
2, B	
3, C	
4, D	
5, E	
6, F	
7, H	
8, J	
9, K	
10, L	+ 5 Volt Supply
11, M	
12, N	Latch Output
13, P	
14, R	Input, 3 kHz Det.
15, S	
16, T	Input, 7 kHz Det.
17, U	
18, V	Data Stream Output
19, W	
20, X	
21, Y	
22, Z	Ground

Figure 7: Digital Board Layout

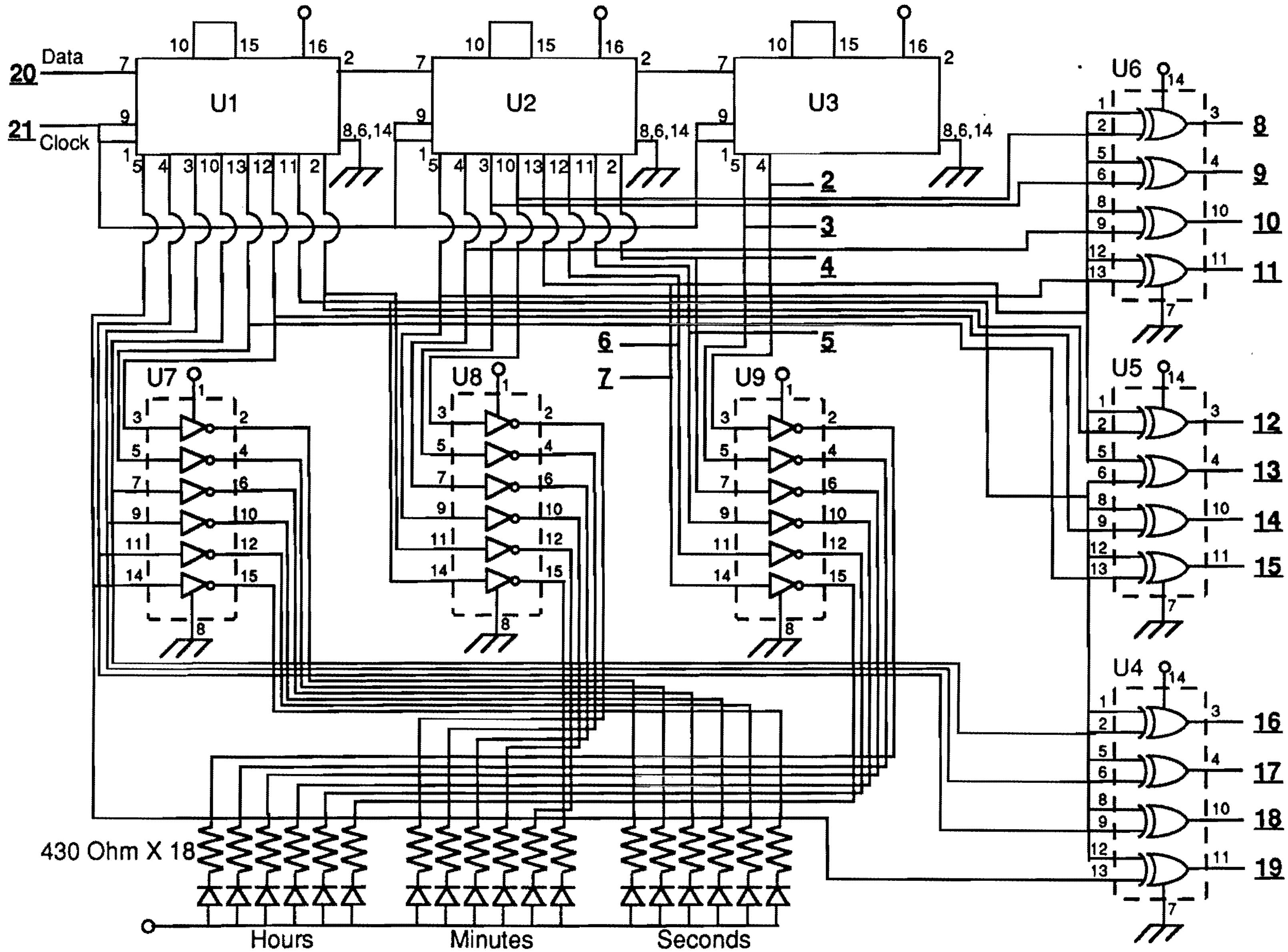
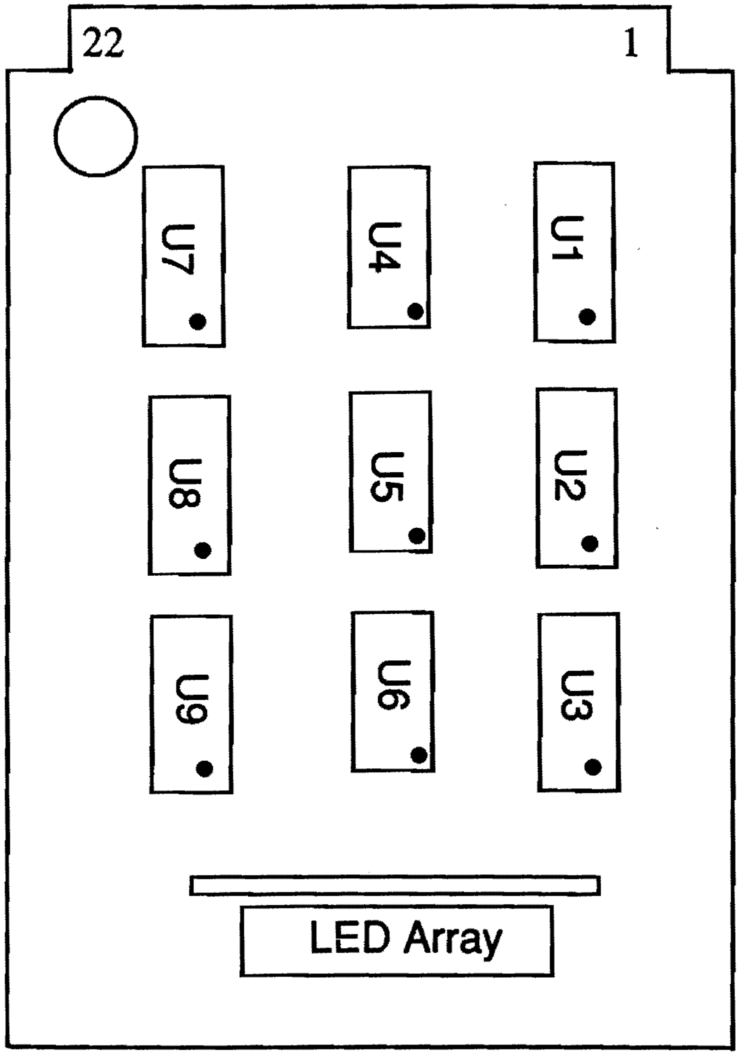


Figure 8: Shift Register Board Schematic



Pin	Function
1, A	Ground
2	Hrs., MSB
3	Hrs.
4	Hrs.
5	Hrs.
6	Hrs.
7	Hrs., LSB
8	Min., MSB
9	Min.
10	Min.
11	Min.
12	Min.
13	Min., LSB
14	Sec., MSB
15	Sec.
16	Sec.
17	Sec.
18	Sec.
19	Sec., LSB
20	Data Stream Input
21	Sampling Pulses Input
22, Z	+ 5 volts

U1, U2, U3 = CD4015
U4, U5, U6 = CD4070
U7, U8, U9 = CD4049

Figure 9: Shift Register Board Layout

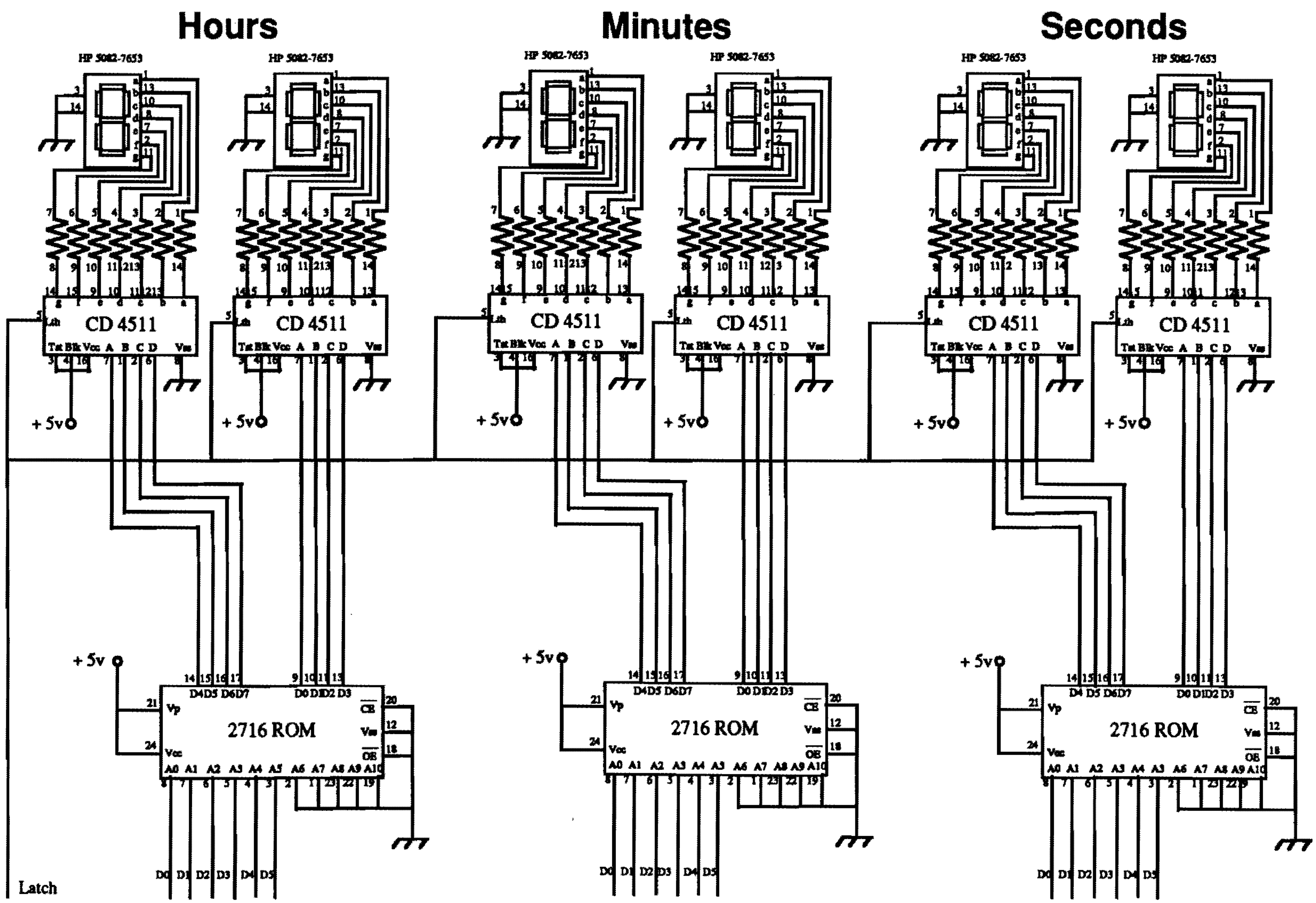
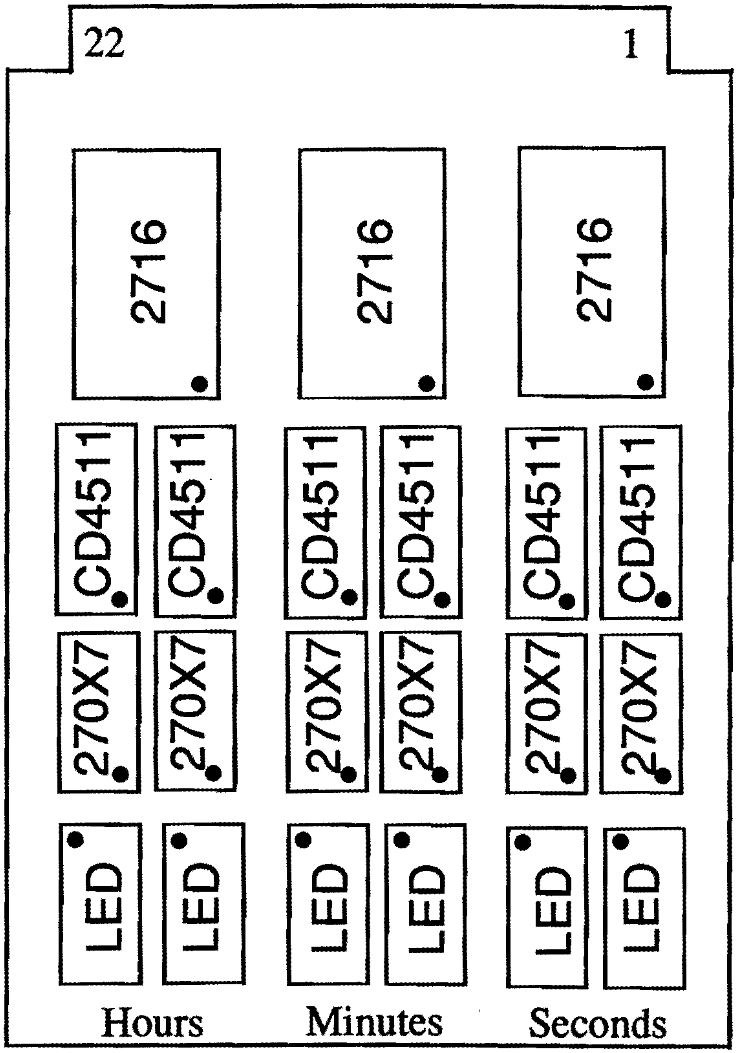


Figure 10: Display Board Schematic



Pin	Function
1, A	Ground
2	Hrs., MSB
3	Hrs.
4	Hrs.
5	Hrs.
6	Hrs.
7	Hrs., LSB
8	Min., MSB
9	Min.
10	Min.
11	Min.
12	Min.
13	Min., LSB
14	Sec., MSB
15	Sec.
16	Sec.
17	Sec.
18	Sec.
19	Sec., LSB
20	
21	Latch
22, Z	+ 5 volts

Figure 11: Display Board Layout and Pinout Charts

1996 AMSAT Annual Meeting and Space Symposium-

Beginners' Forum Papers

AMSAT: A Tutorial for Beginners.

Barry A. Baines, WD4ASW
VP-Field Operations
AMSAT-North America

Introduction

- What is an Amateur Radio Satellite?
- What Types of Satellites Are Operational?
- Tracking
- Sources of Information
- How Do I Get Help?
- Where Do I Go From Here?

What is a Satellite?
Like a Repeater

- Retransmits what it "hears"
- Has Optimized Receivers, Transmitters, Antennas
- Great Location!
- Enables Small Stations to Communicate Over Greater Distances

What is a Satellite?
Unlike a Repeater

- Has A Moving Footprint!
  - Location Changes/Availability Varies
  - Frequency Alteration due to Doppler Shift
- Full Duplex
  - Uplink and Downlink on Different Bands Simultaneously
- Multi-mode (CW/SSB/Digital)
- "World Wide" Coverage

Satellites Utilize "Transponders"

- Receives a SEGMENT of one band
- Retransmits EVERYTHING it hears on another band
- Inverting Transponders
  - Lowest Incoming Frequency is Retransmitted Over the Highest Outgoing Frequency
  - Invert the Signal (USB to LSB)

A Wide Variety of Satellites Exist

- 17 Satellites Currently in Operation
- JAS-2 Will Be Launched in August
- Phase-3D Will be Launched Within a Year
- Other Satellites Under Construction

Satellite Characteristics

- Digital /Analog
- Orbital Parameters
- Frequencies Utilized
- “Payload”

Orbital Parameters

- Eccentricity
- Apogee: Point farthest From Earth
- Perigee: Point closest to Earth
- Inclination relative to the Equator
- Sun Synchronous?
- Keplerian Elements “Describe” the Orbit

Available Satellite Bands

- Bands Exist from 10 Meters to 24 GHz
- 70 CM/Two Meter Often Are Utilized
- Various 'Modes'
  - Combination of Uplinks & Downlinks
- Shift Towards Higher Frequencies
- "Use It or Lose It"

Satellite Categories
EASY Birds

- RS Sats
  - RS-10/11, RS-12/13, RS-15
- Manned Satellites
  - SAREX
  - MIR
- Dual Use
  - FO-20
  - AO-27

Satellite Categories
Digital

• Microsats	UoSats
– AO-16	UO-11
– DO-17	UO-22
– WO-18	KO-23
– LU-19	KO-25
– AO-27	PO-28

Satellite Categories
DX Birds

- Phase 3
  - AO-10
  - AO-13
- Phase-3D

EASY Birds
Manned Satellites

- MIR/SAREX Utilize Packet and Voice
- Listen With HT/Two Meter FM Mobile Equipment
- Two-Way QSO With Low Power/Whip Antenna
- Standard TNC Used for Packet

EASY Birds
RS Satellites

- Low-earth Orbit
  - 15-20 Minute "Window" Each Pass
- Continental USA "Footprint"
- 40 KHz wide analog Transponders
- Access with Simple Ground Stations
- Use Existing HF Equipment
  - Transverter for Two Meters

Digital Satellites

- Primarily Digital "Store and Forward"
  - Orbiting Bulletin Boards
- Some Have CCD Cameras
  - Download Images
- Other Experiments/Applications
  - Sensors

EASY Birds DOVE (DO-17)

- Microsat in Low Earth Polar Orbit
- Utilizes Downlink on 145.825 MHz
- 1200 BPS AFSK AX.25 Packet
- Digital Voice

EASY Birds
Dual-Use Satellites

- Some Satellites Have Both Digital and Voice Capability
- AO-27 Utilizes FM Voice over USA
- 145.85 MHz Uplink/436.80 MHz Downlink

Digital Satellites

- Low Earth Polar Orbits
- Relatively Simple Antennas and Low Power
- Special Modem Requirements
  - 1200 PSK or 9600 DFM
- Special Software to Send/Receive Data
  - PB/PG
  - WISP

Phase 3 Satellites
AO-10/13

- Molnyia Orbit
- Analog Communications
- Mode B (70 CM Up/Two Meters Down)
- Mode S (70 CM Up/ 13 CM Down)
- AO-13 'Demise' Late This Year

Phase 3 Satellites Provide DX Capability

- International Coverage
  - Half Earth "Footprint"
- Due to Elliptical Orbit, Longer Windows (>8 Hours)
- Rise/Set Times Provides for Longer QSO's
- Rise/Set Times Best for Beginners

Phase-3D
Expands the "Envelope"

- Analog/Digital Capability
- All Satellite Bands from 10M to 24 GHz
- Two Transponders Operational at One Time
- Sun Synchronous Orbit
- 16 Hour Window
- High Power Budget
- SCOPE Cameras
- Constant Antenna Pointing
- GPS Experiment

Satellite Tracking

- Need to Predict Future Satellite Position
- Keplerian Data Available through PBBS, BBS, Digisats, Internet Sites
- AMSAT Has Tracking Software for Most Platforms
- Control of Rotors and Radios through Interface

Sources of Information

- Books
- Periodicals
- Internet Sites
- Area Coordinators

General Information Books

- How to Use Amateur Radio Satellites
- ARRL Handbook
- ARRL Satellite Anthology
- Satellite Experimenter's Handbook
- Mode S: The Book

AMSAT Books for Specific Satellite Types

- RS Satellites Operating Guide
- Beginner's Guide to OSCAR 13
- AMSAT-NA Digital Satellite Guide
- Decoding Telemetry from Amateur Satellites
- Phase-3D Book Under Development

Periodicals
Amateur Satellite Columns

- CQ Magazine
- CQ/VHF Magazine
- QST
- 73 Magazine
- Satellite Times
- Worldradio
- Digital Journal

Periodicals
Amateur Satellite Publications

- AMSAT Journal
  - Bimonthly
- OSCAR Satellite Report
  - Biweekly Newsletter
- Satellite Operator
  - Monthly

E-Mail Resources from AMSAT

- AMSAT News Service
- KEPS (Keplerian Data)
- AMSAT-BB
- NASAINFO
- SAREX
- Sent to your Internet E-mail Address
  - Subscribe via listserv@amsat.org

Other E-Mail Resources

- ARRL Mail Server
- Ham-Space Digest
  - News Group rec.radio.amateur.space
- Space News from KD2BD
- Packet Bulletins
  - ANS /Space News/Keplerian Elements

FTP Resources

- ftp.amsat.org
- ftp.tapr.org
- oak.oakland.edu

World Wide Web Resources

- http://www.amsat.org/
- http://www.arrl.org/
- http://www.tapr.org/
- http://gndstn.sp.nps.navy.mil/
- http://www.grove.net/~tkelso/
- http://www.accessone.com/~emunger/KA7LD/

How Do I Get Help?

- Local Satellite Operators
- AMSAT Field Organization
- E-Mail (AMSAT-BB)
- Hamfest Forums
- AMSAT Exhibits

AMSAT Field Organization

- Area Coordinators: AMSAT Ambassadors
- 160 Volunteers in USA and Canada
- 75% Use E-Mail
- Have Knowledge/Get Answers
- Area Coordinator List Available

Where DO I Go From Here?

- Visit the AMSAT Booth
- Contact an AMSAT Local Area Coordinator
- Request a Club Satellite Presentation
- Check out the WD4ASW Gateway Node
  - c wd4asw via k4ubr-7 904026 (Clay)
  - landline 904-396-7114

JOIN AMSAT
Membership Benefits

- AMSAT Journal
- How To Use Amateur Radio Satellites
- Frequency Chart for Amateur Satellites
- Current Keplerian Data Sheet
- Support the Program!

For More Information

- AMSAT-North America

  P.O. Box 27

  Washington, DC 20044-0027

  tel. (301) 589-6062

- Barry A. Baines, WD4ASW

  e-mail: wd4asw@amsat.org

  tel. (904) 398-5185

Keplerian Element Fundamentals

Ken Ernandes, N2WWD

INTRODUCTION

Keplerian elements are the primary orbital description used for amateur satellite tracking. A Keplerian *element set* provides a mathematical model of a satellite's orbit. Using standard orbital prediction algorithms, satellite tracking software can compute past, current, and future positions (and velocities) for the satellite. This paper provides an overview of: orbital flight dynamics, the types of Keplerian element data commonly available, and how to use this data for orbital prediction.

Key terms are defined in the appendix. You are encouraged to refer to this section if you encounter an unfamiliar term or unclear concept.

SATELLITE TRACKING

Satellite tracking is any activity in which the position or flight progress of an orbiting object is monitored. Tracking is used for visual observation, active or passive radio communication, or simply following the current location and ground track of the satellite.

The two most common tracking activities are: satellite *pass predictions* and *real-time* satellite tracking.

Pass predictions are, in their most basic form, determinations of times when the satellite will have a clear line-of-sight with a specific location on the surface of the Earth (usually a ground station). Pass predictions may also be further filtered by additional constraints such as times in which the satellite is operating within certain frequency bands or modes (amateur radio satellites) or when the satellite is in the sunlight and the observer is in the darkness (i.e., twilight for visual tracking).

Real-time satellite tracking is monitoring where the satellite is now and where it is going. Information derivable from real-time tracking includes *azimuth* and *elevation* antenna pointing angles and the determination of the *Doppler shift* on communication frequencies caused by satellite motion.

The most common tool is a computer using software designed for satellite tracking. AMSAT has a good selection of graphic- and tabular-based satellite tracking software, each one designed to operate on one of the popular types of desktop or portable computers. There is also a significant selection of professional and shareware satellite tracking software available. These programs usually use Keplerian elements to mathematically describe satellite orbits.

KEPLER'S LAWS

Keplerian elements are named for Johannes Kepler who first characterized orbital motion with three basic laws. Kepler's laws may be paraphrased as follows:

First Law: *A satellite's orbit is an ellipse, with the major attracting body at one focus of the ellipse* (see figure 1).

Second Law: *A line drawn from the major attracting body to the satellite sweeps out equal areas in equal intervals of time* (see figure 2).

Third Law: *The square of the orbital period is proportional to the cube of the semimajor axis of the orbital ellipse.*

While Kepler's laws came from observing planetary motion, these laws are derivable mathematically. Deriving Kepler's laws mathematically requires knowledge that gravitational force follows an inverse square law; the gravitational inverse square law was discovered by Isaac Newton.

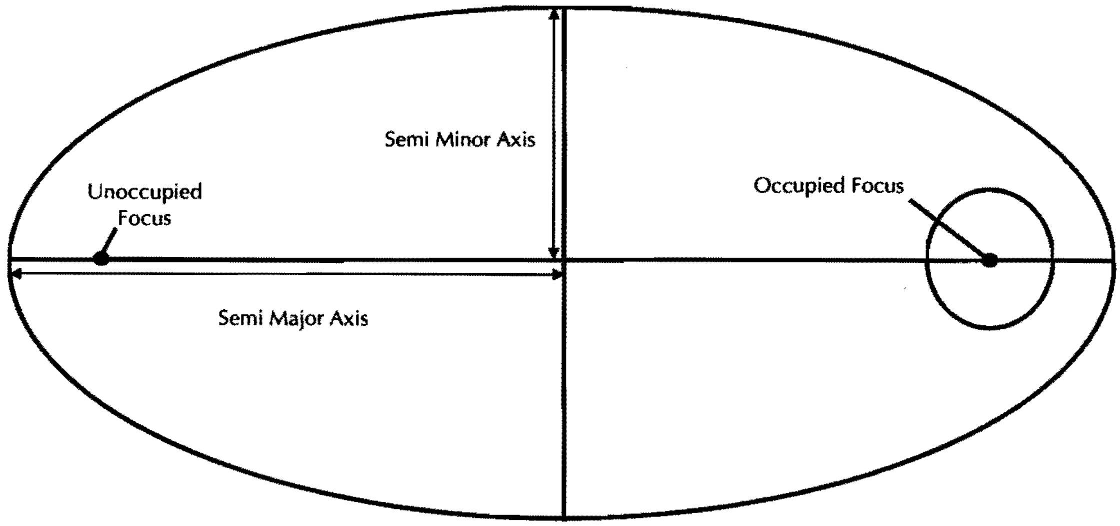
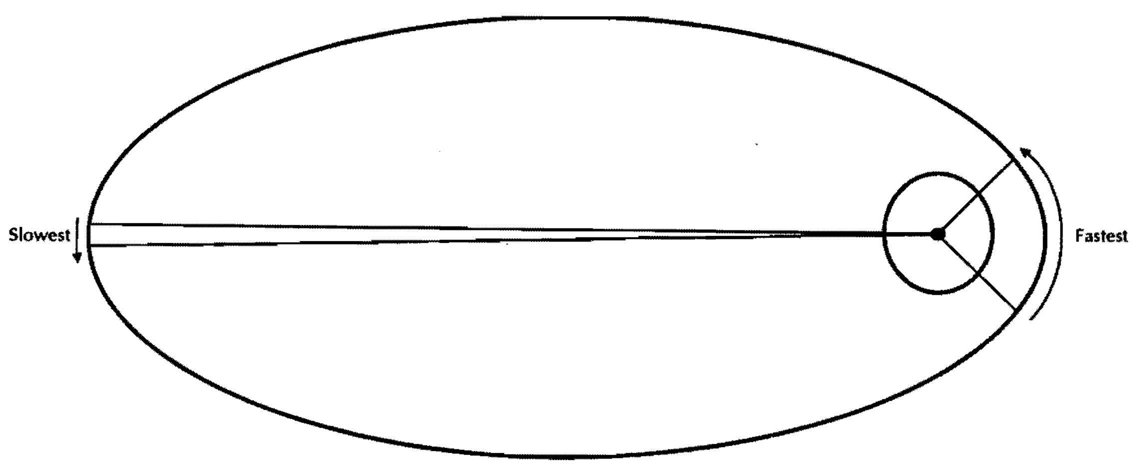


Figure 1., Orbital Ellipse Components

Kepler's Second Law is a direct consequence of the physical law of conservation of angular momentum. Conservation of angular momentum is the phenomenon that causes ice skaters to rotate faster when they pull in their arms and rotate more slowly when they extend their arms outward.

ELEMENT DESCRIPTIONS

Keplerian elements physically describe a satellite's orbit in terms of: (1) the *Size* and *Shape* of the orbital ellipse, (2) the *Orientation* of the orbital ellipse with respect to the Earth, and (3) a "snapshot" *Position* of the Satellite at a specified *Epoch Time*. Figure 3 illustrates the physical relationships of the Keplerian elements.



Satellite moves fastest at lower altitudes; slower at higher altitudes: a consequence of conservation of angular momentum.

Figure 2., Illustration of Kepler's Second Law

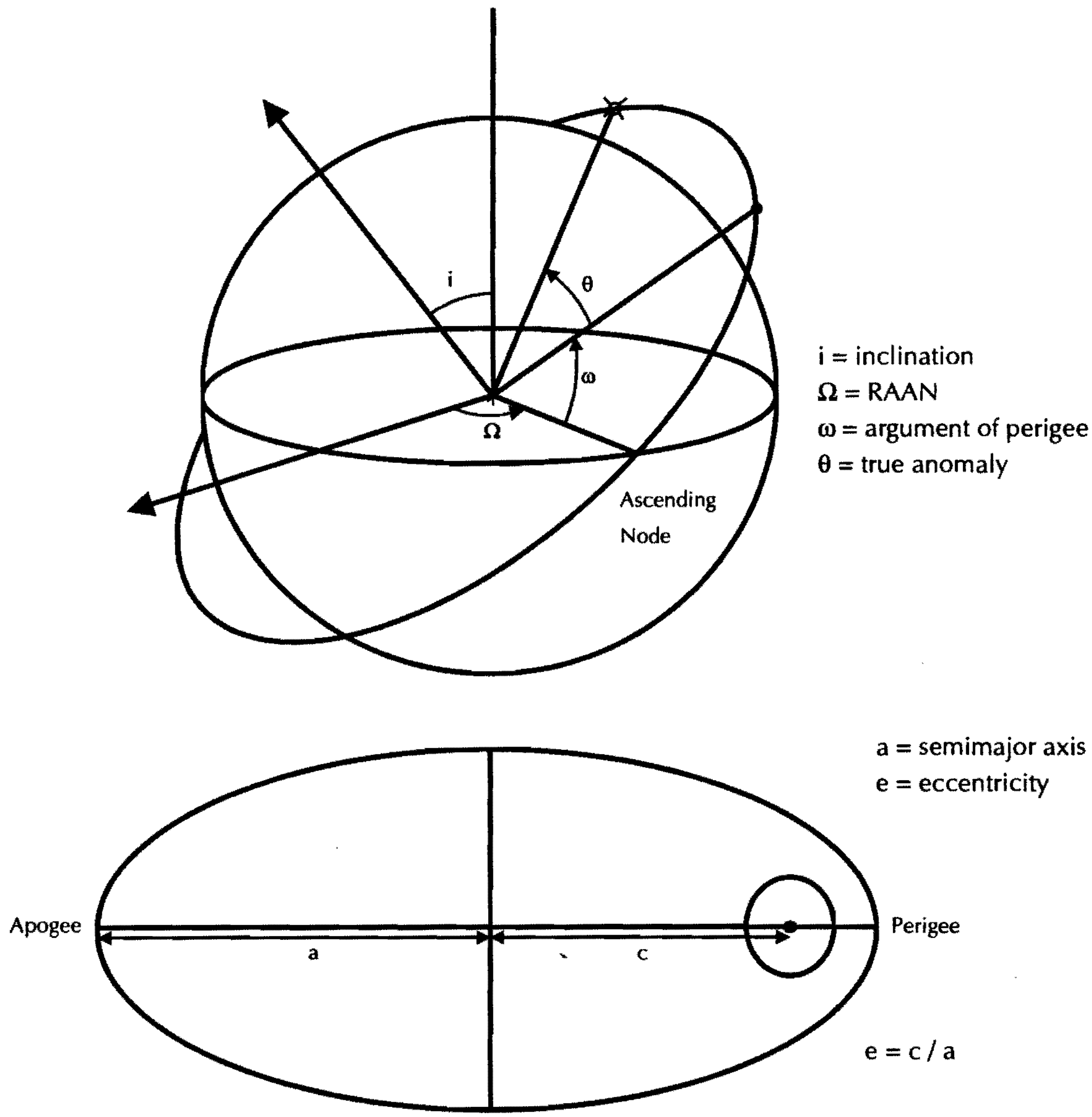


Figure 3., Keplerian Elements Illustration

ORBITAL SIZE AND SHAPE

The size and shape of the orbital ellipse are traditionally described by the semimajor axis and eccentricity.

Using Kepler's Third Law, the orbital *Period* (i.e., the time to complete one orbit around the Earth) can be computed from the semimajor axis. Thus, the orbital period can be used as an alternate description of the size of the orbit. More commonly, the *Mean Motion* (i.e., the orbital frequency in revolutions per day) is used to describe the size of the orbit. The mean motion is computed from the reciprocal of the orbital period.

The shape of the orbit is described by the *Eccentricity* of the ellipse. Eccentricity is the deviation of the ellipse from a circle. An orbit with a zero (or nearly zero) eccentricity is circular; as eccentricity *approaches* 1.0 the orbit's shape becomes more elongated or eccentric.

When the orbital size and shape are known, the maximum and minimum altitudes of the orbit can also be computed. The maximum orbital radius is called *Apogee*; the minimum orbital radius called *Perigee.*

ORBITAL ORIENTATION

Because of conservation of angular momentum, all orbital motion is within a plane. The orientation of the orbital plane is described by the *Inclination* and *Right Ascension of the Ascending Node* (RAAN).

The inclination is an angle that defines the "tilt" of the orbital plane with respect to the equator. An orbit with a zero inclination over-flies the equator in the direction of Earth rotation. This is called an equatorial orbit. An orbit with a 90 degree inclination over-flies both the north and south poles and therefore is called a polar orbit. The inclination angle specifies the greatest north and south latitudes over which the satellite will directly over-fly.

Orbital inclinations greater than 90 degrees move against the Earth's rotational motion. These are called retrograde orbits (as opposed to prograde orbits which have a less than 90 degree inclination). Few satellites have a retrograde orbit because launching against Earth rotation is expensive. If an orbit has a retrograde inclination, the maximum latitudes over which the satellite will over-fly is the inclination's supplementary angle.

The orbit's *ascending node* is the position at which the satellite crosses the equator, moving from south to north. This position is measured from the *Vernal Equinox,* which is the Sun's ascending equatorial crossing (that marks the beginning of spring in the northern hemisphere). Specifically, the right ascension of the ascending node is the angle measured eastward from the Vernal Equinox to the orbit's ascending node.

The orientation of the orbit's apogee-perigee line is defined within the orbital plane. The *Argument of Perigee* is the angle measured in the direction of satellite motion from the ascending node to perigee. If the argument of perigee is between 0 and 180 degrees, perigee is in the northern hemisphere and apogee is in the southern hemisphere. Likewise, if the argument of perigee is between 180 and 360 degrees, perigee is in the southern hemisphere and apogee is in the northern hemisphere.

ORBITAL POSITION

Location of the satellite at a specified time completes the orbital description. *The True Anomaly* is the angle measured in the direction of satellite motion from perigee to the satellite's position at the *Epoch Time.* Since satellite speed varies from fastest at perigee to slowest at apogee, the rate of change of true anomaly varies with time. The *Mean Anomaly* is the abstract counterpart of true anomaly, assuming a perfectly circular orbit of equal semimajor axis. Mean anomaly is used instead of true anomaly in Keplerian element sets since it has a constant rate of change (i.e., is linear with time). This constant rate makes it easy to compute satellite positions at any desired time.

The Keplerian elements' epoch may be any arbitrary time, though it often describes the time of an ascending node. Since the epoch time usually occurs near the end of the data span for the orbital fit, it provides an excellent indication of how current are the Keplerian elements.

The format of epoch time is not intuitively obvious. The first two digits are the year (96 = 1996) and the next three digits are the sequential day of the year (001-366 with January 1 being 001, etc.). Following the decimal point is the fractional portion of the day representing time.

NON-KEPLERIAN MOTION

In the absence of any external forces, a Keplerian element set could predict a satellite's positions and velocities indefinitely. However, there are external forces in the local space environment that change orbits over time. The forces that cause deviations from Keplerian motion are known as *Perturbations*.

The primary perturbative forces are: atmospheric drag, non-spherical Earth gravitation, and third body gravitational attraction from the Sun, Moon, and other planets.

Atmospheric drag primarily affects satellites at low altitudes; the strongest drag effects occur at altitudes below 500 kilometers. Drag affects satellites with low cross-sectional densities more so than satellites with high cross-sectional densities. The drag slows the satellite down slightly, which causes a decrease in altitude over time. Drag is sometimes represented in Keplerian elements by half the rate of change of mean motion called *Ndot/2* or *Decay Rate*. Drag may also be represented in Keplerian elements by a pseudo ballistic coefficient called *Bstar*. Since drag modeling is only an approximation, orbits subject to significant drag require frequent updates of the Keplerian elements.

The Earth is not a perfect sphere, so the gravitational field does not follow a uniform inverse square law. The most significant gravitational perturbations result from the concentration of mass around the equator (equatorial bulge). This mass concentration applies torque to the orbit. The torque causes drift to both the right ascension of the ascending node (RAAN) and the argument of perigee. Both of these effects are quite predictable and corrections for the drift rates are accomplished automatically by the orbital prediction algorithms. You may notice the changes to these Keplerian elements if you review old and new element sets side-by-side.

The RAAN drift rate (nodal regression) depends primarily on the orbit's semimajor axis and inclination. Nodal regression is highest for low inclination orbits and is zero for exactly polar orbits. Figure 4 is a plot of nodal regression rates versus inclination for some sample orbital altitudes.

The argument of perigee drift rate (apsidal rotation) also depends primarily on semimajor axis and inclination (see figure 5). Once again the drift rate is greatest for low inclination orbits. The zero drift balance point occurs at a critical inclination of approximately 63.4 degrees. This inclination is very popular for highly eccentric orbits since the apogee and perigee can be maintained in a constant orientation.

In order to accommodate the modeling of the Earth's gravitational perturbations, it is standard practice to use the *mean* values of the Keplerian elements rather than the instantaneous physical parameters (known as the *osculating* elements).

Gravitational attractions by the Sun, Moon, and other planets have significant long-term effects for high altitude orbits. These are more difficult to predict than are other perturbations, but there are some orbital prediction models that take these effects into account. However, the effects are relatively slow and can be countered by reasonably frequent updates of the Keplerian elements.

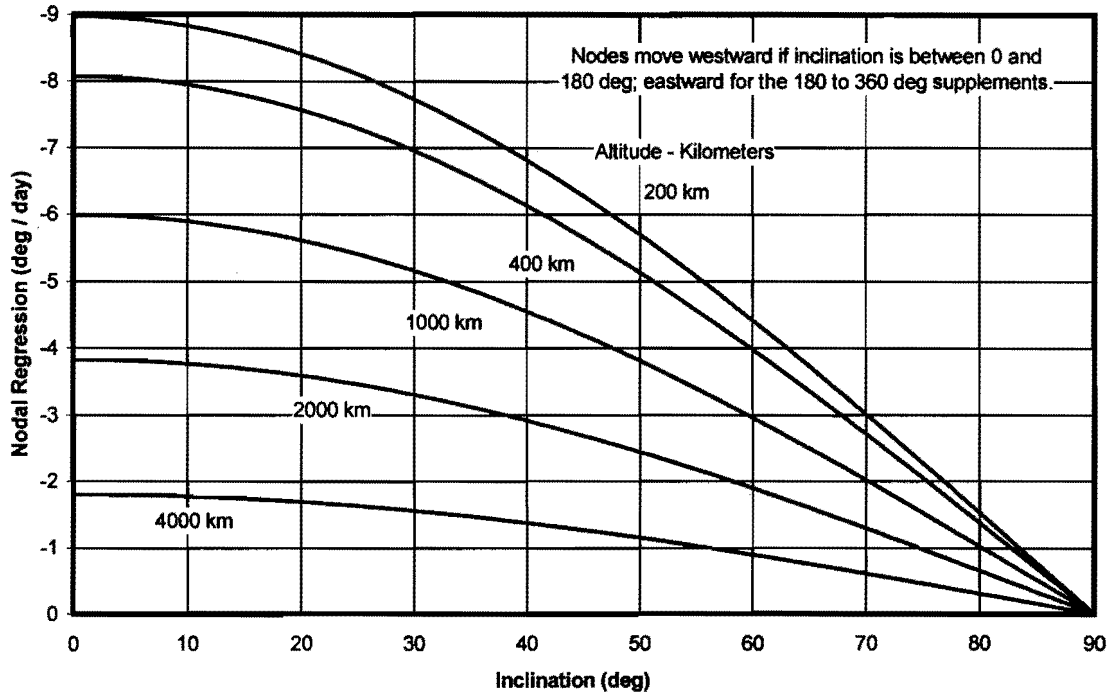


Figure 4., Perturbative Nodal Regression Rate

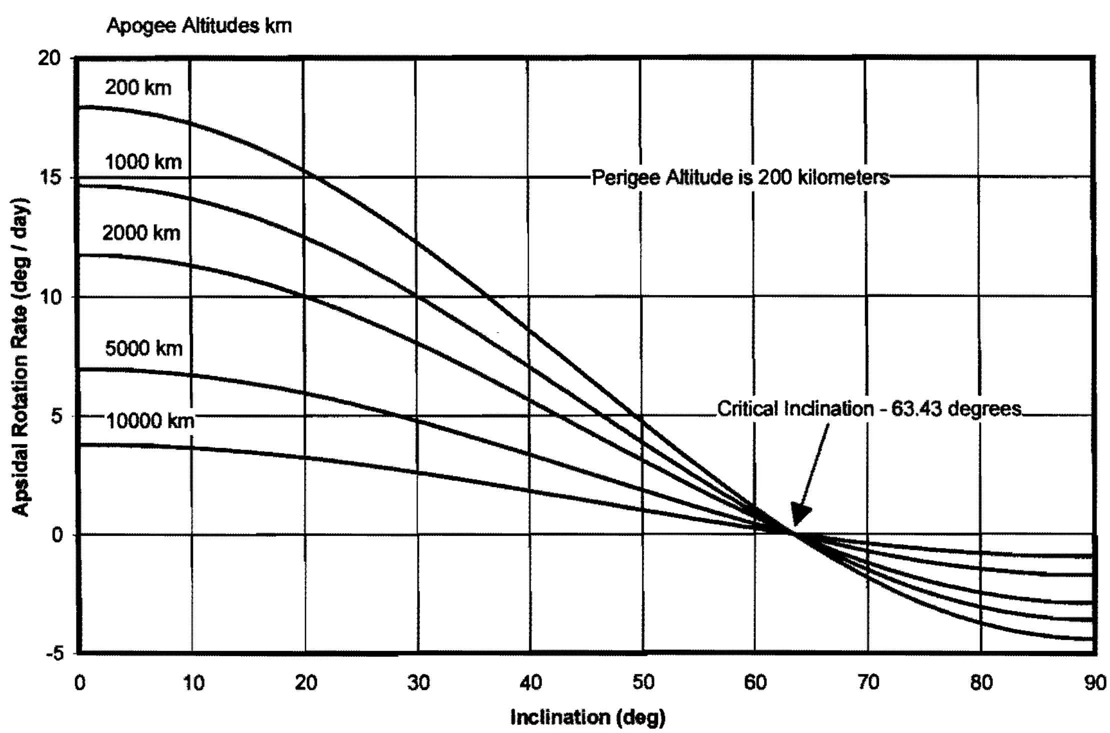


Figure 5., Perturbative Apsidal Rotation Rate

Augmented NORAD/NASA *Two-Line Element (TLE)* Format:

International Designator, Epoch Time, Ndot/2, Nddot/6, Bstar, Element Set #

```
STS-78
1 23931U 96036A   96182.50020602  .00092026  35242-7  14266-3 0   347
2 23931  39.0142 303.7075 0006937 341.9766 236.3355 16.03034716  1598
```

Catalog Number, Inclination, RAAN, Eccentricity, Argument of Perigee, Mean Anomaly, Mean Motion, Epoch Rev, Checksums

AMSAT Keplerian Format:

```
Satellite: STS-78
Catalog number: 23931
Epoch time:      96182.50020602
Element set:      34
Inclination:       39.0142 deg
RA of node:       303.7075 deg
Eccentricity:    0.0006937
Arg of perigee:   341.9766 deg
Mean anomaly:     236.3355 deg
Mean motion:   16.03034716 rev/day
Decay rate:    9.20265e-04 rev/day^2
Epoch rev:             159
Checksum:              291
```

Figure 6., Keplerian Element Formats

DATA FORMATS

Keplerian elements come in two basic data formats: the NORAD/NASA Two-Line Elements (TLEs) and the more verbose AMSAT format. A comparison of the two formats is in figure 6.

An important item to note when looking at Keplerian elements is that all satellites have a unique five digit Catalog Number. These numbers are assigned sequentially (satellite #00001 being Sputnik 1's upper stage rocket body). The catalog number is an unambiguous identifier when locating the Keplerian elements for a particular satellite.

The TLE format is a relic of the early Cold War. One important application of satellite tracking for the North American Aerospace Defense Command (NORAD) was to ensure that a radar whose job it was to detect incoming ballistic missiles, did not trigger a false alarm when tracking a satellite. NORAD's space surveillance activity began maintaining Keplerian elements for all Earth-orbiting objects in order to provide the ballistic missile warning radar's with the ability to immediately identify any satellite they were tracking. Part of this process required that the radar's provide the tracking data to NORAD from which they could update the Keplerian elements.

The data communications equipment of the early Cold War (teletype) was slow. Hence the two-line format packs a lot of data into very few characters for communications efficiency. The two-line format used by amateurs is typically augmented with a third (prefix) line identifying the satellite by its common name.

The advantage of the AMSAT format is readability. Each parameter is clearly labeled, so the user can get an idea of what the orbit looks like. The AMSAT format contains most of the same data as the augmented two-line format. The exceptions are the lack of the Bstar and Nddot/6 drag terms. Nddot/6 is usually zero and otherwise is generally insignificant. Bstar may be derived mathematically from Ndot/2 (decay rate) as is done by some tracking software.

Most satellite tracking software can read and update the two-line and/or the AMSAT Keplerian formats automatically.

UPDATE INTERVALS

As indicated in the section on non-Keplerian motion, the inability to exactly model perturbations requires that the elements be updated at regular intervals. The first recommendation on update intervals is to use the most current Keplerian elements that are readily available. It cannot hurt to update the Keplerian elements more frequently than necessary, but using elements that are too old can result in frustrating tracking inaccuracies.

The update intervals provided in this section are rules of thumb. They are intended to define the maximum update intervals for automatic antenna tracking and/or automatic Doppler correction. Should these intervals be too long to accommodate a particular orbit, then feel free to update the Keplerian elements more frequently (i.e., use what works).

The Space Shuttle's orbit is the most critical in terms of update frequency since the Shuttle makes frequent orbital changes. It is not unusual for the Space Shuttle to use its thrusters to make several orbit changes in one day. For a typical Shuttle mission, the Keplerian elements should be updated at least once per day. If you are planning a SAREX contact, you should ensure that no orbital changes occurred since the epoch time of your most current Keplerian elements.

Low altitude orbits (i.e., below 500 km) require relatively frequent updates because of atmospheric drag. The maximum recommended update interval for orbits below 500 km is seven days. If an orbit is elliptical and some portion of it is below 500 km, its Keplerian elements should also be updated every seven days if not sooner.

Medium altitude orbits (i.e., between 500 and 2000 km) should typically be updated every 14 days. High altitude orbits (i.e., greater than 2000 km) should be updated every 30 days.

DATA SOURCES

The good news is that there are more places to get Keplerian elements than can be conveniently listed in this paper. Therefore, I shall provide details only for the sources provided by AMSAT including: Packet Radio, Internet E-Mail, and the Internet World-Wide Web. In addition to these sources, data is also available directly from NASA Internet resources and private dial-up BBS's.

Keplerian elements are posted in files on many packet radio sites, specifically AMSAT sites. To get listings of Keplerian element messages on an AMSAT packet site, enter the following command:

L> KEPS

The Keplerian element files generally are labeled with a three-digit sequential day-of-year identifier, indicating the age of the data.

Frequent updates of Keplerian elements for SAREX missions are also posed on AMSAT packet sites. To get a message listing for SAREX Keplerian elements, enter the following command:

L> SAREX

Keplerian elements are also available by direct Internet E-Mail subscription from AMSAT. To obtain to this service, send a message with the text: "subscribe KEPS" to: listserv@amsat.org (Internet address).

Keplerian elements are also available from the AMSAT World Wide Web site. The Uniform Resource Locator (URL -- i.e., address) for the AMSAT Web site is:

http://www.amsat.org/

The URL for the current amateur radio satellite Keplerian elements is:

http://www.amsat.org/amsat/keps/menu.html

The URL for Space Shuttle Keplerian elements (pre-launch and during a mission) is:

http://www.amsat.org/amsat/sarex/orbit.html

SUMMARY

By this point you should be familiar with the basic concepts of orbital flight dynamics and how a satellite's orbit is described by Keplerian elements. You should also be aware that satellites do not orbit with perfect Keplerian motion, since there are external perturbing forces. While details of the mathematics involved are interesting to some, most amateurs rely on computers and tracking software to do orbital computations and perturbations modeling.

In order to get accurate predictions from satellite tracking software, you must update your Keplerian elements on a regular basis with current data. Current Keplerian elements are readily available from AMSAT and other sources.

GLOSSARY OF KEY TERMS

This section provides definitions of key terms used in this paper. The terms are organized alphabetically.

AMSAT - The Radio Amateur Satellite Corporation.

AMSAT Format - the verbose Keplerian element format established by AMSAT. AMSAT format has most of the data contained in Two-Line Elements and has the advantage of readability since the parameters are clearly labeled.

Apogee - an orbit's maximum distance from the Earth's center.

Apsidal Line - an orbit's apogee-perigee line.

Apsidal Rotation - rotation of an orbit's apogee-perigee (apsidal) line. Natural apsidal drift occurs from perturbations caused by the Earth's non-uniform gravitational field.

Argument of Perigee - the angle measured from an orbit's ascending node to perigee, in the direction of orbital motion.

Ascending Node - an orbit's south-to-north equatorial crossing point.

Azimuth - a bearing to a satellite in the observer's local horizontal plane. Azimuth is an angle measured clockwise from True North with values ranging from 0 to 360 degrees.

Bstar - a pseudo ballistic coefficient that is an alternative to the Ndot/2 drag parameter.

Catalog Number - the unique 5-digit satellite identifier. Catalog numbers are assigned sequentially and are an unambiguous means of identifying a satellite in a Keplerian element set.

Checksum - an additive (or modulo 10) sum of digits (and "-" symbols) used for detecting corrupted Keplerian elements.

Critical Inclination - the inclinations (64.4 and 116.6 degrees) in which there is no perturbative apsidal rotation. This is the zero "balance" point for natural apsidal drift.

Decay Rate - the drag parameter in AMSAT format Keplerian elements. This is the same as Ndot/2 in the Two-Line Elements.

Doppler Shift - a frequency shift caused by a relative velocity between a satellite and an observer. This is the same effect as heard by the change of a passing train's whistle pitch.

Eccentricity - a dimensionless parameter expressing the elongation of an ellipse (or its relative deviation from a circle). A circle has zero eccentricity; eccentricity may come close to, but is always less than one.

Element Set Number - the sequential number for a Keplerian element set.

Elevation - the angle a satellite makes above (or below) the observer's local horizon.

Ellipse - a geometric figure resembling an elongated circle. A circle viewed at an oblique angle will appear elliptical.

Epoch Time - the time associated with true anomaly. Epoch time is also an indicator of the age of the Keplerian elements.

Focus - one of two geometric reference points on an ellipse's major axis. The sum of the distances from the focii to all points on the ellipse is equal to the major axis.

Inclination - the tilt angle of the orbital plane when measured against the equator.

International Designator - An satellite identifer that is an alternative to Catalog Number and Common Name. Format is: YYLLLPPP (YY = Launch Year; LLL = Sequential Launch Number for Year; PPP = Sequential Piece ID for this Launch).

Keplerian Elements - a mathematical description of an orbit that also provides a physical picture of the orbit.

Mean Anomaly - the abstract counterpart of true anomaly, assuming a circular orbit of equal semimajor axis. The advantage of mean anomaly is that it has a constant rate (i.e., varies directly with time).

Mean Elements - the mean values of an orbit's Keplerian elements after subtracting the perturbative variations to the osculating elements.

Mean Motion - The orbital frequency usually in units of revolutions (orbits) per day.

NASA - National Aeronautics and Space Administration.

Ndot/2 - one half the rate of change of mean motion, generally due to atmospheric drag. This ultimately provides an orbital decay rate because of the relationship between semimajor axis and period and mean motion in Kepler's third law.

Nddot/6 - one third the rate of change of Ndot/2. This parameter is usually insignificant (i.e., zero or nearly zero).

Nodal Regression - a perturbative drift in an orbit's ascending node caused by the Earth's non-uniform gravitational field.

NORAD - North American Aerospace Defense Command.

Osculating Elements - the exact physical Keplerian elements for a given instant of time. Osculating elements vary over time because of perturbations.

Perigee - an orbit's minimum distance from the Earth's center.

Right Ascension of the Ascending Node (RAAN) - the angle measured eastward from the Vernal Equinox to an orbit's ascending node.

Period - The time it takes for a satellite to make one complete orbit of the Earth.

Perturbations - natural external forces that cause changes to a satellite's orbit over time.

Prograde - an orbit whose general motion is in the direction of Earth rotation (i.e., eastward).

Retrograde - an orbit whose general motion is opposite the direction of Earth rotation (i.e., westward).

Revolution Number - the sequential orbit number (since launch) in a Keplerian element set. This is an excellent indicator of the age of an element set.

SAREX - Shuttle Amateur Radio Experiment. An amateur radio payload carried on many Space Shuttle missions that allows students and radio amateurs communication with astronauts on orbit.

Semimajor Axis - one half of the longest distance across an ellipse (i.e., half the major axis).

Tracking, Satellite - any activity in which the position or flight progress of an orbiting object is monitored.

True Anomaly - the angle measured from perigee to the satellite's position at a specified epoch time. True anomaly is measured in the direction of orbital motion.

Two-Line Elements (TLEs) - Keplerian elements in NORAD teletype format. TLEs are usually augmented with a third (prefix) line identifying the satellite's common name.

Uniform Resource Locator (URL) - and address for Internet World Wide Web pages.

Vernal Equinox - the Sun's apparent south-to-north equatorial crossing point. The Sun reaches the Vernal Equinox at the beginning of Spring in the northern hemisphere.

THE VIEW FROM BELOW: THOUGHTS ON PHASE 3D GROUNDSTATION REQUIREMENTS

Ed Krome KA9LNV
Columbus, Indiana USA
ka9lnv@amsat.org

To date, much has been written about the features and technical aspects of the incredible OSCAR Phase 3D satellite. This paper, the "View from Below", looks at some of these almost magical things and what they mean to us on the ground. It also includes thoughts on both how to approach the development of an individual groundstation and describes some ideas on possible equipment and antenna configurations. It is not intended to be the last word on any of this subject, but merely the observations of an experienced OSCAR user and microwave experimenter.

Features

P3D has a myriad of features and characteristics, both of the intended orbit and of the satellite itself. Understanding these features and what they mean to us on the ground will help each individual make informed decisions on how to get the most out of P3D. This paper will also compare P3D characteristics to those of the existing Phase 3 satellites, AO-10 and AO-13, with which most of us are familiar.

Orbit

Phase 3D will be in a high inclination elliptical orbit similar to that of the other Phase 3 satellites, but higher and with a different period. The Ariane launch vehicle will leave P3D in a 10 degree inclination GTO, or Geostationary Transfer Orbit. From there, P3D's 400 Newton (or 90 pound force, for those of us who haven't quite gotten with the SI system yet) bi-fuel main motor will move the satellite to the desired orbit in several burns. The final orbit will be at 60 degrees inclination, with a perigee of 4000 km and an apogee of 47000 km. From there, the orbit will drift slightly until it attains about 63 degrees inclination. Compare that with AO-13's present orbit of 325 km perigee and 38500 km apogee, at 57 degrees inclination.

The orbital position of P3D was designed to give a period of 16 hours, as compared to AO-13's period of 11.44 hours. This 16 hour period provides a unique characteristic of P3D's orbit; the fact that the satellite will reappear at the same position in the sky every 48 hours. While this characteristic will definitely not remove the requirement for computer tracking software, it will be very useful in setting up regular schedules and nets.

When I first heard this "same place every 48 hours" phenomena, I wondered how it could be. It works as follows. A satellite's orbit is fixed around the Earth relative to the fixed stars. The Earth rotates as the satellite orbits. P3D attains apogee every 16 hours. Sixteen hours after the initial apogee (when the satellite attains apogee again), the Earth has rotated 240 degrees, or 2/3 of the way around. If the initial apogee occurred over (for example) Kansas City, Missouri, at 100 degree West Longitude, the apogee 16 hours later would occur at 340 degrees West, approximately above Tokyo. Sixteen hours later, at the next apogee, the Earth would have rotated an additional 240 degrees, or 480 degrees from the initial apogee over Kansas City, near Vienna, Austria. Sixteen hours later, at the third apogee, the Earth has rotated an additional 240 degrees, or 720 degrees total, and the satellite winds up back where it started, over Kansas City.

Stabilization and Antenna Orientation

The most important part of commanding a satellite is to keep the batteries charged. Without them, nothing else will work at all! Solar cells are the most practical method of charging batteries. AO-10 and AO-13 have 3 "arms" covered with solar cells. The position of the satellite in orbit must be consistent so as to insure efficient battery charging. Therefore, AO-10 and AO-13 are spin stabilized, where the satellite rotates about it's Z axis. The satellite is oriented so that the Z-axis is approximately perpendicular to a line to the Sun. As the satellite spins, each cell is evenly exposed to Sun and darkness. This rotating motion also insures that the satellite's internal temperature remains even. The spacecraft antennas are on the end of the bird, perpendicular to the Z-axis. Since the orientation of the spacecraft must be such that the solar cells receive adequate illumination, the antennas may or may not be actually pointing anywhere useful, like at the Earth. The ideal situation is with the antennas pointing at the center of the earth at apogee (nadir pointing), but this can only occur if the Sun is in the right position to adequately illuminate the solar cells. Part of the year it is, part it is not. Our tracking programs have "squint angle" calculations that tell us how far off the spacecraft antennas are pointing. This gives us a good idea of what to expect in the quality of the signals from the satellite; the larger the squint angle, the further off the main antenna pattern lobe we are and the weaker the signals become.

P3D takes a completely different approach to stabilization and orientation, and consequently, to antenna pointing. Instead of the entire spacecraft spinning for stabilization, P3D has three internal "reaction wheels" mounted at right angles to each other. These are like large, variable speed gyroscopes, which, at steady state, impart a resistance to change. If, however, the speed of the rotating mass wheels is varied relative to each other, controlled angular motion is imparted to the spacecraft. This 3-dimensional control allows the orientation of the spacecraft itself to be precisely controlled. Additional control is available through magnetorquers, similar to those used on '10 and '13. P3D will also have ATOS, a mono-fuel arcjet motor. These stabilization and control systems allow P3D to always be oriented so that its antennas (on the end of the spacecraft) are pointed toward the Earth. Normally, the squint angle will be zero, optimum for communications. This freedom from spin allows the satellite to have a set of "wings" covered with solar cells, which are folded up around the spacecraft at launch and deployed when in orbit. These wings are oriented for most advantageous sun angle by rotating the entire spacecraft about its Z-axis. Internal temperature stabilization, which was automatic with spin stabilization, is handled by a heat pipe system. This whole package is controlled by the IHU (Internal Housekeeping Unit), the onboard computer.

Communications on the Satellite

P3D is a real flying antenna farm. It has "24 things sticking out of it". Directional antennas for all bands sprout from the +Z (main motor) end and side. Omni-directional antennas for 3 bands (146, 436 and 1269 MHz) are on the -Z (ATOS motor) end. Antenna design involved figuring out how to cram that many antennas on an 8.5 foot wide piece of real estate and getting them all to actually work! Each antenna has to have gain (which is beamwidth) consistent with the requirements of the orbit and path loss.

When P3D is at apogee (47000 km), the Earth appears to be 13 degrees wide. The antennas were designed to have a beamwidth that provides signal strength consistent within 2 dB between the midpoint of the beam and the edges of the Earth. On the other hand, at perigee, the Earth appears to be about 68 degrees wide. The antenna pattern should cover this also. Path loss varies with distance. For example, on 1269 MHz, the path loss at apogee is about -185 dB. It perigee, it is - 165 dB. So there is a 20 dB improvement in path loss while the required beamwidth of the antennas changes from 13 degrees to 68 degrees. The pattern can therefore be 20 dB weaker (at the edge of the Earth) at perigee than at apogee to provide similar signal strength on the ground.

Directional antennas consist of 3 folded dipoles on 146 MHz, 6 patch antennas on 436, a short backfire (a cavity antenna resembling a "dish", but not concave) on 1269 MHz and small dish antennas for 2400 and 5670 MHz. Horn antennas are used for the 10 GHz and 24 GHz downlinks. 29 MHz uses a 2-element beam (a driven element and a director) on the side of the craft. All (except HF) are right hand circular polarized.

Internally, all the antennas are connected to individual transmit or receive converters, which all share a common Intermediate Frequency of 10.7 MHz. Each of the IF inputs and outputs are through a switch matrix that can connect any separate transmitter and receiver together as a crossband transponder. Theoretically, it would be possible to have a 24 GHz downlink with a 29 MHz uplink, but this is not feasible for other reasons. It is not possible to connect a transmitter and receiver in the same band. Each receiver (uplink) is connected to LEILA, the alligator killer. LEILA senses stations that are creating too strong an uplink and warns them of their transgression. If they do not reduce power, LEILA will put a deep notch right on top of the offender's signal, removing him from communications through the satellite. Hopefully, LEILA will not get much use.

So much versatility in selection of up and downlinks has created a requirement for a new mode naming convention. On previous satellites, "Mode B" meant a 2 meter downlink and a 70 cm Uplink. That was easy enough, but when you have 36 different combinations, you run out of letters! So a 2 letter convention has been chosen, "Uplink/Downlink". Bands are still identified by their old conventional or radar designators. 146 MHz is called "V" for VHF. 436 MHz is "U" for UHF, 10 GHz is "X" and so on. Therefore, what we used to call "Mode B" will now be called "Mode U/V".

Why Microwaves?

All this brings up the old grumbling question of "why is everything going to microwaves"? There are several answers; all important. First, goodness of a communications channel is largely determined by the signal to noise ratio. To get a better comm link, you must either improve the signal strength or reduce the noise; preferably do both. Use of microwave frequencies allows narrow, concentrated beamwidths with physically small antennas. These narrow beamwidths allow efficient use of available transmitter energy; a clean narrow pattern concentrates energy that would be lost in broad, ragged pattern. And real estate is expensive and hard to come by, especially in space! P3D is quite large by amateur satellite standards, but it is still only 8.5 feet wide and must provide a platform for antennas for many different bands. Microwave links allow small antennas with efficient, predictable performance.

Noise, the bottom half of the S/N equation, is lower on microwave bands. Noise comes in two forms, man-made and natural. Man-made noise from machinery and electrical equipment drops off greatly by 30 MHz. RF interference decreases as the frequencies increase both because there are fewer RF generating devices (not many 2.4 GHz and up handheld radios around) and those that exist also use gain antennas to concentrate their radiation where the owner wants it, rather than randomly as on HF. Natural noise comes in atmospheric and stellar varieties. We are all familiar with atmospheric noise. Lightning noise is crushing on 160 meters, not much on 10 meters and non-existent on 2 meters or above. Stellar noise is largely from electron motion and is measured in terms of temperature. The Earth is 300 degrees Kelvin; deep space on 2400 MHz is only a few degrees Kelvin. Cold and quiet.

Microwave bands offer wide frequency allocations without a lot of competition. Users don't have to crawl over each other. Those familiar with digital communications know that the bandwidth required to send data is directly related to the data rate. If you combine the excellent signal to noise ratios available on microwave links with the broad bandwidths available, it is obvious that you have the makings for high speed, robust digital communications links.

An additional advantage of having a ham radio presence on the microwave bands is described as "use it or loose it"! As technology progresses, commercial communications users are becoming more and more interested in the higher frequency bands and are fighting hard for all the band allocations they can get. And they have money. In the USA, we lost part of the 220 MHz band and share several bands with commercial and military interests, including radar on 400 MHz and "wireless" LAN's on 2.4 GHz. There is at present an assault on even 2 meters and 70 cm, the most popular VHF bands, for use with commercial "little LEO" satellites. The commercial people really like the results from the Microsats. An amateur presence on the microwave bands will help keep them for our use.

Also, much of the microwave activity built into P3D involves downlinks on the highest frequencies. It is much more difficult and expensive to generate transmit power than it is to add a converter and preamp in front of a receiver. The P3D microwave downlinks will therefore be comparatively inexpensive for implementation in a groundstation..

Finally, this is cutting edge technology, and great fun!

Up and Downlink Requirements

AMSAT-DL has published several descriptions of P3D systems and statistics (in German; I have recently seen English translations by John Bubbers). Frank Sperber DL6DBN has published the calculations of up and downlink power and gain requirements for the various frequencies. These have been related to as close to common antenna configurations as possible, including short yagis for the bands up through 1269 MHz and the use of a 60cm (about 2 feet in diameter) parabolic dish antenna for the higher bands. The 60cm dish provides reasonable received signal strength on all microwave bands. Transmit power on all bands is no more than 10 watts with reasonable sized antennas. Of course, larger antennas may be used with lower power transmitters or less sensitive downlink setups. Omni-directional antennas may be useable up through 70cm.

Problems, problems. With so many up and downlink combinations, how does one figure out what bands to operate and how to make everything work together?

There are no firm plans on what will be the most used uplink/downlink combinations. A committee will be formed from the major contributors who will dictate schedules, consistent with technical requirements. While mode B is the current favorite mode (the only mode on AO-10 and the one with 92% of the time on AO-13), the 2 meter downlink is becoming almost unusable in much of the world due to RF congestion. Try rag chewing with a JA in in Tokyo on mode B. They are almost deaf from local interference. Big cities in Europe and the USA are almost as bad. Therefore, we will probably be seeing increased usage of the higher bands on P3D. Mode V/U (144 MHz up and 436 MHz down; the present mode J) will probably see a lot of use, although many operators have self-interference difficulties with a downlink harmonically related to the uplink. Mode L/S (1269 MHz up and 2401 MHz down) has been touted as the best of all worlds and should offer outstanding performance with inexpensive and easily attainable equipment and really small antennas. We can probably expect to see high percentage of time devoted to these combinations.

The higher frequencies are definitely for the experimenters. Combinations using the X band downlink should be popular since there is a surprisingly large amount of terrestrial activity on 10 GHz, and equipment is available in both kit and assembled form. Amplifiers for uplinks on 2.4 GHz will be available, but will probably be in the 2 watt range, which would dictate use of larger antennas. There are no amplifiers commercially available to amateurs for 5.7 GHz, though there is reputed to be sporadic availability of surplus amplifiers. Down East Microwave is in process of having their 2.4, 5.6 and 10 GHz equipment (both kits and built-up) redesigned to make them more "user friendly". SSB Electronic (Germany) will have built-up equipment available for all bands through 10GHz. The 24 GHz downlink will probably see limited use since I am only aware of two European sources of mixers and preamps for that band, and they are definitely not plug and play.

Groundstation Matrix

Each individual will want to put together a groundstation that will best suit his operating habits. Just figuring out what the options are is confusing. One of the best ways to determine what makes sense for your own operating is to put together a matrix comparing modes to available bands. It is not necessary to put together every possible combination; some will never be implemented (such as a mode H/X or any up/down in the same band) and few of us will want to work them all. There are a few ground rules that make things fit together.

This is the "what do you have and where do you want to go" part. First, figure out what equipment that you have or intend to obtain. The most common arrangements seem to be either a multi-band satellite rig (such as the Yeasu FT-736R or ICOM 970) with 2 meter and 70 cm modules or separate 2 meter and 70 cm transceivers, such as the ICOM 275/475. Either of these arrangements are useful for modes V/U or U/V.. The addition of a 23cm module to the multi-band rigs or the purchase of a separate 23cm transceiver (such as the ICOM 1271) will add L band. These arrangements can all operate full duplex, satellite crossband style, with the uplink in one band and the downlink in the other, but cannot go up and down in the same band. Either arrangement will allow operation on 6 separate modes (not counting HF), which should keep an operator busy. Many other arrangements are possible. For example, I have never owned a commercial radio that would tune above 30 MHz, but have relied on converters up through 10 GHz.

Adding additional bands can be done most economically by sticking with available uplink bands. Additional downlink bands can be implemented by adding receive converters in front of your existing transceivers. Converters and preamps are cheaper than RF power amps. This is where a written matrix comes in handy. Converters can be obtained with various IF outputs. The most common IF's are 144 MHz and 432 MHz. In order to operate crossband full duplex, you must use one of your existing radios for uplink, and the other for downlink. Therefore, you want to chose converters that have IF's on the opposite band as the required uplink. For example, 10 GHz converters are available using either 144 or 432 MHz IF's. If you intend to work mode V/X, you would not want a converter with a "V" (144 MHz) IF, since you could not transmit and receive on 144 MHz at the same time. So a 10 GHz converter with a 432 MHz IF is the best choice. On the other hand, the modes that use S downlinks (U/S and L/S) have either 436 MHz or 1269 MHz uplinks, so a 144 MHz IF would be best. Operating both of the S up and downlinks will be challenging, since it will require two separate converters with different IF's.

Typical P3D Groundstation Equipment Matrix

Assume:

AO-13 station with FT-736R (2 meter and 70cm)

add:

1269 MHz transmit module
2400 MHz Receive Converter (144 MHz IF)
10 GHz Receive Converter (432 MHz IF)

Up/Down	146 ↑	146 ↓	436 ↑	436	1269 ↑
V/U	↑			↓	
V/X	↑			X↓	
U/V		↓	↑		
U/S		S↓	↑		
L/V		↓			↑
L/U				↓	↑
L/S		S↓			↑
L/X				X↓	↑

Microwaves pose some interesting problems that influence equipment decisions. As we have mentioned, transmit power is much more expensive than receive gear. A real problem is that coaxial cable losses become so high that it is necessary to use as little cable between the antenna and the active stage (whether transmit or receive) as possible. Cable losses also add directly to receive system noise figure. On AO-13 Mode S (2400 MHz downlink), the standard practice is to mount a low noise preamplifier directly at the antenna feedpoint. Many operators even mount the receive converter itself "up on the pole" near the antenna to keep line losses on 2400 MHz as low as possible. The trip to the shack is done at 144 MHz, where even RG-58 is satisfactory. This technique will be mandatory at higher frequencies.

On the transmit side, there is no point in loosing all your expensive RF watts to line losses, so final amplifiers on the highest bands should be tower mounted. On 1269, this is convenient due to the availability of small "brick" linear amplifier modules that produce 10 to 18 watts RF out for a few milliwatts of RF in. Since 1269 uplink requirements are predicted to require 10 watts into a 12 turn helix, a very nice package could be made of a "brick" amp mounted on the back of a short helix and serving as its counterweight on the cross boom. A few milliwatts of RF at 1269 could be brought up from the shack in standard RG-213 cable. No hardline needed here.

Mode S (2400 MHz) is unique in that it has both up and down links. One possibility is to mount a complete S band transverter with separate T/R inputs and outputs up on the tower in a weatherproof box, then mount a few watt amplifier behind a transmit antenna and a preamp and feed at a separate receive antenna. A pair of RG-58 cables could connect 144 MHz to and from the shack. Once again, cable expenses and losses are minimized.

The Antenna Farm

The attached figure of a proposed P3D groundstation antenna arrangement incorporates these ideas and more and crams complete 7 band operation into an antenna farm only 5 feet long, 7 feet wide (fits on a standard 6 foot fiberglass cross boom) and about 2 feet thick.

Probably the most prominent characteristic of the system is the lack of a 2 meter antenna. The 2 meter antenna was left out for two reasons, the first being that they are physically large. Second, with the previously mentioned problems being experienced with 2 meter downlinks in Japan and Europe, 2 meters will not be a popular downlink. If, however, a 2 meter uplink is desired, the numbers indicate that a separate omni-directional antenna and 50 or so watts of transmit power will provide a satisfactory communications link. This is convenient, since RF power is common and inexpensive on 2 meters.

The second characteristic is the presence of two separate parabolic dish antennas. One is the uplink and one is the downlink. Both dishes use clustered feeds (feeds for several different bands located next to each other). Clustering feeds works satisfactorily with the following cautions. First, put the highest frequency feed in the center, since it is the most critical to pointing and feed positioning (the "phase center" of the feed must be at the focal point of the dish). Second, several feeds will block and reduce the effective capture area of the dish. A larger dish may be required to compensate. Third, stick with "shallow" dishes (say, .5 to .6 f/d) so the curvature of the dish does not vary radically; it still must concentrate energy on the feedpoint and with multiple feeds, this is easier to do with the less precise focus offered by a shallow dish. Fourth, expect to off-point the dish slightly to get maximum signal to those feeds not directly in the center of the dish.

Since all transmitting is done with one dish and all receiving with the other, it is not necessary to protect delicate receive preamps from the RF energy of transmitters. When using a single dish for both transmit and receive, it is necessary to use some sort of coaxial relay arrangement to disconnect the inputs of any receive systems from their dish feeds to keep from frying the preamp front ends. This need to protect receive front ends means that full duplex operation will not be possible with a single dish doing double duty. Coaxial relays are expensive and heavy. And any mechanical device on the antenna is just something else to fail at the least opportune times. Also, spacing the transmit and receive dishes physically apart reduces receiver desense experienced when a transmitter is operating in close proximity to a sensitive receiver.

The two dish arrangement offers several other advantages. Switching is simplified, especially on S band, where separate dishes and separate feeds fed from separate ports on a transverter completely eliminate relays and switching.

I have seen some proposed dish feed arrangements which mount 1269 MHz (for uplink) and 2400 MHz (for downlink) helix feeds concentrically. This looks good at first, but will prove impractical, since it would require expensive relays for preamp protection and still not allow full duplex crossband operation on mode L/S. A much better arrangement is to use a separate L band uplink helix antenna (as previously described) and put the S band downlink in a small dish.

Parabolic Dish Antennas

Parabolic dish antennas come in many forms. The size-independent parameter that characterizes any dish is the f/d ratio. This ratio gives the relationship between the focal length, f (where the "phase center" of the dish feed is positioned) and the dish diameter, d. Most dishes have an f/d between .3 (called a "deep" dish) and .8 ("shallow"). The characteristics of the feed must be matched to the f/d ratio, in that the feed must have a beamwidth that illuminates the dish from edge to edge, typically at the -10 dB points. If the beamwidth is too narrow, not all the area of the dish is utilized. If the beamwidth is too wide, on receive the feed will "see" the warm Earth behind the dish, receiving excessive noise along with the signal. Many references exist on the subject of matching dish feed to dish geometry. Note that f/d ratio is just that, a ratio, and is not related to the actual physical size of the dish. The distance of the phase center of the feed from the dish is calculated from the f/d and the actual dish diameter. In practice, this is usually optimized by peaking on Sun noise.

Dish construction varies from solid metal forms to almost invisible wide open mesh designs. The advantage of open mesh is that it has much less wind load than an equivalent solid dish. The "quality" of the dish, it's trueness to the actual parabolic form and the allowable spacing between wires in open mesh dishes, is determined by the frequencies over which it will be used. A rule of thumb, from optical practice, is that there is no measurable difference between a 100% accurate dish form and one where the maximum deviation from theoretical is less than 1/10 wavelength at the highest frequency of use. This also applies to allowable mesh spacing in open mesh dishes. Remember that this is not a hard and fast rule. Greater variations will only result in a progressive deterioration of performance (reduced efficiency) on form or increased noise level and reduced efficiency on mesh size. This rule indicates that a dish which will be used at or below 2400 MHz (13cm) need only be accurate within 1/2 inch of true form. I have used small, homemade, stressed construction dishes covered with 1/2 inch mesh "hardware cloth" for years on mode S and experienced quite satisfactory performance. For 5670 MHz, the form and mesh needs to be .21 inch or less. On 24 GHz, this must be .06 inch. This accuracy will probably dictate use of solid commercial dishes.

Additional Thoughts

One possible method of reducing cabling and line losses is to mount certain equipment up on the antenna tower. We have already mentioned the advantage to mounting an entire S band transceiver and transmit amplifier on the tower (with the receive preamp mounted on the dish feed). Two other good candidates for tower mounting would be a 5668 MHz transmit converter and amplifier and a 15-20 watt L band (1269 MHz) "brick" amplifier. If the 5668 converter uses a 1269 MHz IF, a single length of RG-213 coax can be used to supply low level RF from the shack-mounted 1269 MHz exciter to either the amplifier or converter, switched by means of a small RF relay. The milliwatt power levels involved may even allow switching with an inexpensive TO-5 can type RF relay. Of course, 10 GHz and 24 GHz receive converters must be tower mounted, most preferably directly at the dish feedpoints. To keep the weight at the feedpoints down, it may be desireable to mount only the RF stage and mixer at the dish feed, with the local oscillator mounted remotely. If the LO is mounted behind the dish antenna, it will help serve as a counterweight. A short run of UT-141 copper hardline could be used to connect the LO and the mixer. There is lots of room for creativity here.

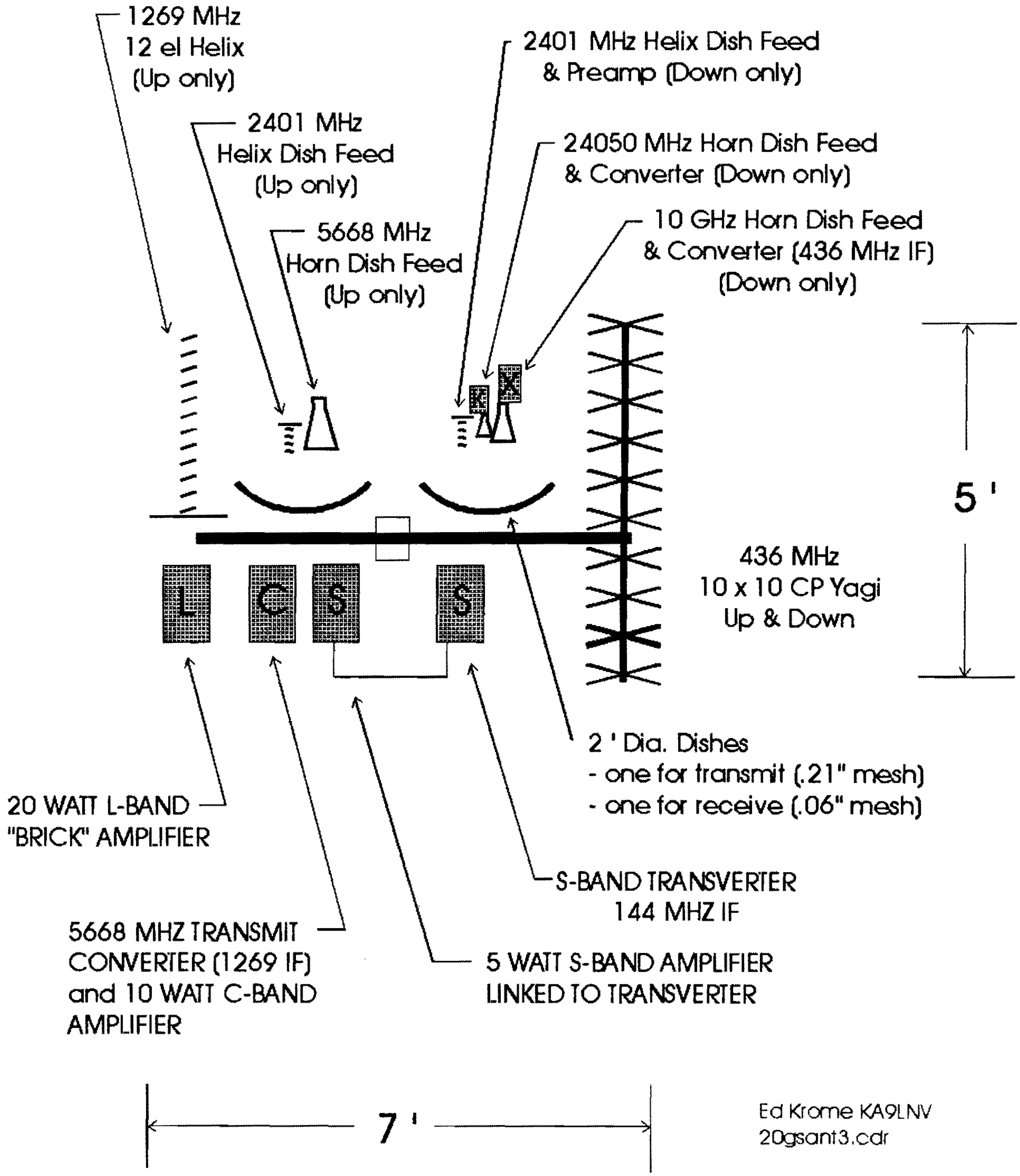
An extremely important consideration is mechanical stability and ruggedness of the antenna system. OSCAR antennas can become large and complex, which means they are heavy and present large wind loads to the rotors. It is poor practice to rely on the elevation rotor and the strength of boom clamps to support off-center loads applied to the cross boom. Parabolic dish antennas and their feed arrangements can be quite heavy and are extended away from the cross boom. Even mesh dishes can have large wind loads. Always counterbalance your antennas in elevation and equalize loads in azimuth directions.

Small dish antennas frequently use a non-metallic center support to which the dish and feed are attached; this also serves as the attachment point to the cross boom. Extending this support behind the cross boom gives an ideal attachment point for microwave transmit amplifiers, local oscillators and other devices which are necessary to operation. At the same time, these make very practical counterweights. Also, attempt to equalize wind load on either side of the azimuth rotor. The double dish arrangement (with one on each side of the azimuth rotor) accomplishes this. That layout also has the balance of a short yagi on one end of the cross boom and a helix (with it's wind catching mesh reflector plate) on the other end. When not in use, the entire antenna should be rotated for minimum or equalized wind load, which (for dish antennas) may be at 90 degrees elevation, cross boom parallel to the prevailing winds. This orientation is sometimes referred to as the "birdbath" position. Under snow and ice conditions, dish antennas should be pointing to the horizon, as this will prevent them from gaining a lot of weight.

And so...

This paper was written for two reasons; first, to explain how P3D's physical and orbital characteristics relate to the groundstation user and, second, to suggest some possible configurations for a multi-purpose groundstation. The concentration is on antennas and intermediate frequencies, since those take the most "juggling" to coordinate. None of this is the last word on the subject, but maybe will give users a place to start in assembling versatile groundstations for Phase 3D.

PHASE IIID GROUNDSTATION ANTENNAS
7 BANDS IN A 5' X 7' SPACE!



(My) Hamshack of the Future

A simple, low-cost, ground station for P3D

Andrew A. Skattebo - KA0SNL
ka0snl@amsat.org

Goals

With the demise of AO-13 imminent and the launch of P3D now on the horizon I feel it is time to look toward our future communications opportunities. In this paper and the resulting station, I want to show that a high performance mode L/S station for the next generation of hamsat doesn't have to be complex or costly. The station I will describe was originally designed as a portable set-up but the beauty of the layout is that it will work just as well as a permanent station at home. The microwave bands were purposely chosen to promote the higher frequencies and to gain excellent performance with small antennas for portable use. All components (except the antennas) are available "off the shelf" to avoid the need for microwave building skills to duplicate this station.

The goals here were to build on a current AO-13 station and add mode L/S capability for the least money and without homebrewing all the components. I would like this paper to be an invitation to ALL HAMS to become involved with satellite operation and start thinking NOW about their future and the future of amateur radio in space.

OVERALL DESIGN CONSIDERATIONS

This mode L/S station is basically and extension of my mode B and S efforts on AO-13. That station wasn't really portable, but it was fairly easy to set up and take down. Some of the components were already on hand so that did influence my choices when assembling the new station. A ham setting up a completely new station may make different choices. Also, someone will better building skills (and more free time!) than I, could get on the air for even less.

The overall layout of the station is shown in figure 1. The basic building blocks are a 10M radio and 2M radio connected to receive and transmit converters to achieve the final microwave frequencies. This arrangement is flexible (for future operating modes) and cost-effective (less expensive than a new multi-mode transceiver).

I chose a two-part installation keeping the microwave transmit and receive equipment at the antenna location to reduce feedline losses. The splitting of these components is central to my station design. This arrangement allows me to set up the station in any location and should I need additional feedline between the rigs and converters I can add inexpensive coax instead of hardline, keeping costs down and performance up. This is just good microwave design practice, but it has the benefit of decreasing cost and increasing performance of a satellite station. What follows is a breakdown of the entire station section by section along with enough additional information to make your own equipment choices for your station.

THE RIGS

I would say that the heart of my station in the Yeasu FT290RII 2M multi-mode radio. It is my only 2m rig and serves as satellite radio, FM mobile rig and with the battery pack, as a portable alternative to an HT. I purchased the unit new at a cost a little higher than a two meter FM only mobile. It has proven to be a versatile radio well worth the additional cost. With the battery pack installed it has an output of .4 watts, just right to drive the transmit converter.

Many other good two meter multi-mode radios are available from various manufacturers. I have found many available on the used market at prices close to the cost of a new FM only radio. For satellite work you are concerned with the sensitivity of the receiver. Also, you need to make sure that the output of your transmitter is matched to the drive requirements of your transmit converter. If the minimum output for your radio is higher than the maximum allowed for your converter, an attenuator may be needed. These are available from several sources including Down East Microwave. If you are interested in digital satellites, a radio with computer control capabilities may be required. This is something to consider before making a purchase.

The other radio in use for this station is a Uniden HR 2600 10M all-mode. It is a typical "beginner" radio and available used for around $150. I picked up this unit for use in my mode U/V station for AO-13. It was on the transmit side feeding a Microwave Modules 435 transverter. It has been slightly modified to reduce output power to a maximum of .5 watts for driving transverter equipment. The transmit side is not used in this particular arrangement however, since it is used with two receive converters for the S band downlink. I chose this arrangement since, to reduce costs, I had to work with what I already had available. I had this radio and the 2M receive converter so I just hooked these to the 2.4GHz converter. Using another 2M all-mode radio would simplify this arrangement, eliminating the need for the 2M converter and 10M radio. Something for a future upgrade.

THE TRANSVERTERS

For the transmit side I was able to purchase a used SSB Electronics model LT-23 1296 transverter with approximately 10watts output. Purchased new this unit is rather pricey. However ,used it was quite reasonable at $400.00. Other vendors also have transverters available for this band. Check the resource list for details. With a suitable antenna, 10watts should be plenty of power for good signals through the satellite. Since the satellite carries a system to mark and attenuate strong signals overloading the on-board receivers, excess uplink power will translate into embarrassment instead of improved signals. The only advantage to using a higher power level is that it provides the opportunity to use even smaller antennas. For me it was cheaper to create higher ERP (effective radiated power) with antenna gain rather than with more transmit power. You will also probably find this is true in your situation. Check the AMSAT P3D Manual or the ARRL Handbook for details on the ERP you should shoot for on a particular band and mode.

For the Downlink on mode S, I again found a used SSB Electronic unit. This one is the UEK 2000 SAT, satellite receive converter. As before, check the resource list for other vendors and sources. This converter takes the 2.4GHz signal and converts it down to 2 meters. A great feature of this unit is that with the 30dB of conversion gain and the low noise figure of the unit, it is not necessary to use an outboard pre-amp. This can reduce overall cost and complexity.

The 2 meter output of the receive converter is fed to a 2M to 10M receive converter from Hamtronics. I built this unit from their kit but they also offer a wired and tested model. It is fairly simple to assemble and a good opportunity to try your hand at building without getting too complex.

The output of the Hamtronics converter is fed to the Uniden 2600 10M radio for our listening pleasure. As I said before, this arrangement could be simplified. A two-meter all-mode radio or receiver could be used, eliminating the extra conversion step. There are interesting home-brew projects for two-meter receivers. Also, the new Icom HF radio with two meters built in has a few possibilities for transverter operation. I simply chose to use what I had on hand and build on that.

THE ANTENNAS

The antennas used in this station are home brew helix antennas. Both were easy to construct and were built from dimensions published in the ARRL Antenna Handbook. The S-band downlink antenna is a 14 turn helix similar to the antenna built by G3RUH. His antenna is described in the ARRL 1996 Handbook Chapter 23. Details of this antenna can also be found on the AMSAT web site.

The L-band uplink antenna is a 12 turn helix built entirely from the dimensions given in the ARRL Antenna Book. This combination of antennas should give reliable signal margins on both the uplink and downlink. I hope to publish construction details for these antennas soon, after some testing has been accomplished and performance verified.

PUTTING IT ALL TOGETHER

All connections use a 100% double shielded cable and silver/teflon 'N' connectors. This keeps the RF in its proper place and reduces any interference from the 2M transmitter. Also, the transmit and receive equipment use two separate power supplies to reduce the possibilities of interference through the power cables. (A tip from W0DEN) This technique has been used successfully with two 10M radios for transmit and receive and I do not anticipate many interference problems.

To allow use of the transverter equipment outdoors and permit mounting near the antenna, a weather resistant housing is required. I chose to fabricate one since I had trouble finding just the right box to use. The housing is a fiberglass composite box made very cheaply by using CAD, (Cardboard Aided Design and construction). The construction is similar to that used in modern composite aircraft, except with aircraft a special foam and high strength epoxies are used. I didn't need the exceptional strength and high cost of the aircraft grade supplies, so cardboard and regular autobody fiberglass was used. The housing is basically a box assembled from cardboard to my needed dimensions then covered with fiberglass inside and out. Credit for this "budget composite" goes to N4RVE whom I've never had the chance to meet. Thanks Steve!

The next step in this station's development will be to create a console for the radios using the same technique. The packaging is important from a user standpoint and I don't think enough attention is paid to aesthetics in some ham home-brew arrangements. When the electronic testing and shakedown is complete I will try to work more on this part of the project.

PRESENT and FUTURE

I think I have succeeded in my goal of creating a low-cost station that is portable and practical. The portability does not mean a compromise in performance because of careful station design. As stated earlier, central to the concept of this station is the fact that the radios are the only thing at the operating position. The conversion on transmit and receive are done at the antenna to reduce cost and greatly increase performance. I feel this is a superb approach to station design and credit other satellite operators for giving me the idea.

The station will be ever evolving. This is an early attempt and no doubt many manufacturers will step forward with new designs and equipment when P3D is successfully launched. I look forward to the new equipment and the great opportunities for use of this new satellite. However, I wanted to show myself and others that all the building blocks are available now, so you really don't have to wait. Also, I wanted to prove you can be on the 'cutting edge' of satellite stations without shelling out mega-bucks for state of the art, commercial satellite rigs.

This paper is not a complete blueprint for successful satellite operation. Nor does it address the many varied bands and operating modes such as digital operation. It is simply a way to stimulate interest in assembling a station by using an actual example. This is real hands on hardware that was assembled to be able to work our newest satellite, as soon as it is launched.

I hope to use this station as a tool for recruiting hams into the satellite service. Additionally, it could be used to show the public how far we've come in ham radio and maybe interest them in becoming hams themselves. To be able to have a live demonstration with a station that is totally portable, will bring life to the presentations and will dramatically demonstrate what amateur radio and amateur satellites have to offer.

I hope I have succeeded in stirring your interest and hope to hear you on our new high-orbit satellite!!

RESOURCES

Companies and Sources of Information used in the Building of the Station

Down East Microwave Inc.
954 Rt. 519
Frenchtown, NJ 08825
908-966-3584
Full line of transverters and other VHF to Microwave equipment including kits.

SSB Electronic USA
124 Cherrywood Dr.
Mountaintop, PA 18707
717-868-5643
Full line of high-performance VHF,UHF,SHF equipment and service

The Radio Works
Box 6159
Portsmouth, VA 23703
804-484-0140 (info)
800-280-8327 (orders)
email jim@RadioWorks.com
My source for cable and connectors at reasonable prices

Ham Trader Yellow Sheets
PO Box 2057
Glen Ellyn, IL 60138
Subscription $18 per year for 24 issues
By-weekly source for used equipment of all descriptions. Absolutely my best source for gear!

BOOKS, PUBLICATIONS & SOFTWARE

The ARRL Handbook for Radio Amateurs 1996
The ARRL UHF/Microwave Experimenter's Manual
The ARRL Antenna Book 14th Edition
ARRL
225 Main Street
Newington,CT 06111
Ph 860-594-0200
WEB www.arrl.org/

The Satellite Experimenter's Handbook
NOVA for windows Satellite Tracking program
(Many other software titles available from AMSAT)
AMSAT P3D Operating Guide (soon to be released)
Journal subscription with membership-best information available!
AMSAT
850 Sligo Ave.#600
Silver Spring, MD 20910
PH 301-589-6062
WEB www.amsat.org

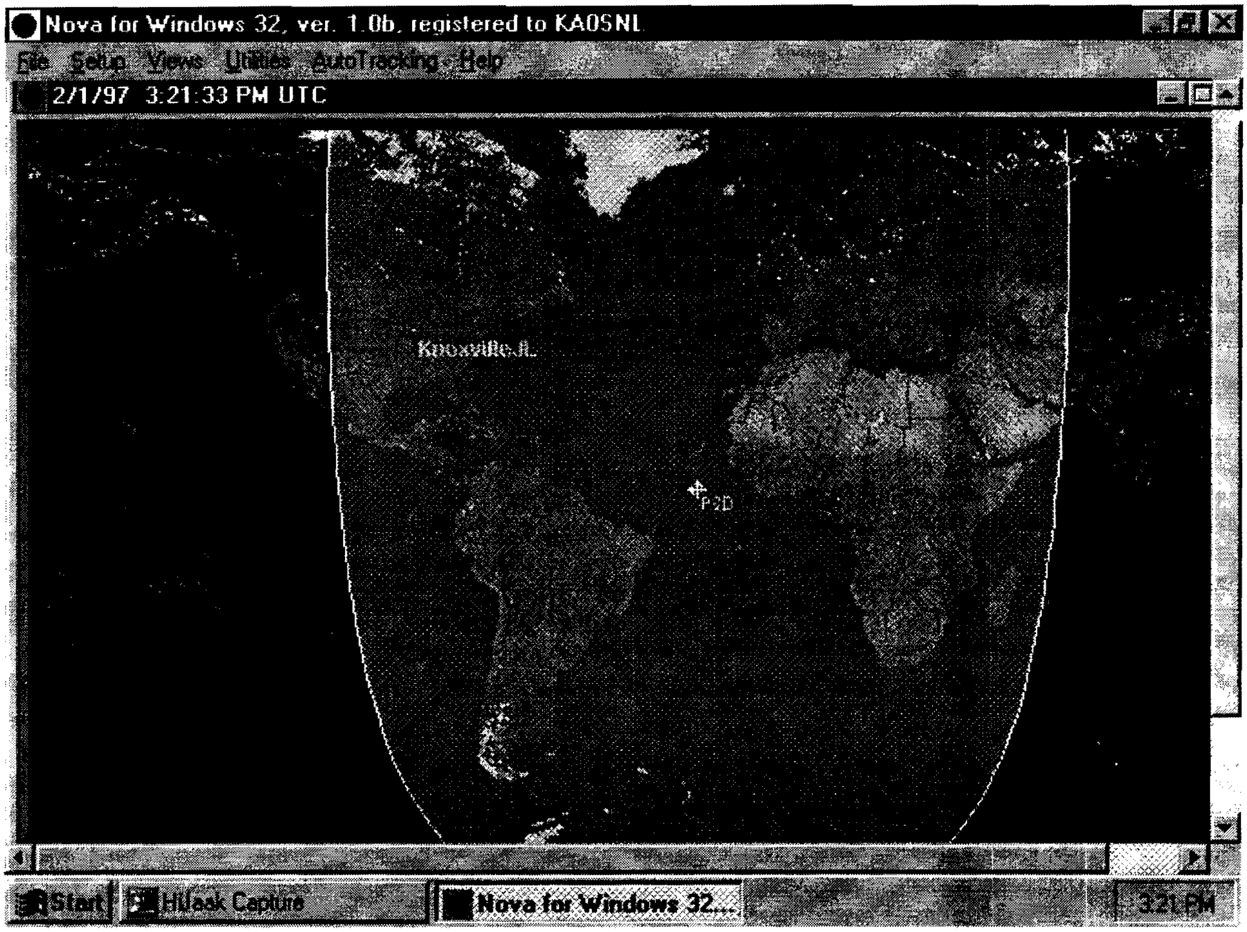
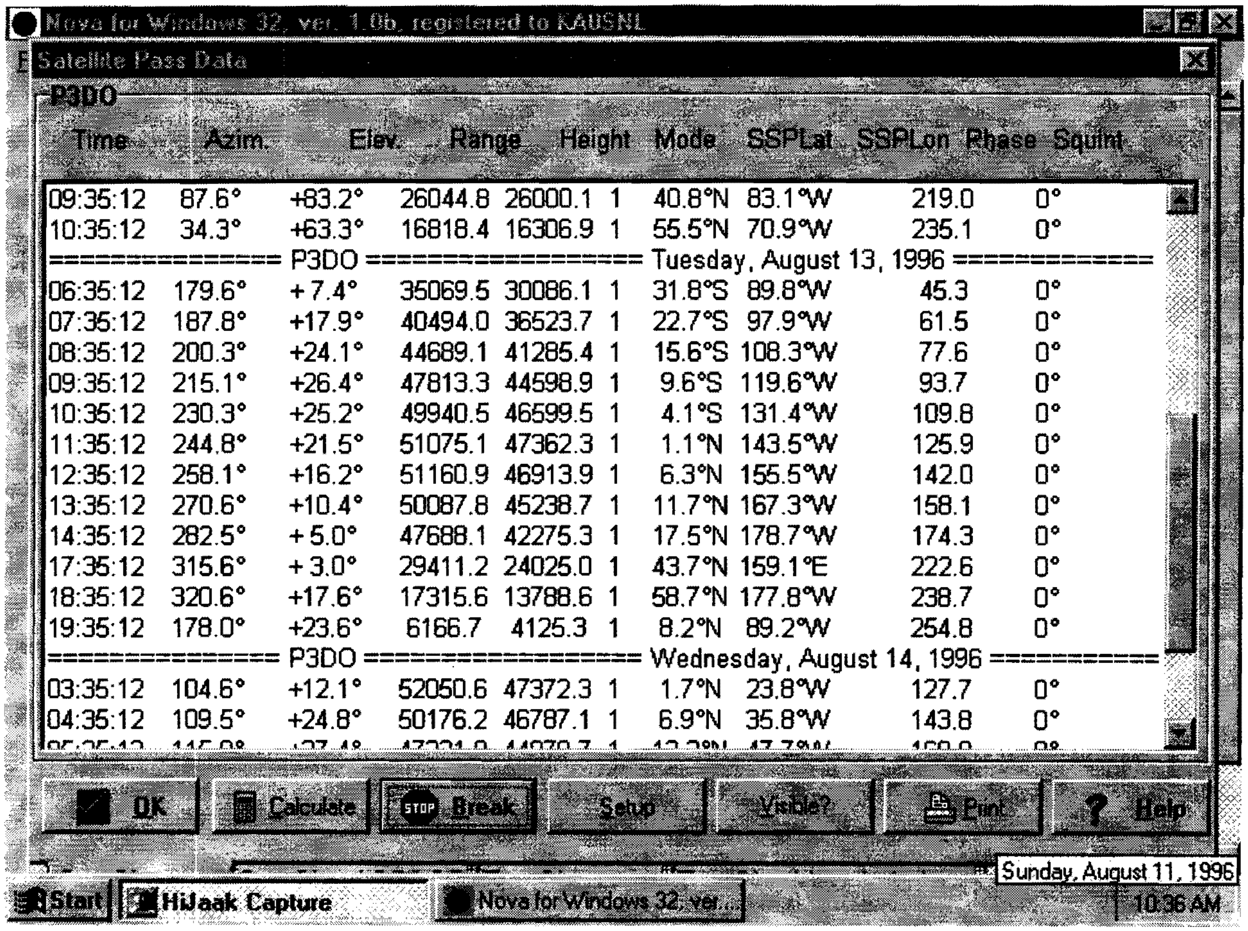
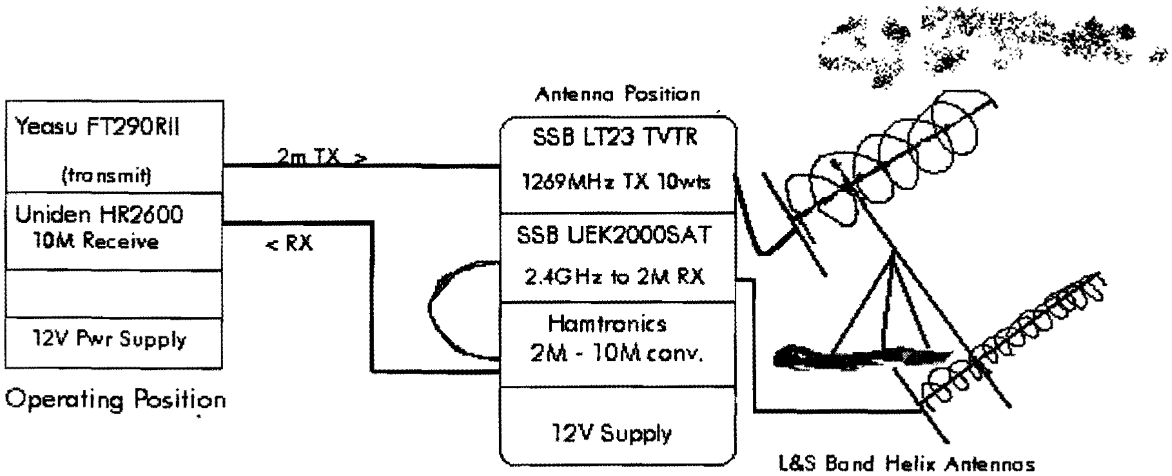

Nova for Windows 32, ver. 1.0b, registered to KA0SNL
File Setup Views Utilities AutoTracking Help
2/1/97 3:21:33 PM UTC
P3D
Start
HiJaak Capture
Nova for Windows 32...
3:21 PM

Figure 1



Time	Azim.	Elev.	Range	Height	Mode	SSPLat	SSPLon	Phase	Squint
09:35:12	87.6°	+83.2°	26044.8	26000.1	1	40.8°N	83.1°W	219.0	0°
10:35:12	34.3°	+63.3°	16818.4	16306.9	1	55.5°N	70.9°W	235.1	0°
============== P3DO ================= Tuesday, August 13, 1996 ============									
06:35:12	179.6°	+ 7.4°	35069.5	30086.1	1	31.8°S	89.8°W	45.3	0°
07:35:12	187.8°	+17.9°	40494.0	36523.7	1	22.7°S	97.9°W	61.5	0°
08:35:12	200.3°	+24.1°	44689.1	41285.4	1	15.6°S	108.3°W	77.6	0°
09:35:12	215.1°	+26.4°	47813.3	44598.9	1	9.6°S	119.6°W	93.7	0°
10:35:12	230.3°	+25.2°	49940.5	46599.5	1	4.1°S	131.4°W	109.8	0°
11:35:12	244.8°	+21.5°	51075.1	47362.3	1	1.1°N	143.5°W	125.9	0°
12:35:12	258.1°	+16.2°	51160.9	46913.9	1	6.3°N	155.5°W	142.0	0°
13:35:12	270.6°	+10.4°	50087.8	45238.7	1	11.7°N	167.3°W	158.1	0°
14:35:12	282.5°	+ 5.0°	47688.1	42275.3	1	17.5°N	178.7°W	174.3	0°
17:35:12	315.6°	+ 3.0°	29411.2	24025.0	1	43.7°N	159.1°E	222.6	0°
18:35:12	320.6°	+17.6°	17315.6	13788.6	1	58.7°N	177.8°W	238.7	0°
19:35:12	178.0°	+23.6°	6166.7	4125.3	1	8.2°N	89.2°W	254.8	0°
============== P3DO ================= Wednesday, August 14, 1996 ==========									
03:35:12	104.6°	+12.1°	52050.6	47372.3	1	1.7°N	23.8°W	127.7	0°
04:35:12	109.5°	+24.8°	50176.2	46787.1	1	6.9°N	35.8°W	143.8	0°

Figure 2



Mode L/S Groundstation
byKA0SNL

Figure 3

Quick, Inexpensive and Effective: A Simple Satellite Mobile QRP Station for the Beginner

by Douglas Quagliana, KA2UPW
dquagliana@aol.com

Abstract

This article describes how the author's AO-27 satellite station evolved from its simple beginnings. The author has used this station to make contacts with fifteen states and over twenty grid squares while operating satellite QRP mobile. This article was written for the Amateur Radio operator who has little or no experience using satellites and is interested in creating and operating a simple inexpensive satellite station for AO-27.

Introduction

AO-27, also known as EYESAT, was one of several amateur radio low-earth orbit satellites that hitched rides as secondary payloads on an Ariane V-59 rocket launched in September 1993. AO-27 is a small microsat class satellite that performs commercial functions and also acts as a part-time mode J FM repeater within the amateur radio bands. At present (August 1996), the satellite is configured to turn on its FM transponder for a fixed amount of time starting several minutes after it emerges from the Earth's shadow. AO-27 has a very sensitive receiver that will detect even a few watts from an HT.

The Satellite Station

My original satellite station was a Tempo S1 two meter HT, a 5/8 wavelength magmount, a homebrew quagi and a handheld scanner. I have improved upon the original quagi and replaced the scanner with a preamp, a downconverter and a Uniden HR2600 10 meter transceiver. My whole station fits neatly into the trunk of the car, and easily sets up in less than five minutes. (See Photo 1) When necessary, everything except the quagi boom and 5/8 wavelength antenna can collapse down into a backpack or carrying case. The entire station runs off of batteries, which allows me to operate from just about anywhere. Since the very beginning I have tried to keep everything as simple as possible, consistent with successful operations and good operating practice.

AO-27 : The QRP satellite

While AO-27's uplink receiver is very sensitive, the downlink is usually at the 600 milliwatt level. This means that a good low noise preamp with 15 to 20 dB gain, or at least a five element beam, is needed. I made my first AO-27 contact with a homemade five element quagi that I built from an article in the December 1987 _QST_. The first quagi was just thrown together. The boom was a wooden dowel. The reflector and driven element were #12 insulated solid copper wire supported by wooden dowel spreaders which were held in place with hot-melt glue. The directors were one-eighth inch welding rods secured to the boom with rubber bands. The quagi was pointed manually and fed a few feet of RG-8 connected to my Radio Shack Pro-38 scanner. It worked. For an uplink signal, I used my HT and a 5/8-wave antenna magmounted on my car. The antenna was is a commercial version, but the magmount was homemade. The HT put out about one and a half watts. Using the quagi, scanner, two meter ht, and 5/8-wave, I worked six states in my first month of QRP mobile satellite operations.

Downlink Improvements : The Receiver

After the first few contacts, I found that the scanner didn't receive very well except during the highest elevation passes. I also observed that there were times when the downlink would doppler between two channels, and neither one was copyable. This had more to do with the fact that the scanner tuned in 15 kHz steps at 435 MHz than the doppler. My first solution was to use a 435 MHz downconverter with the scanner set at 29 MHz, where it tuned in 5 kHz steps. This reduced, but didn't eliminate completely, the problem of the downlink being between channels on the scanner. However, it also added a new bigger problem : there were now three times as many channels, and the scanner could only scan in one direction. If I scanned too far I had to go all the way to the end and start over. If not for this problem, I probably would have stayed with the downconverter and scanner with 5 kHz tuning. The current solution uses my Uniden HR2600 10m HF rig with the 435 MHz downconverter, effectively turning it into a 435 MHz all mode receiver. This provided several advantages over the handheld scanner. The combined preamp/downconverter/HR2600 receiver has finer tuning (100 Hz) and copies the downlink at lower elevations better than the scanner. The only disadvantage of the HR2600 was the higher current that it requires. This was easily overcome with a 7 amp-hour "brick" gel cell.

Downlink Improvements : The Quagi

Soon after I finished the first quagi, I started thinking about improvements. While it fit in the trunk of my car, it seemed to occupy more volume than it should. Since I wanted it to be portable, it had to be collapsible, light weight and easy to hold and point. In addition, I didn't want something which was overly complicated or required tools for assembly and disassembly. With these goals in mind, I redesigned the quagi.

To solve the pointing and holding problem, I took an angled handle from an old garden tool and attached it to one end of the boom. It allows my hand to grip the handle at a natural angle. I also used a smaller diameter dowel as the boom to make the whole antenna lighter. These two improvements made the antenna aiming much easier and reduced the arm strain. Next, I connected four short wooden dowels to each of the loops with some creatively cut plastic tubing. The other ends of the dowels are plugged into wooden spools attached to the boom. This allows the loops to be removed from the boom if necessary. The directors are held in place with cord locks from the local camping supply store. Two cord locks, one above the boom and one below, effectively hold the directors in place while providing an extremely quick assembly and disassembly. (See

Photo 2) The preamp was tied to the boom and configured to run off of a 9-volt battery. (See Photo 3) The director is soldered to an N-type connector for convenience of connecting it to the preamp, but it should work just as well with the director connected to the coax shield and braid.

When building this antenna, the prospective quagi builder should follow the old axiom, measuring the lengths of the loops and directors twice then cutting once. Also, the builder shouldn't be overly concerned about the exact resonant frequency, the antenna pattern or the absolute gain. The 435 MHz quagi was only used on receive with AO-27 so the dimension were not as critical as they would be if the antenna was used for transmitting.

Although it is possible to get started without one, I highly recommend the use of a preamp. I built a Down East Microwave 70-cm preamp from a kit. This kit was almost entirely surface mount but contains only a few parts. I mounted mine directly on the boom by tying it down with a strap from an old backpack. Power was supplied from a 9-volt battery attached to the case with double sided sticky tape. A small battery connector with alligator clips served a means of connecting and disconnecting the battery. The difference was dramatic. A downlink signal which was completely unreadable without the preamp became easy to copy with it. The 436.8 MHz downlink signal, once amplified by the preamp, was converted to 29.3 MHz by a Hamtronics 435 MHz downconverter that was also built from a kit. Interested builders should be aware that the kit contains numerous small surface mount parts. The version which I bought requires an enclosure and connectors. I mounted mine in a small 3"x5"x2" box and powered it from another 9-volt battery. While it does an adequate job of downconverting, my version required a preamp to allow reception of AO-27 with the HR2600.

Once the downconverter was built, I needed to test and align it. Normal alignment required a 435 MHz signal generator, which I didn't have. I suspect most beginners won't have one either. I did have the previously mentioned handheld scanner, which it turned out was a very effective VHF/UHF programmable signal generator. The scanner allowed me to easily test and align the downconveter. A quick examination of the insides of the scanner revealed a crystal and what was probably a 455 kHz ceramic resonator. This suggested that the first intermediate frequency (IF) was near 10 MHz and that the second IF was 455 khz. Knowing that the scanner did receive on 435 Mhz, it seemed reasonable that the local oscillator was near 435 Mhz also. Not knowing the exact IF frequencies, I set the scanner for 446.00 MHz, connected the downconverter and HR2600 and tuned until I found the local oscillator signal. On my scanner the frequency of the local oscillator (LO) was about 10.85 MHz below the scanner's programmed receive frequency. When the scanner was set to receive 447.65 MHz, the local oscillator became a 436.80 MHz signal generator. Other scanners use different intermediate frequencies and different mixing schemes but will probably still have a LO frequency about ten megahertz from the received frequency.

The local oscillator signal was quite strong and easily detectable when placed near the downconverter. To distinguish it from other signals and images in the receiver bandpass, I configured the scanner to scan between two or more channels; only one of which had a LO signal near 435 MHz. The desired LO signal will be present and absent as the scanner moves among different channels, giving it a distinctive beeping sound.

The preamp can be tested in a very similar manner. I again configured the scanner such that the downconverter could receive the local oscillator signal. Next I placed the scanner at a distance from the receiver such that the signal was just barely discernible and installed the preamp with the power disconnected. The preamp was inline after the antenna but before the downconverter. After I found the local oscillator signal and applied power to the preamp, there was a noticeable increase in the received signal strength. As a check, I removed the power from the preamp and moved the scanner farther away to the point where it was undetectable. When the preamp was turned back on, the signal was clearly audible.

It also turns out that the antenna can be tested using this technique. Although the actual gain can not be determined, I verified that my antenna was directional and that it did provide some amount of gain. As before, I placed the scanner at a distance from the receiver. Then I alternately pointed the antenna at the scanner and away from the scanner. The received signal strength increased as the antenna moved towards the scanner and decreased as antenna was pointed away from the scanner.

Basic Operations : Making your first contact on AO-27

Before you can make your first contact through any satellite, there are several pieces of information you will need to know: when the satellite is above your horizon, exactly where in the sky it will be, and when it will be available for use. The first and second are determined through satellite tracking and the third requires knowledge of the transponder schedule. You should also find out what your grid square is. This isn't really necessary, but just about everyone will ask you for it.

These days the way to track satellites is to use a computer with a satellite tracking program. Several tracking programs for various computers as well as the necessary up to date Keplerian elements are available from AMSAT at **http://www.amsat.org**. Any of the tracking programs will give all of the details necessary to access the bird: the exact time that AO-27 will be visible above the horizon, the compass direction to point the antenna (the azimuth) and how far above the horizon to tilt it (the elevation).

Once I started working stations on AO-27, I noticed some of the nice regular characteristics of its orbit: most of the passes are near lunch time, and on these passes it will always rise towards the north and set towards the south. Whether the satellite tracks more to the east or west depends on the particular pass. The transponder schedule for AO-27 has the mode J transponder active for these passes all the time. Less frequently, the transponder will also be active on the evening passes when AO-27 rises from the south and moves north. Compare this to RS-10 or MIR, whose schedule and directions vary greatly from month to month. It is relatively easy to follow AO-27 in its path across the sky once the signal is found. At the time indicated by the tracking program, point the antenna at the azimuth where the satellite should rise. You may need to adjust the antenna to obtain the best signal on the downlink. Try moving it left or right, up or down, or rotating it ninety degrees clockwise or counterclockwise. The important point is to aim the antenna for the strongest signal, using the exact azimuth heading as a rough guide only. Once the downlink has been acquired, adjust the antenna in azimuth, elevation and rotation as necessary to maintain the signal. It might take a few tries to get the hang of how to do this.

All satellite passes are not created equally. When I was using my original station with the scanner, I only tried to work AO-27 on those passes that would reach a maximum elevation of at least forty-five degrees. Lower elevation passes will place the satellite at a greater distance exceeding the capability of both the HT and the scanner. Passes earlier in the day will be more to the east and those later in the day will be more to the west. You can use this to your advantage. For example, along the eastern coast of the United States, the earlier passes will place most of the satellite's footprint out over open ocean. This reduces the number of satellite stations which can access the transponder, but it also reduces the interference caused by other signals in the two meter band. Certain passes over the Atlantic include both the United States and England within the footprint for a few minutes. When combined, these features make the lower elevation earlier passes a favorite among some of the operators on the eastern United States.

As the satellite travels overhead, its signal will appear to change frequency. This phenomenon is known as the Doppler shift. In order to compensate for doppler on AO-27, lower the receiver's frequency gradually as needed. Start listening five to ten kilohertz above the actual downlink frequency of 436.8 MHz. Set the two meter FM transmitter to the satellite's uplink (145.850 MHz) and leave it there. The satellite will compensate for the doppler on the uplink. On FM, you want to listen for silence or a drop in the static level. This is your clue that you have the antenna pointed in the right direction and AO-27 is getting closer. Now wait until you can hear the downlink from AO-27. DON'T TRANSMIT UNTIL THE DOWNLINK FROM THE SATELLITE CAN BE HEARD! This is very important. The satellite WILL retransmit all the signals it hears. Some people transmit without hearing the downlink and only succeed in disrupting the pass for everyone else who can. You might want to listen to two or three complete passes before you even try transmitting. When the satellite hears your signal you will hear your own voice on the downlink. This is normal, but might take some operators by surprise. Headphones or earphones are highly recommended. It's very easy for the sounds from the receiver to get into the microphone and distort your uplink signal. There will be times when the signal from the satellite appears to be rapidly switching polarity and times when the signal fades for short periods of time. This is normal. Just try to work around it.

Satellite contacts on low Earth orbit birds like AO-27 are usually short and contest style, especially on weekends when many stations are trying at the same time. On weekdays there are far fewer stations.

Assorted Tips and Tricks for Working Amateur Radio Satellites

- I try to be ready for the pass five to ten minutes before the expected starting time. This allows adequate time for any last minute complications.

- During each pass I wrote down call signs, names and grid squares of every station that I heard that I didn't recognize. If I later worked one of those stations, I could use this information as a check that I had copied the QSO information correctly. I used a preprinted list that contained the time, azimuth and elevation along with room on the right hand side to write in callsigns, names and grids. This served as a quick log during the pass. The details were later entered into my logbook.

- I concentrated my efforts on improving the downlink. The uplink was easily obtained with just a few watts from my HT. The only problem is when it's captured (and denied to others) by stations running excessive power. As a beginner, I could not compete against the higher powered stations with large directional antennas, but I was able to make contacts when I dropped my callsign immediately after two other stations ended their conversation. I found that adding "QRP" or "mobile" to the end of my call makes me a more desirable contact.

- When working AO-27 mobile, I always brought two sets of keys and tried to find a good spot to set up my station. A great spot would have a perfectly flat horizon in all directions. Being on top of a hill was not necessary a good thing, especially if there was a radio tower on the hill with me. Strong signals from the tower could desense the receiver. I usually set up the components of my station on the trunk of my car in roughly the same positions. This minimized the confusion when looking for a particular knob, the microphone, log sheet, or whatever. Permanent stations don't have this problem.

- I didn't try to start off with a great station. I started simple. I got it to work first and then made incremental improvements. This way I got on the birds sooner than if I had waited and tried to build a really terrific station. I also learned how well the various parts of the station worked, and this allowed me to know when a modification had improved or degraded the performance of the whole system.

- I noticed that there is sometimes a slight difference between the predicted azimuth for a pass and the actual azimuth which gives the best signal. In these cases, I just pointed the antenna for the best reception and adjusted it periodically.

Conclusion

Getting started on AO-27 is easy. Anyone can do it, and most amateurs probably already own everything they need for the uplink! In addition, several characteristics of AO-27's transponder and orbit make it ideally suited to the beginner. I hope this paper has been informative and instructive.

That's all folks! And of course, thanks to my wife who assisted in the preparation of this work. If you have questions or comments, feel free to contact me at dquagliana@aol.com.

See you on the birds.

Figure 1 The KA2UPW Satellite QRP Mobile station

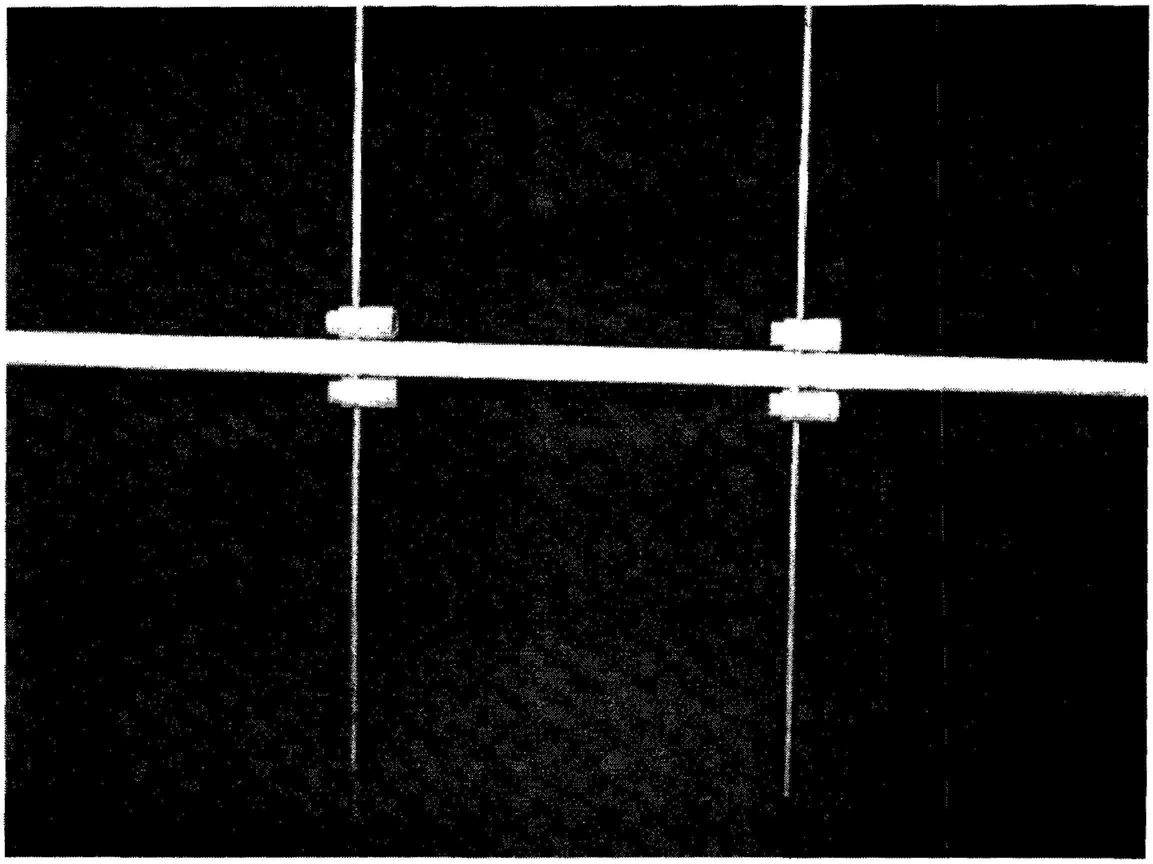


Figure 2 Closeup picture of the 435 quagi directors and cord locks.

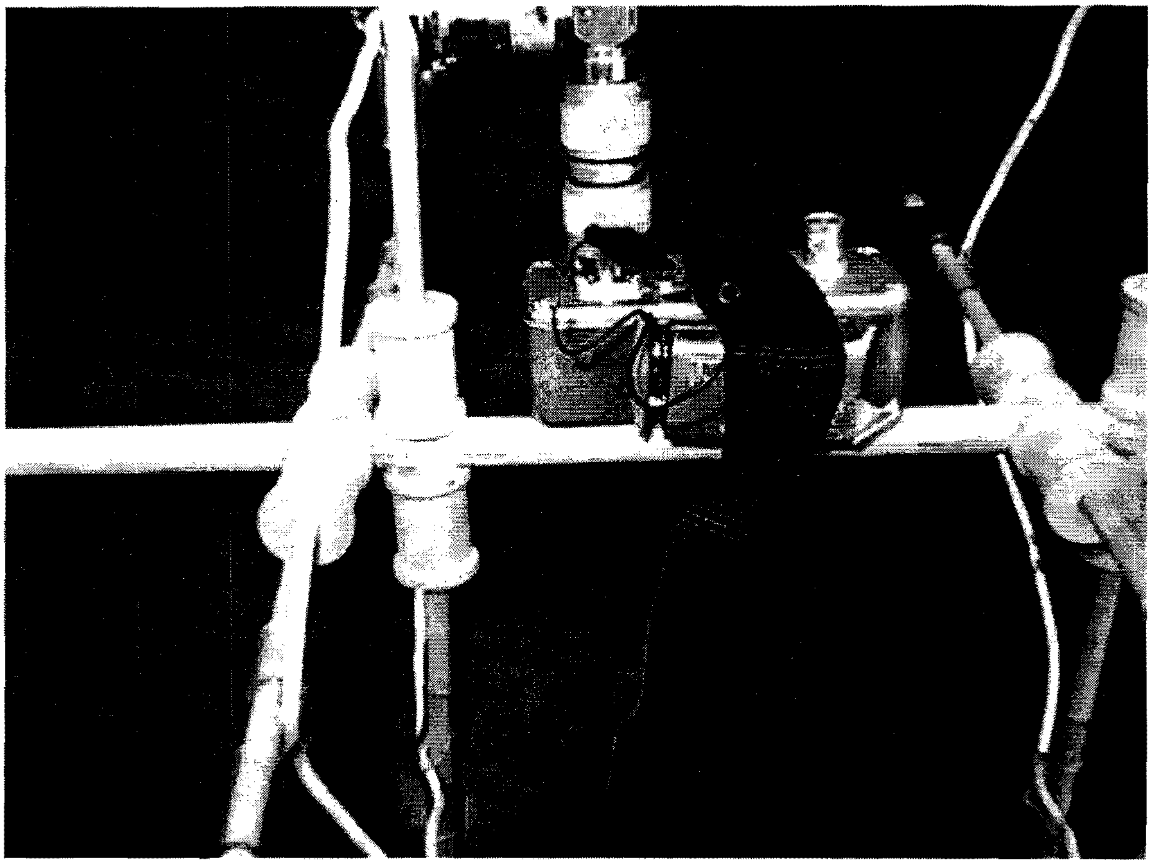


Figure 3 The 435 MHz DEM preamp mounted directly on the boom.

My "Landfill Special" RS-10 Satellite Station

William D. Rausch
billraus@ix.netcom.com

As an AMSAT Area Coordinator, I have a lot of contact with the general ham population. I have a booth (See Fig. 1) which I take to the very popular Foothill College and Livermore Ham Radio Flea Markets in the San Francisco Bay region. I also speak before radio club general meetings. When I exhort other hams in these contexts to try using our satellites, the most common protests that I hear are "It's too expensive!" and "I'd have to buy a whole new station!" Telling them that there are solutions to both of these obstacles seems to have little effect. I dreamed of having a demonstration station, put together from low cost equipment, that I could exhibit in my booth, but I'm on a tight budget myself. Well, I didn't expect that it would be as easy as it actually came to be.

I have a ham friend, Brian Yee, KD6LI. Brian is a microwave enthusiast of the first order, and an avid contester, besides. He's also notorious as a packrat - well, aren't most of us who like to build things? But in Brian's case, it got so out of hand that he couldn't move around in his ham shack or workshop! So, one day early in June of this year he had a cleanout session. He used the triage method. The stuff which was in bad shape or just plain junk was destined for the ashcan if one of his friends didn't pick it up. There was another pile in which the items were for sale. And then there was the small pile of goodies which he wanted to keep. They were salvaged, some because he had forgotten about them, and others had been buried under the stuff that wound up in piles 1 & 2. I visited him and picked around in it. I spied an Icom IC-245, which appeared to be an older 2 M. mobile FM rig, in the first pile. My first reaction was "No- I don't need any more 2 M. FM gear". Then I saw a small label on the front panel which said "FM-SSB-CW". That piqued my interest! I wasn't sure whether Brian had put it in the wrong pile, so I asked him. He replied "No, I got that from Pete, and he said that it didn't work. It's free to you, otherwise it goes into the landfill!" At that price, I figured that I could take it home and try it out, and if it didn't work, I'd be the one to put it in the landfill.

On the way home from Brian's place, I hooked it up in my pickup truck for a smoke test and an attempt to raise someone on one of my habitual repeaters. On powering up, the smoke stayed inside of the chips, but the display wouldn't light, so I didn't know what I was tuned to. I soon found a sequence of button pushes, nothing really logical, that would make the display light up. Then I tried tuning into a repeater, but the receiver tuning calibration seemed to be off by 70-80 khz. I had no luck accessing a repeater, but working simplex to an HT I had with me was fine. When I put it on the bench at home, with a wattmeter, power attenuator and frequency counter connected to the antenna jack, the transmitter put out 8.5 w of cw and several peak watts of reasonable sounding USB. None of its' defects were a hindrance to its use as a Mode A uplink. So I had one half of an RS-10 station! See Fig. 2. The other half came in the form of a Radio Shack HTX-100 10 M. mobile rig that I'd bought back when that band was hot several years ago. For most of that time, it'd gathered dust in my garage workshop. I'd paid full price for it when I bought it, but you can find them, or equivalent Uniden or Ranger models for about $125 -175 at flea markets like the ones that I set up my AMSAT booth at. See Fig. 3. You might even find one with a blown transmitter final at a friend's house, ready to go to the landfill!

For antennas, I've experimented with a 15' 11" long wire dipole suspended between two 10' pieces of TV mast for the downlink, and a turnstile made from 300 ohm twinlead and PVC pipe over a hardware cloth groundplane for the uplink. See Figs. 4 & 5. Since this is a demonstration station, any antenna that I use has to fit into the size of two parking spaces, the usual allotment for sellers/exhibitors at the flea markets.

But what about tracking? I have an old PC laptop with 1 M of RAM, two 3½" floppy drives and no hard drive. It runs MS-DOS 3.3 and QUIKTRAK. See Fig. 6. You can find clunkers like this rather easily at garage sales, etc. for cheap. They are just fine for the majority of ham applications. You certainly don't need a Pentium! Two of my fellow Project Oscar Board of Directors members have come up with a tracking program for the old Radio Shack Model 100 series laptops. You could even use the old OSCARLOCATOR method and no computer for those who are still computerphobic. It can be found in the back of the Satellite Experimenter's Handbook.

Extensions - I have a Mirage B-108 amplifier for use with my little ugly station with RS-15. That bird is far enough out that the extra 8.6 dB on the uplink would be needed. A 435 MHZ to 29 MHz downconverter would allow contacts through FO-20, although at this point, you might think about better antennas. Also available to you at this point with a computer and the proper TNC/PSK modem and software would be AO-16, WO-18 and LO-19, but we're getting out of the "landfill" domain by then.

Since I've just built this station, I don't have any on-the-air results to report. I hope to have this rectified by the annual meeting, as I'm sure that that's the proof of all of this for many hams.