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AMSAT

RADIO AMATEUR SATELLITE CORPORATION

PROCEEDINGS OF THE

AMSAT-NA

Eleventh Space Symposium, and **AMSAT** Annual Meeting

October 8-10 **1993**

Arlington, TX

Cliff Buttschardt K7RR
950 Pacific Street
Morro Bay CA 93442

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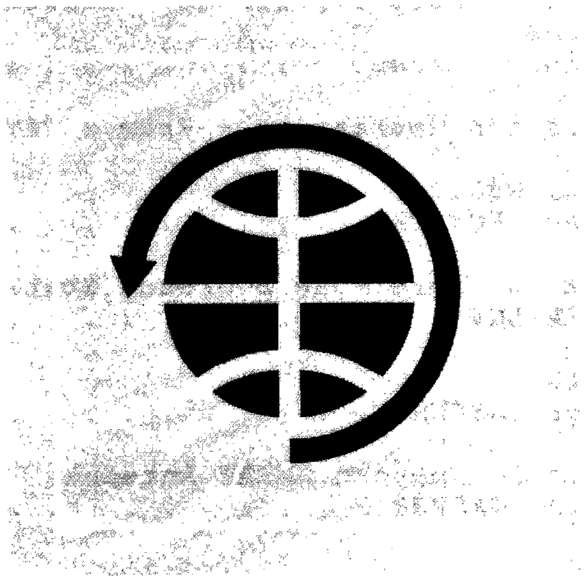

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Welcome to the
1993 Space Symposium
& AMSAT-NA Annual Meeting

This is a very important year for the amateur radio space community and for AMSAT-NA in particular. It is the year that, after several years of planning, construction actually began on the most challenging amateur spacecraft yet - Phase 3D. But, there are other new amateur satellites besides Phase 3D. If all goes as planned, we will have four new ones up by the time you arrive at this meeting. The Ariane V-59 launch, scheduled for September 21, should have taken place carrying IT-Sat, Eye-Sat, PoSat and KitSat-B into orbit. As in January 1990, we should soon experience the challenge of learning to use a bunch of new birds at once.

Although the Phase 3D spaceframe, constructed in Germany during the summer, is not the one intended to be flown on the big new Ariane-5 launch vehicle in April 1996, it does represent the first hardware produced in the long and involved task of building this most ambitious of amateur satellites. First, it answers a lot of detailed design questions and confirms that the hundreds of drawings, slaved over so long by WD4FAB, are correct and sufficient to produce the flight hardware. Second, it may very well serve as a backup, or second, spaceframe if such is ever needed. In addition, over the past few months, actual design work was begun on various electronic modules. Several German teams are hard at work designing and building transmitters for 70 cm and 13 cm and receivers for 2 meters, 70 cm and 23 cm. A Finnish group is making good progress on a 10 GHz transmitter and have shown "brassboard" hardware. A Belgian group has stated its intention to construct a 24 GHz transmitter. As previously noted, the South Africans have signed up to provide a 10 meter bulletin transmitter. Work on the IHU (central spacecraft computer) has also begun in Germany. By now, everyone has heard that a 2 meter transmitter is to be built in Great Britain. This effort is now also underway.

Yes, Phase 3D has finally begun the transition from an idea on a blackboard to actual hardware. That does not mean that its successful completion is a foregone conclusion. There is a long way to go and additional competent electronic designers and builders are still needed to assure a completed satellite. The GPS subsystem is but one example. W3IWI can address that situation. There may also be a need for someone to provide a 5.7 GHz receiver. Talk to WD4FAB, W4PUJ or me, if you think you can help on this or anything that needs to be done.

The other reason why this is an important year is that AMSAT-NA is making a concerted effort to project its presence and expand its membership. This will help assure the future of the organization after the launch of Phase 3D, as well as contribute to that spacecraft's fundraising effort. The ARRL Phase 3D fundraising campaign is a tremendous help. Not only is it raising a substantial amount of money, well over $100,000 as of mid-August, but it is carrying the amateur space program message to nearly 200,000 hams; a significant number, newly licensed. Until the ARRL campaign began, many amateurs had only vaguely heard of AMSAT or the OSCAR satellites. This new awareness, on the part of many more "average" amateurs, is greatly aiding the AMSAT-NA drive to recruit new members. Couple this with the ads for this meeting, placed in all of the major amateur media and the special new member offer, and you can see that AMSAT-NA, and the entire international amateur space community, is becoming an increasingly important factor in Amateur Radio. You can aid this process, when you return home, by urging your friends to become AMSAT-NA members. For a limited time, all new members will receive a copy of the fine introductory book, "How to Use the Amateur Satellites" by Keith Baker KB1SF and "ORBITS-2" tracking software by Roy Welch W0SL.

We are glad to see you here; and please feel free to ask me, or other Board members or officers, any questions you like - or just tell us what's on your mind.

73,

Bill Tynan W3XO
President
AMSAT-NA

The AMSAT Phase 3D Spacecraft

by Dick Jansson, WD4FAB

for presentation to the AMSAT-NA Space Symposium, October 1993

ABSTRACT

Following an ESA-dictated change in the design of the P3D spacecraft, AMSAT has reevaluated the entire design and created a spaceframe that is truly tuned to our needs. This paper will address the key Mechanical Engineering aspects of this design for both the spaceframe and the launch adaptor. It will cover the mechanical, structural and thermal designs of the spaceframe. Descriptions will also be given on the antennas to be carried and the launch vehicle separation system to be used.

INTRODUCTION

The AMSAT International Phase 3D (P3D) Spacecraft Program took an unwanted backward step, in November 1992, as a result of the decision by the European Space Agency, ESA, to withdraw the use of the ø1920mm launch vehicle interface, both of the bolted and separable designs. This calamitous event totally trashed the "Falcon" spacecraft design that was about to be constructed at Weber State University in Ogden, Utah.

Rising from the ashes of the events of November 1992, the multi-national P3D Project Team has now created a spacecraft design that is much more likable and workable. Team members will also appreciate the improved access to their units contained in the sides of the spacecraft. AMSAT-DL and AMSAT-NA workers have completed their basic efforts to construct an Engineering Model spaceframe in Marburg, Germany, working with Project Leader, Karl Meinzer, DJ4ZC, and Konrad Müller, DG7FDQ. The US participants of this team are now applying the resulting spacecraft design and fabrication experience in fabricating a Flight Model spacecraft at Weber State University, Ogden, Utah. The Utah group is lead by Ralph Butler and Jaim Parsons. This paper will discuss some of the construction experiences of this summer 1993.

LAUNCH VEHICLE INTERFACE

Fig.1 illustrates the payload sections of the Ariane AR502 vehicle, showing that P3D could be launched from either the upper or lower launch positions. Basically, the plan is to simply raise one of the conical Adaptor sections, used to attach a payload spacecraft to the launch vehicle, spacing it with a cylindrical section, Fig.2. This cylinder is called a ø2624 Specific Bearing Structure (SBS). Mounted to the top of the SBS is an ESA provided separation section, the ø2624 ACU. This, in turn, supports the 1194V Adaptor and its attached spacecraft. This arrangement provides the P3D a volume of ø2300x750mm, including the P3D separation system.

The P3D spacecraft is designed to fit within a volume of ø2300x675mm. There is 75mm allowed on the bottom for the separation hardware and omnidirectional antennas. On the top there is an additional 310mm for the main antennas and propulsion motor. Fig.3 shows the composite three-dimensional view of the P3D spacecraft and the SBS, ACU and Adaptor. Also shown are representations of a P3C (AO-13) and a PACSAT (AO-16) spacecraft.

ø2624 SBS

The preliminary design of the ø2624 SBS is shown in Fig.4. The design uses a rather unsophisticated sheet aluminum structure with internal stiffening stringers and machined rings, or Frames for bolting to adjacent structures. Internal sheet metal structures are located in three places to support the P3D and its separation system. These details are shown in Fig.5, and show two possible separation pyrotechnic options.

A considerable effort has been made to create usable engineering analyses of the structural characteristics of the SBS. Basically, it meant that I had to return to the 'books' to re-learn engineering methods long lost, and bring them into the modern world of computer analysis. I also found that the computer software far exceeded the capacity of the personal computer being used. My equipment had to go through a very serious upgrading to permit operating high-speed PC units for many hours at a time for "number crunching". There are many days that even the newly acquired 80386/80486 computer facility is never off, being required to operate a 24 hour day on long analyses.

Structurally speaking, we are designing to have the first structural lateral resonant frequency greater than 30 Hz. This high of a frequency gives us a very safe high-value Buckling Factor (BF). Under these constraints the issue of structural stresses have become so low as to be of little concern, typically 20-35% of material yield strength.

While AMSAT has been basically tasked to construct the ø2624 SBS, the final construction details are not totally clear. Internationally, AMSAT has an acute labor base shortage, both mechanically and electronically. We barely have sufficient personnel to construct the spaceframe by June 1994, without consideration of the SBS. After June, we may have the next group of students to construct the SBS, but that availability may not agree with ESA requirements, and the issue will need to be resolved.

THE SPACEFRAME

Fig.3 shows many of the basic features of the P3D spaceframe. The structure is a hexagonal cylinder that is 2240mm across the corners. Permanently mounted solar panels are attached to two sides of the spacecraft, centered on the +X direction. The other four sides have deployable solar panels held closely to the frame for the launch and motor burn phases of operation. Upon completion of these propulsive efforts, the spacecraft will be magnetically torqued to stop the initial spinning motion. Once stopped, the spacecraft's internal reaction wheels will provide the motion control mechanization and the solar panels will be deployed as shown.

Underneath the outer skin of this spacecraft there is a lot of detailed structure and many subsystems. Fig.6 depicts an exploded view of the spacecraft, courtesy of Wilfried Gladisch, the very talented Technical Illustrator of the Marburg group. This shows the radial, sheer-loaded Divider Panels and three concentric hexagonal cylinders, composed of the external Side Panels, Equipment Panels and the Center Panels. Below Side Panels, are the equipment bays and all of the electronic modules. These bays are only 200mm deep and are therefore readily accessible (even by my "short-armed" electronic colleagues).

The next hexagonal cylinder is constructed of the Equipment Panels. These panels have become rather complex structural subassemblies, having the Module Mounts attached on one side, and one end of the Tank Mounts on the other side. Also mounted on interior side of the Equipment Panels are the Heat Pipes used for the spacecraft thermal control system. The equipment bays can contain up to 36 full sized modules with PC boards of 200x270mm. Only some 28 modules are expected to be flown. Obviously there are some special sized cases, and these will also be discussed.

An important aspect of mounting the Equipment Panels is in achieving a coplanar coincidence of the heat pipe facets with the surfaces of the panels. In the world of sheet metal this is somewhat of a difficult challenge. (An analog would be that of the probability of rolling six 300 Bowling games in a row.) This was considered one of the major goals to be met by the Marburg fabrication of the Engineering Model spacecraft. It was accomplished with precision by the team, certainly a high-point of our effort.

Moving further inside, past the equipment bays, are the propellant bays, with the six spherical Propellant Tanks, Fig.7, currently being fabricated in Russia. About 46% of the 400kg (881lb.) launch separation mass of P3D will be the liquid propellants needed to get the spacecraft to its final orbit. While in Marburg, the Russian drawings for the tanks were reviewed and some adjustments were made. The drawings forwarded to us were not copies or machine prints, but a second set of *hand-drawn originals*, made because there are no large copy machines in Russia.

Also mounted in these propellant bays will be the spacecraft's attitude controlling Reaction Wheels and the Battery power storage cells. The Propellant Tanks are also supported on the inner-most hexagonal cylinder by the Center Panels, which provide a hollow internal cylinder for the high-pressure helium tank, routing of propellant lines and accommodating portions of the two motors that will be an intimate part of the spacecraft.

On the top and bottom surfaces of the spacecraft there will be an outer ring of thin aluminum permanently attached to the Divider and Equipment Panels. Inner removable panel sections on the top and bottom provide easy access to the propellant bays.

Careful assembly of the various parts and subassemblies will be needed, along with a large quantity of rivets. The machined Corner Posts are products of student labors at Weber State University. It can also be seen that the Heat Pipes have been carefully installed into the holes provided in the Divider Panels. In the fabrication of the Engineering Model of spacecraft, we generated some impressive statistics. In the finished spaceframe, there will be a total of 9,954 holes or drilling operations of some kind. This also means some 19,908 deburring operations. Most of these holes were drilled during our stay in Marburg. The equipment panels alone have 3,282 holes in them, and we did them in just one week with the assistance of the drilling templates provided by the WSU student efforts.

The Engineering Model spacecraft construction effort got to the point of having the principal structural panels fabricated and assembled with the Heat Pipes. The Top Plates (for both top and bottom of the spacecraft) did not get done nor were any of the internal stringers that will be needed on some panels. Konrad Müller will complete these items in the near future.

THERMAL DESIGN

There are steps and technologies that had to be applied to the satellite design long before any of the sheet metal bending activities. One of these is that of the spacecraft thermal design. Construction and launch activities are rather useless if satellite designers fail to deal with the thermal requirements. Several Amateur satellite thermal design failures have been seen in the near and distant past and those design errors need to be avoided.

Our challenge is to keep the equipment on the sun side of the spacecraft from becoming too warm and the equipment on the rear of the spacecraft from becoming too cold. Sizeable amounts of power dissipation from transmitters also needed to be accommodated safely. All of these objectives are being met by the fabrication of only four internally mounted heat pipes. (The Falcon spacecraft used 16 heat pipes.) For the uninitiated, a heat pipe is a tubular device that is an extremely effective transporter of thermal energy over considerable distances - a *super* thermal conductor - using anhydrous ammonia as the fluid.

The four Heat Pipes in the spacecraft are mounted to the propellant bay side of each of the six Equipment Panels. This places the Heat Pipes immediately underneath the electronic modules on the spacecraft internal structure. No disassembly of these Heat Pipes will be needed for access to the spacecraft interior and the electronics bays. Fundamentally, these Heat Pipes are used to redistribute the thermal energy uniformly throughout the spacecraft, equalizing the sun and anti-sun side differences, as well as the transmitter power dissipations.

One thermal control method, used on OSCARs 10 & 13, employed insulation blankets, Multi-Layer Insulation (MLI), using a very specific type of thermal insulation for space use. These are messy to construct and use and we want to avoid them on P3D.

We have deliberately changed some of the solar panel precepts of this spacecraft from its predecessor Falcon design. The earlier design planned to have one of its three solar panels fully populated with solar cells, which in turn required that a considerable amount (≈700W) of rejected solar heat to be removed from the *backside* of the panel, in addition to that radiated from the front of the panel. Accomplishing this thermal transport, without creating undue heating of the spacecraft internal components, required the mounting of an array of heat pipes on the exterior surfaces and closely coupled to both the solar panel and adjacent radiator panels. This system would have been complex at best and would have required extensive (read that as *messy*!) thermal structure disassembly to gain access to the spacecraft interior.

The current design of the P3D also has one-third of its solar panel area as body-mounted units. We have, however, taken deliberate steps to alleviate the need for any *backside* heat transfer from these panels by only populating these panels with one-half of the solar cells in the available area. The other half of the area has solar reflecting surfaces mounted alternating with the solar cells. These Optical Solar Reflector (OSR) surfaces are actually second-surface quartz mirrors and do a very thorough job of getting rid of unwanted solar energy.

In the thermal design consideration for the spacecraft we will again employ a device that has been quite successful in prior Phase 3 spacecraft. This is the use of a thermally insulating fiberglass channel for mounting the electronic modules. This channel also reinforces the Equipment Panels. This thermal technique isolates modules from thermal conduction heat transfer with the spacecraft. Most modules are quite low power dissipation and they enjoy only modest temperatures. They are isolated from any significant temperature changes of the spacecraft, such as seen from eclipse events. This technique has worked very well in the past and will again be implemented.

Some electronic modules have a high power dissipation, however, and for these situations we have designed a modified module, one that will permit direct mounting to the Equipment Panel and the Heat Pipes. Thus we will have a solid thermal design with adequate cooling of high power components and the availability of that rejected thermal energy to insure that the spacecraft will not become unnecessarily cooled. A series of thermal tests is being planned with the use of a section of heat pipe and modelling of part of the power module. The data generated will give us some degree of confidence about achievable heat transfer values using some of the materials and surface finishes of interest.

ANTENNAS

One of the subjects that is close to nearly every Radio Amateur, and for which nearly all of us become 'expert,' is that of antennas. We are fortunate that we have the services of one of the more ingenious participants in the P3D program, Stan Wood, WA4NFY. Stan has had no preconceptions about the antennas needed, and has done a large amount of research to find suitable designs. Fig.3 illustrates most of this current thinking. Not illustrated, however, is the ≈¼ wavelength driven element and reflector monopoles for the 0.29 GHz perigee broadcast transmitter. This radiating element uses the spacecraft as a counterpoise and achieves a ≈3dBi gain.

Next in line are the 0.145 GHz "V Band" elements, which have caused by far, the greatest amount of work to be done. The design that has been selected uses three double-folded dipole radiators spaced above the spacecraft Top Plate, which acts as a reflector plane. The three radiators are feed in CP phase for an ≈10 dBic performance, which is pretty good considering the limited space available.

Going upward in frequency are the elements for 0.435 GHz, "U band" array consisting of six patch antennas in a hexagonal arrangement. The ideal configuration of such elements actually uses seven patches, with the added unit in center. As the Top Plate "real estate" parameters dictated that the element spacing on this array could not be at the ideal one-wavelength spacing. The array gain had to be compromised. That compromise, in turn, meant that the center element could be deleted, substituting the MBB 400N propulsion motor without any appreciable effects on gain. The patch elements use a unity dielectric spacer and achieve nearly full theoretical gain in the range of ≈8.7dBic each. The array gain is in the 14-15dBic range. Each patch element has its own CP phasing feed built-in, and the group will be feed in-phase.

Continuing into the microwave domain is the 1.27 GHz, "L band" antenna consisting of a design known as a Short BackFire Array, SBFA. This design has a ¼ wave high fence at a diameter of 2 wavelengths. It uses crossed dipole elements on the center post and has a small reflector at a height of ½ wavelength. Gain performance is consistently ≈15dBic. It is expected that the U band and L band antennas will be the work-horse spacecraft receiving elements.

Antennas for the 2.4 GHz, "S band," and 5.6 GHz, "C band," operations will consist of either parabolic reflectors (the C band antenna is not illustrated) or SBFA units. In either case, these designs will permit performances of ≈20dBic, which is the highest that we desire to go and still achieve full illumination of the Earth. This type of performance can be achieved with the space available, using ø0.5m for the S band and ø0.25m for the C band antennas. The basic consideration for setting the gain for any antenna is that it provides full illumination of the Earth at apogee and that at perigee the signals seen on the Earth limb will be no less that those seen at apogee. The only bands for which these parameters may be of concern are for S, C, X and K. Meeting this criteria is seen as no problem for the lower gain V, U and L bands. Such RF design precepts will allow operating all of these bands without the need of any antenna gain switching or changing, keeping with the KISS principles for this spacecraft.

Partially blocked from our view by a V band element in Fig.3 is the horn antenna that will be used by the AMSAT-OH designers for the 10.5 GHz, "X band" transmitter radiator. There may also be a low-powered transmitter on "K band" at 24 GHz. This is seen as the P3D analog to the current S band operation of OSCAR 13.

Omnidirectional antennas for the spinning-mode of spacecraft operation are now being designed. There is a lot of busy 'action' happening on the Top Plate of the spacecraft. Careful selection of candidate antenna designs and management of the area resources will make all of this capability a reality.

PROPULSION AND ORBIT

Getting to the final orbit, where this spacecraft can provide the ultimate service that is intended, will require a substantial propulsive effort. In the terms of the rocket experts, a ΔV≈1800m/s (a propulsion energy term) will be required, resulting in the need for 46% of the spacecraft's separation mass to be high-efficiency propellants. For the principal propulsion, the design is to use the proven 400N (95lb.) thrust DASA (former MBB) hypergolic motor that has been successfully used in two previous Phase 3 missions, OSCAR 10 and OSCAR 13. This approach is well understood, and is not 'broken' so we do not intend to 'fix' it. Fig.8 illustrates the orbital stages that are currently forecast to reach this 16.0 hour final orbit.

The key element in propulsion for the final orbit, and possibly some level of orbital maintenance to avert such disastrous orbital problems as are now forecast for OSCAR 13, is the inclusion of a small Arc Jet motor. This thruster has only a value of 0.1N, but it also operates on only a single fluid, anhydrous ammonia, which can be stored for long periods. The motor uses 1 kW of electrical power to gasify the ammonia to high temperatures, achieving the needed thrust. This operation will happen for about a one hour time period for a number of apogee burns to increase the orbital plane from 60° to the stable 63.4° Molnia orbit. With a spacecraft capacity of up to 80 liter of ammonia, we have a maximum "burn" time of about 452 hours.

SPECIAL MODULES

In addition to the previously noted special designs needed to adapt high power electronic modules to provide cooling, there are some other cased worthy of note. The X band transmitter has some substantial thermal energy to be dissipated as it will probably have the poorest RF efficiency of all of the transmitters. In addition, the coupling of the RF output power must be given special consideration as efficient transmission techniques must be used to avoid merely heating the coaxial cable with RF energy. The geometric arrangement of this transmitter assembly will need careful design consideration, as has been recently discussed with the AMSAT-OH team members.

Other modules that have special needs, and also great interest, are the receivers for emissions in the 430,000 GHz region being constructed by JAMSAT. JAMSAT personnel are constructing three such receivers with different beamwidth receiving antennas. These are the SCOPE experiment cameras, A, B and C. The last of these will have a ø180mm reflective optical system capable of resolving celestial objects. The A and B cameras will be Earth viewing. The placement of the SCOPE C camera will require a special mounting provision and an optical path toward the -X side of the spacecraft, away from both the Sun and the Earth.

SPACECRAFT MASS

One very hard number in this design is that we must separate from the Ariane 5 at a mass of no more than 400kg. This means that the dry mass of the spacecraft can be no more than 216kg. In early July, Stan Wood totaled a value of up to 310kg, essentially a 100kg problem. The structure has shed some 15kg and is now 52kg. The propellant tanks are now 15kg lighter, leaving us still with a 60-70kg problem that will have to come from the support equipment and possibly even the experimental payload. Every worker needs to be aware of these problems. There may actually come a day in which some hard decisions will have to be made. Some of the payload may have to be removed from the spacecraft, as was necessary for the ill-fated Phase 3A spacecraft. We may, in the end, not be able to fly some experimenter's favorite package. The highest priorities will obviously be given to the Amateur communications equipment, but even those packages are not totally secure from such truly difficult decisions.

OBSERVATIONS

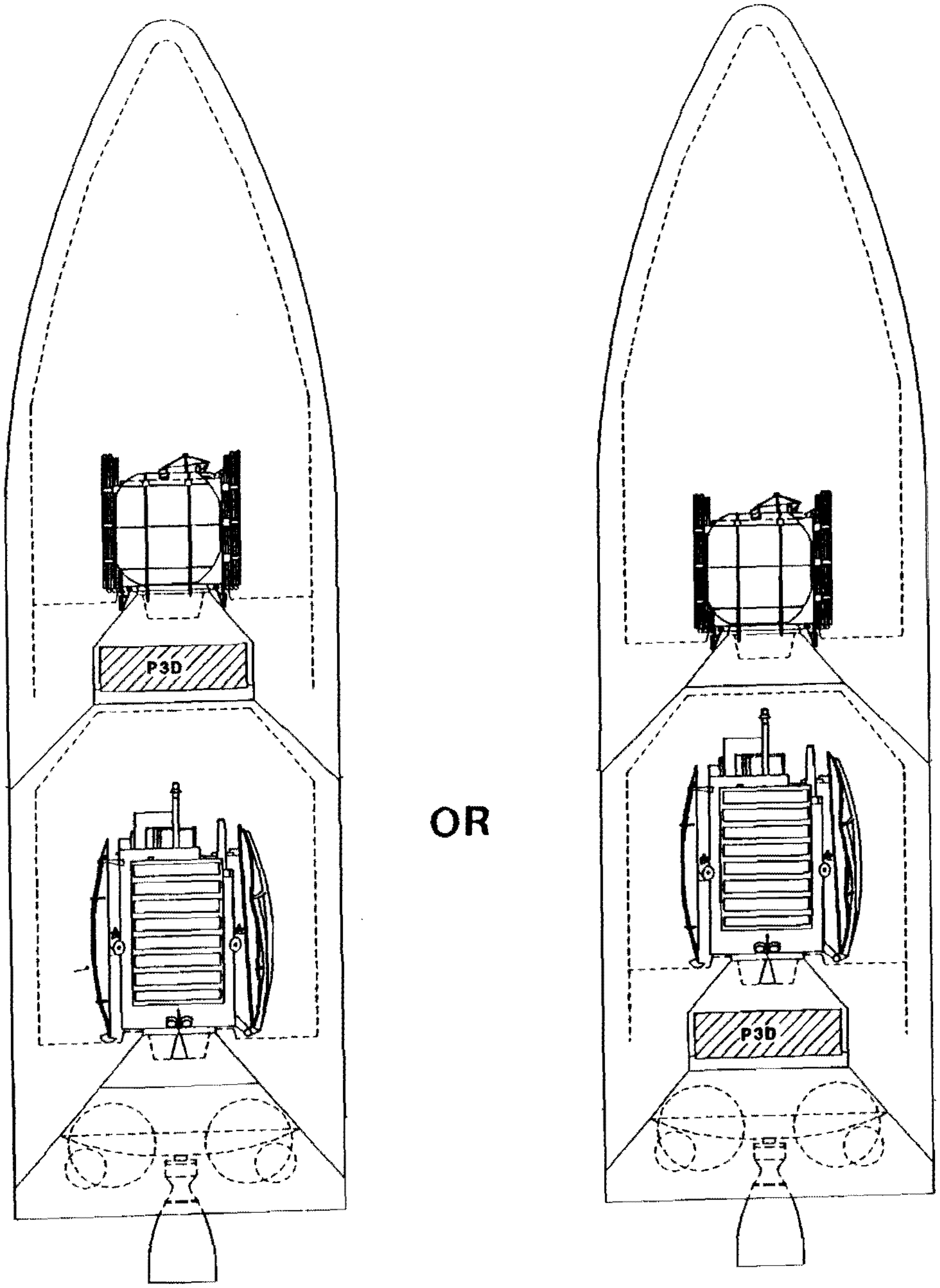
An intense two months was spent this past summer in Marburg, Germany, with the P3D Project Leader, Karl Meinzer, and his talented group of workers. This P3D project is Karl's creation, and he has substantial support from AMSAT-DL in seeing it through. As the spaceframe construction effort was not electronically oriented, not too much has been noted about the very sizeable effort that has just begun for constructing these modular units. One very key AMSAT-DL participant in this electronic effort is Werner Haas, DJ5KQ, who has worked on Amateur satellites since the early 1970's. There is another group of electronic workers in the Munich area of Germany as well as other units being built in Hungary, South Africa, Finland, Czech Republic, Great Britain and possibly several other countries. Clearly, the major amount electronics on this mission will be constructed in Europe, but they will be housed in module cases machined by the students at Weber State University, Ogden, Utah. This is only a small example of the international cooperation that *must* be accommodated and acknowledged for this mission to be successful.

The degree of international cooperation that will be required to bring this highly complex spacecraft to final orbit is unprecedented in the history of AMSAT. Quite naturally, the P3D supporters of each participating AMSAT group can take justifiable pride in the accomplishments of their particular group's contribution to the project. We must all remember, however, that this is an international team effort, and that no single group's contributions are "more important" than any other. Each piece forms an integral part of the whole. Without each group's contribution, the spacecraft cannot fly. It's that simple.

Phase 3D began as an AMSAT-DL project. AMSAT-NA and other AMSAT groups were cordially invited to join AMSAT-DL in the effort. We in AMSAT-NA accepted the offer and have been spending a lot of time and effort working for that day in 1996 when the P3D spacecraft is finally in orbit. Those of us now busting our rear ends to make the mission a success also know that it is far too complex a project for any one of us to "go it alone".

CONCLUSION

With all of the radio communications equipment and the special experiments on board the Phase 3D spacecraft, we have a very special spacecraft that can serve the needs of many Amateurs with many interests for a very many years. This is truly a satellite for all Amateurs.



A502 LAUNCH CONFIGURATIONS

Figure 1

A502-142

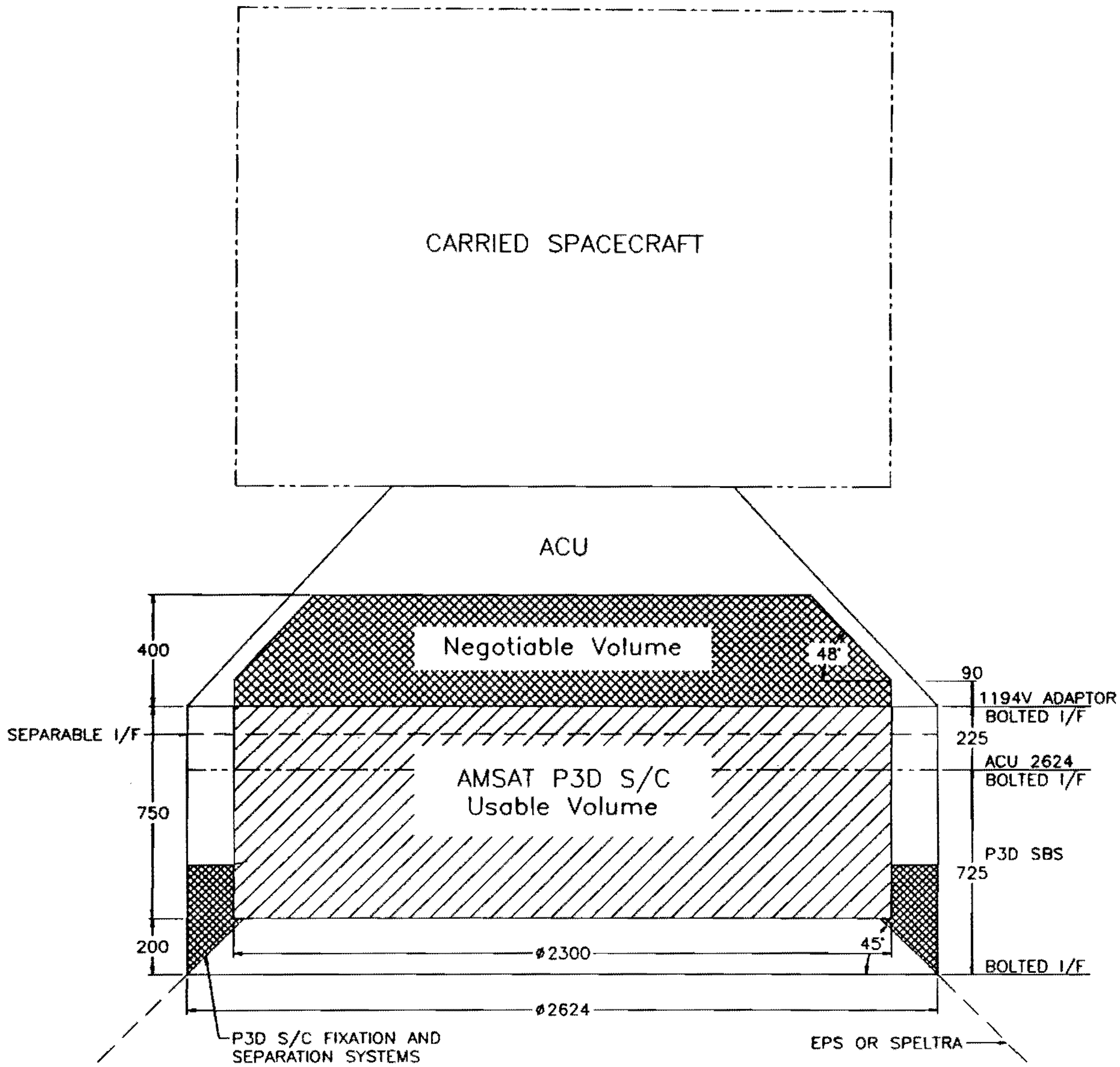


Fig.2 P3D Composite and Usable Volume

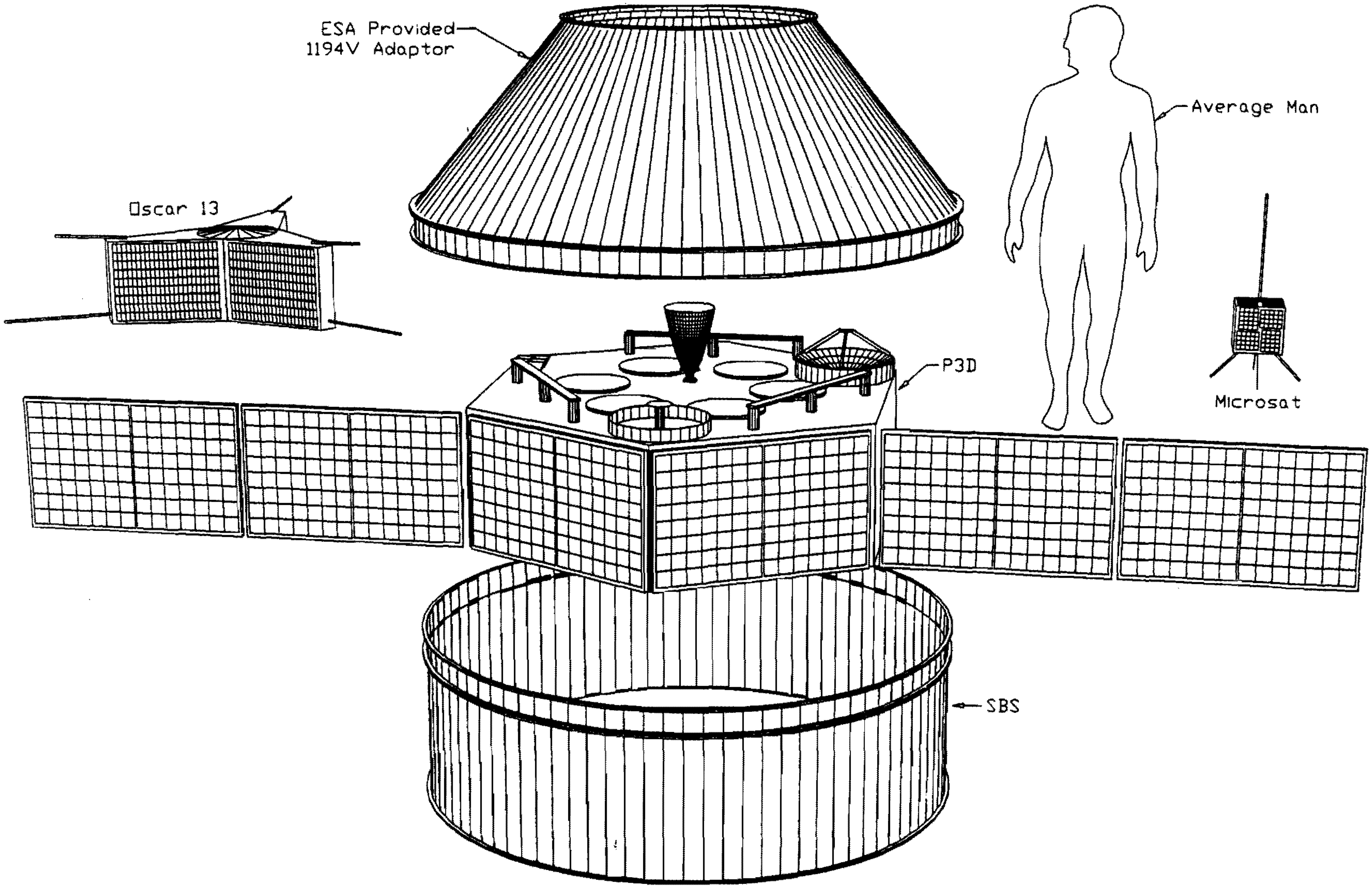


Fig.3, Phase 3D Spacecraft and SBS

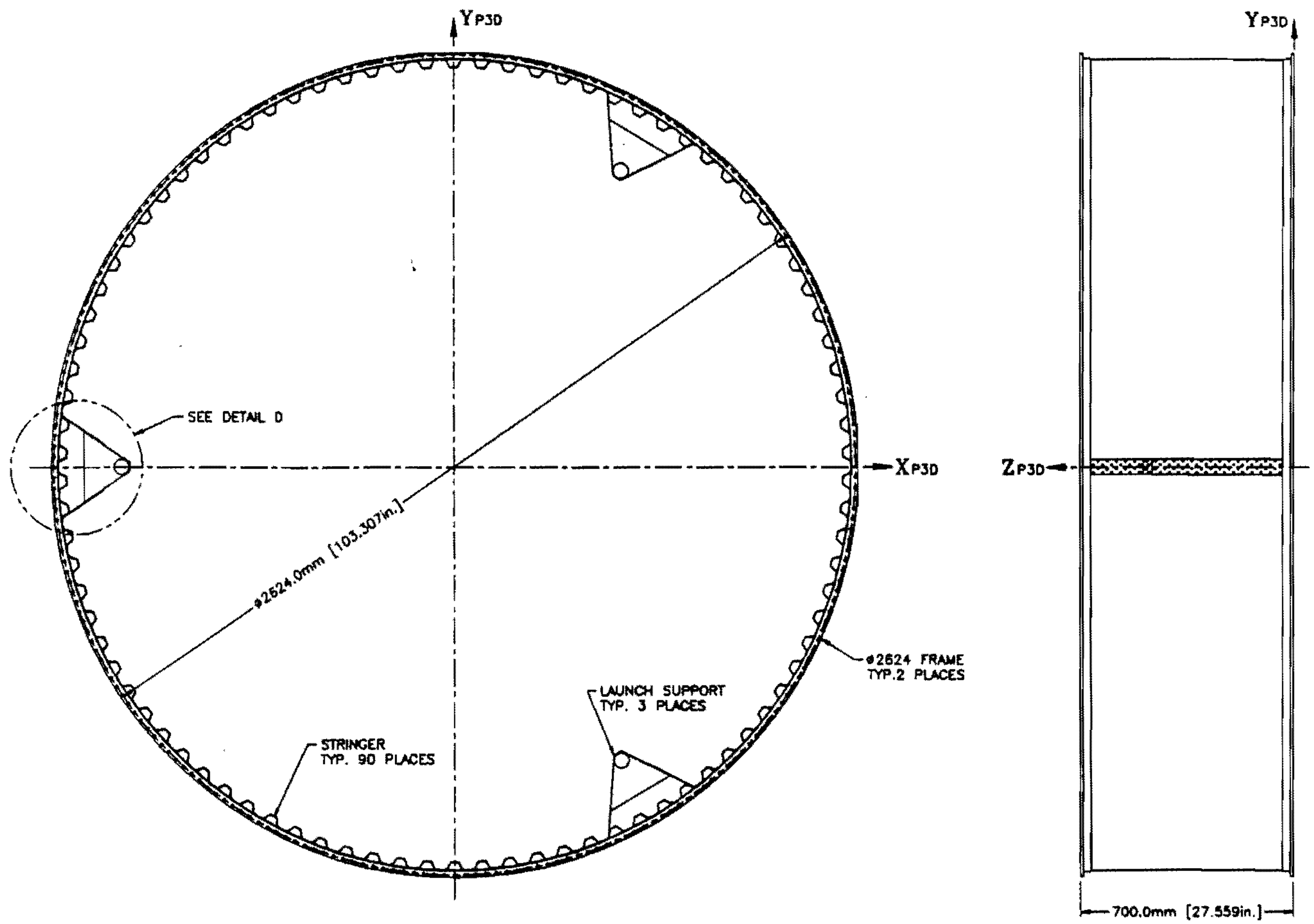


Fig.4 ø2624 Specific Bearing Structure (SBS)

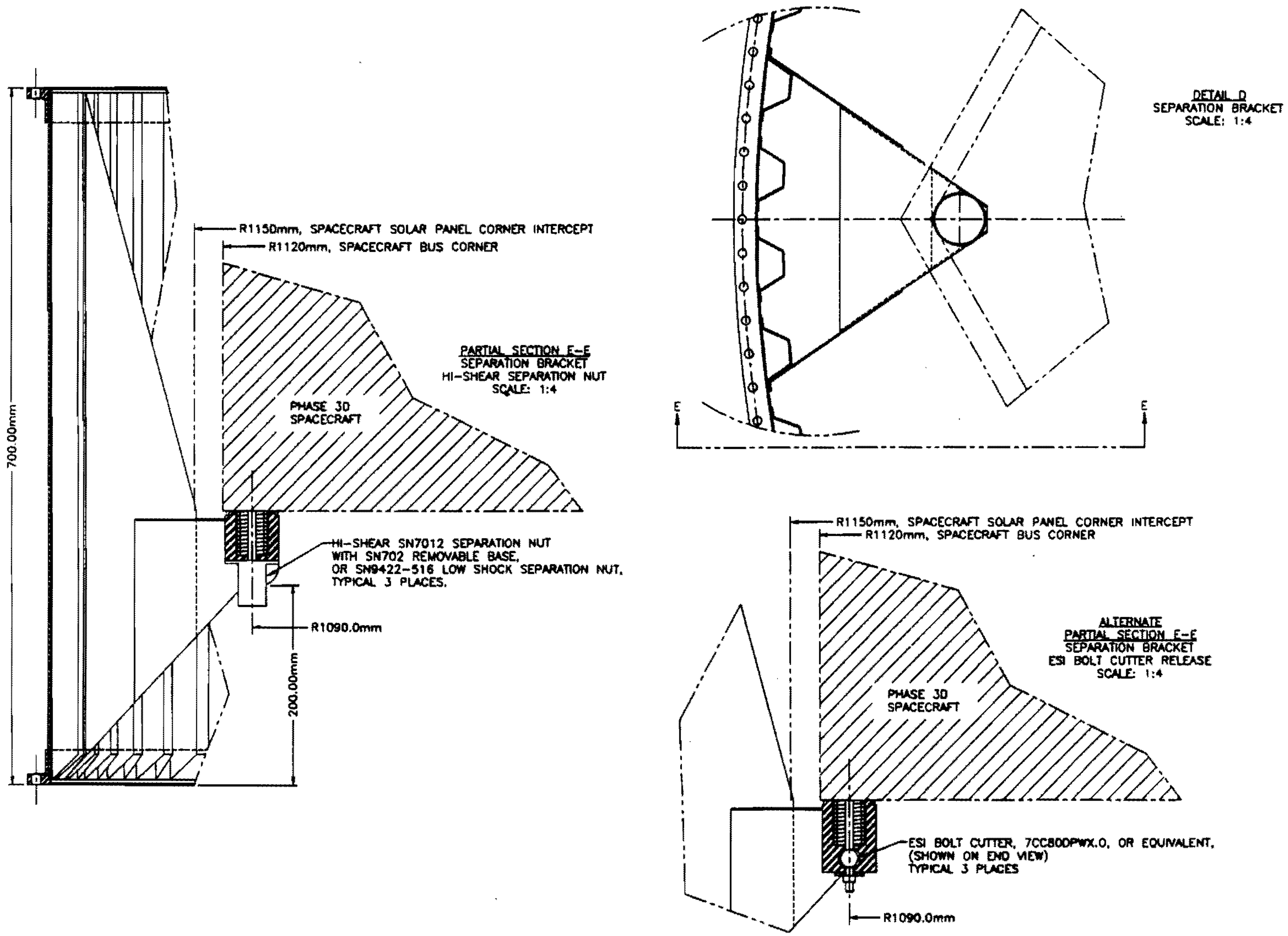
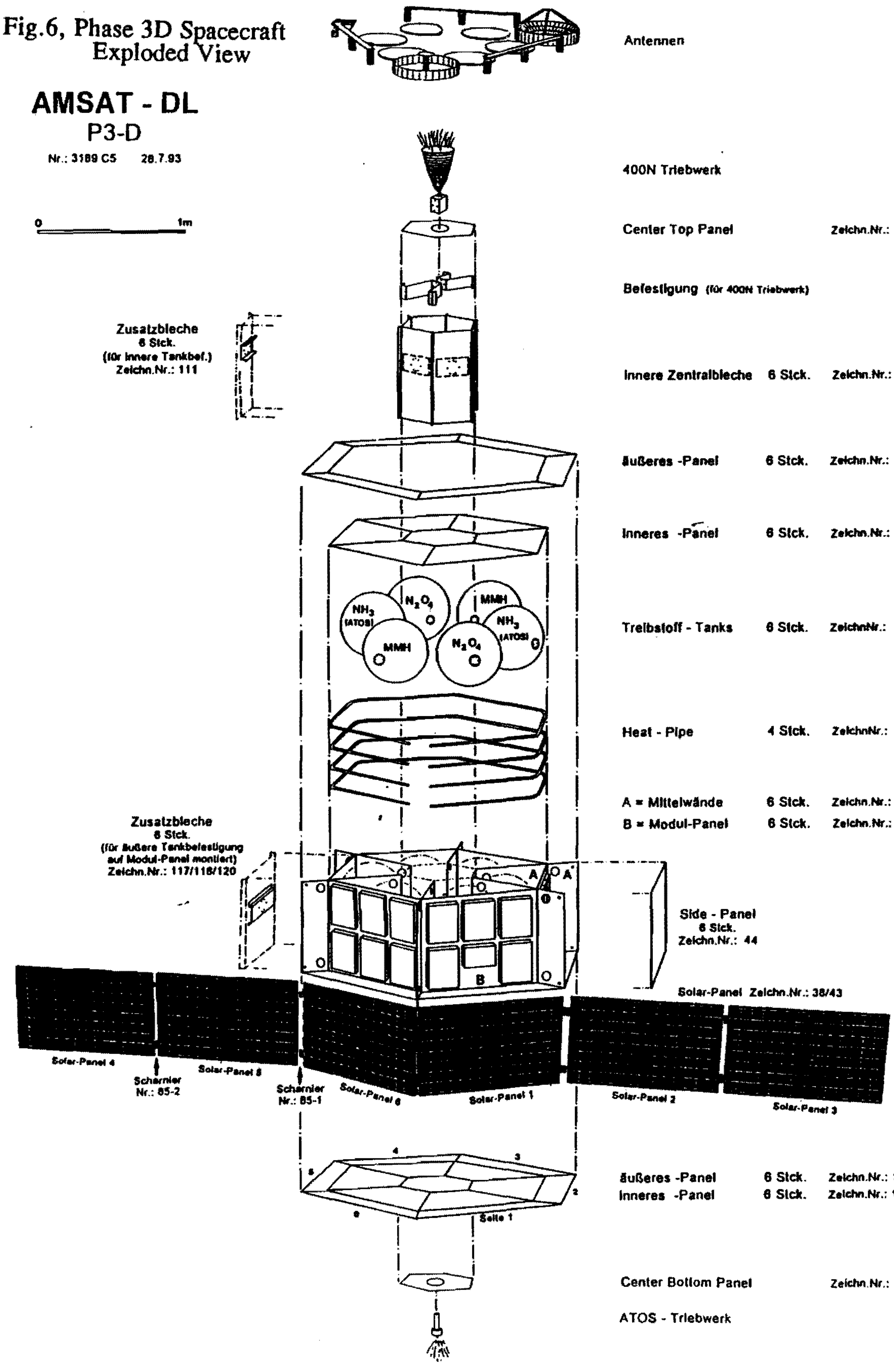


Fig.5, SBS Separation Support Details

Fig.6, Phase 3D Spacecraft Exploded View



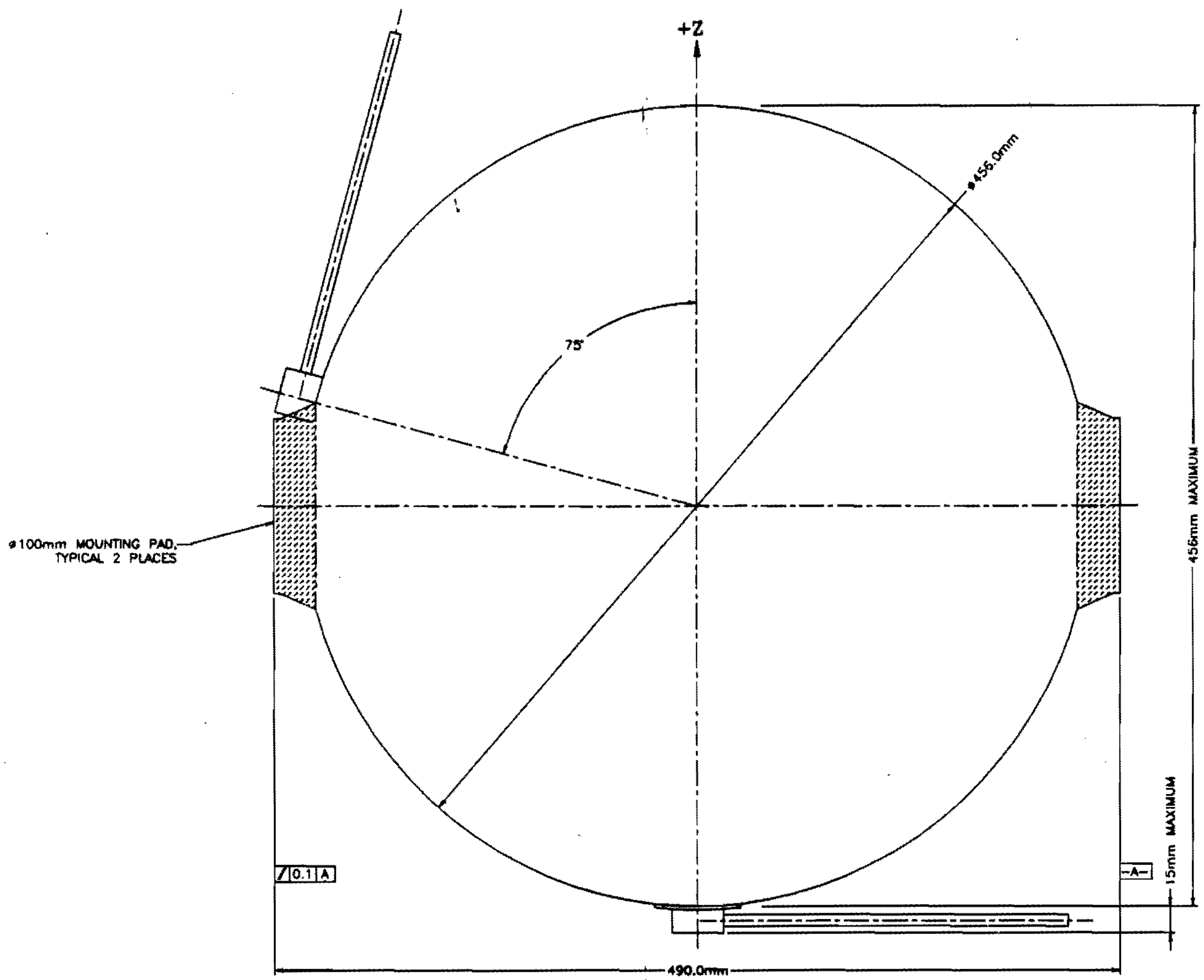
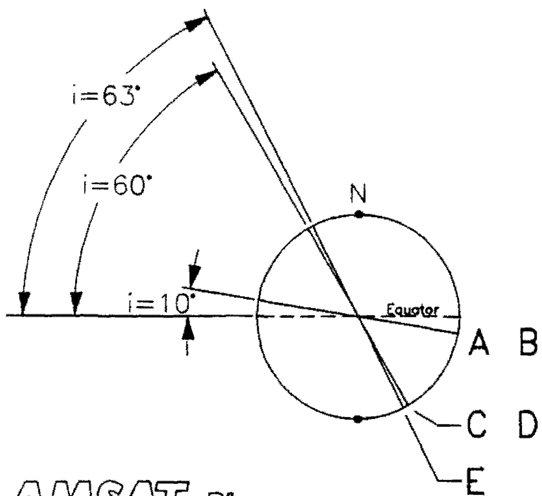


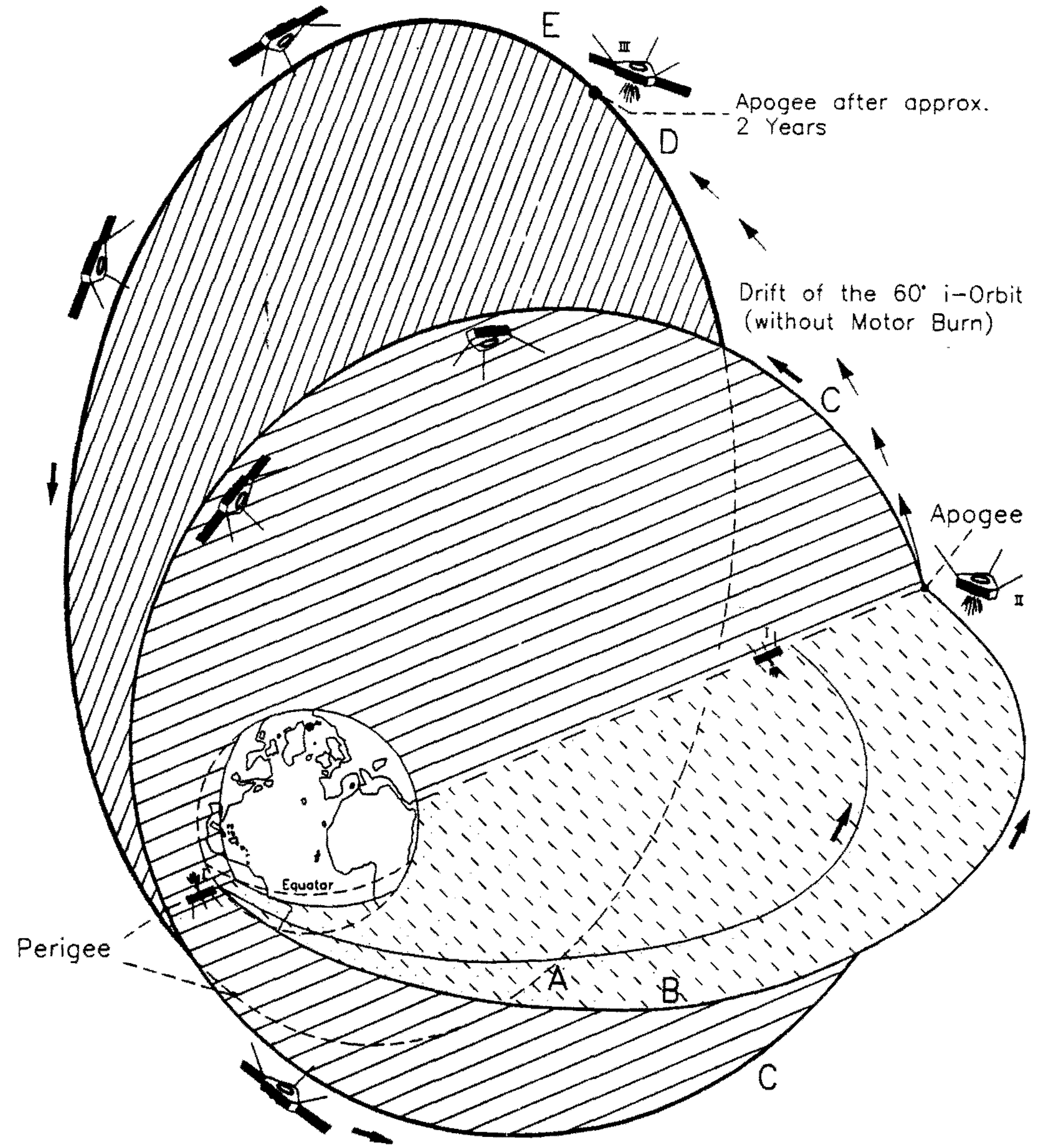
Fig.7, Propellant Tank

	Motor Burn	Orbit	Inclination	Distance from Earth (km) Perigee	Apogee
1.		A	i=10°	500	35000
2.	I in Perig.				
3.		B	i=10°	500	47000
4.	II in Apog.				
5.		C	i=60°	4000	47000
6.		Drift without Motor Burn			
7.		D	i=60°	4000	47000
8.	III in Apog.				
9.		E	i=63,4° Stable Orbit	4000	47000



AMSAT-DL

Fig.8, Phase 3D Orbits



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AMSAT Phase 3D Antenna Design Review

by

Stan Wood, WA4NFY &
Dick Jansson, WD4FAB

Introduction:

Well a few things have changed since the last AMSAT Annual Meeting. For the structural design team, it has been a total reset. For the antenna design team it has been almost a total reset. A decision was made by the AMSAT Antenna Design Team to use only fixed-gain antennas. This was done to increase reliability and to simplify RF and antenna design. Some may feel this is a mistake. Path loss will decrease 20 dB as P3D descends from apogee to perigee. Signal levels would also increase 20 dB if P3D was directly over the ground station at apogee and again at perigee. This is never the case. At apogee the earth is 13° wide and all stations in view of P3D will have a squint angle of less than 7°. With an antenna gain of 15 dBic, the gain for stations in view should not vary more than 2 dB. At perigee the earth is 68° wide and stations could have squint angles of 39°. This means that stations directly under P3D at apogee would see no loss in antenna gain. Stations with low elevation would be looking at a squint angle of up to 39° and could see a loss of antenna gain of more than 15 dB. The real test is to design antennas that will maintain the same or better signal levels for all stations at perigee. This requires antennas with slightly lower gain (15 dBic) and very smooth patterns at wide pointing angles.

Spacecraft Limitations:

All the high gain antennas are placed on the top of the spacecraft. The principal radiation direction is along the +Z axis, the center line of the spacecraft, toward the top. On the Phase 3D satellite we have the entire top surface available for RF capture area, a fact that has not gone unnoticed. This top area amounts to 3.7 square meters. While this is slightly less surface area on the top of the spacecraft, there is more available height. Antenna height limitations on the top of the spacecraft were increased from 75mm to 330mm. This was done by moving the 400N motor from the bottom to the top of the spacecraft. While this increased our selection of possible high-gain antenna types, it placed the motor right in the center of the antenna arrays. This change also raised concerns of the motor's effect on antenna patterns and the heat radiated during motor firing. The 145 MHz and 437 MHz antennas were redesigned to fit around the motor and to resist the radiant heat from the motor. Computer antenna models show little effect from the motor.

The bottom or -Z surface of the spacecraft is now clean except for the arc-jet motor and the three separation studs. This is where we are mounting the omni-directional antennas. We have a large, flat ground plane with a height limitation of 25mm. We are presently testing an array of flexible ground plane antennas. Omni antennas will be installed for 435 MHz, 1.269 GHz, and 2.401 GHz. A 145 MHz omni-directional antenna was tried but it adversely effected the 435 MHz antenna pattern. A 435/1269 J-Pole may be used with a separate antenna for 2.401 GHz.

The launch of AMSAT P3D into an initial transfer orbit and it's final placement into a 16 hour Molniya orbit places multiple requirements on the antenna system. Initially P3D will be spun on the Z axis to maintain stability. The Z axis will be oriented 90° to the major axis of the orbit and in line with the plane of the orbit. Table 1 shows the link variables encountered in this orbit.

Table 1 - AMSAT P3D Orbit Parameters

Orbit hr	Phase	Range	Path Loss	Earth Angle
8 hr	128	49800 km	185.5 dB	13.00
7 hr	112	48900 km	185.4 dB	13.50
6 hr	96	46600 km	185.0 dB	14.50
5 hr	80	43000 km	184.3 dB	15.00
4 hr	64	38000 km	183.2 dB	17.00
3 hr	48	31500 km	182.6 dB	20.00
2 hr	32	23700 km	180.2 dB	25.50
1 hr	16	15800 km	177.9 dB	38.50
0 hr	0	5000 km	165.5 dB	68.00

This table shows the orbital Phase, Range, Path Loss at 1269 MHz, and the width of the earth as seen from the spacecraft (Earth Angle). The maximum path loss is 185.5 dB at apogee (Phase 128) with a minimum path loss of 165.5 dB at perigee (Phase 0). The path loss varies 20 dB over an entire orbit.

When the spacecraft reaches the final orbit it will be de-spun 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. The spacecraft will rotate to point the +Z surface at the earth for the entire orbit. All high gain antennas are fixed in the +Z direction. Antenna pointing is done by positioning the entire spacecraft during the orbit so that the high gain antennas can be used. At apogee the width of the earth as viewed from the spacecraft is 13°. This limits the maximum gain of the antennas to 19 dBi, as higher gains would not allow proper illumination of the earth. At perigee the width of the earth is 68°. All high gain antennas are fixed gain and designed so the signal on the illumination limb of the earth will be no lower than the signal levels seen with the satellite is at apogee.

Candidate Antennas:

While we cannot pretend to have examined every possibility for all of the antennas needed, the list is significant. For 29.4 MHz the choices are very limited. As this is also a limited use perigee beacon mode operation, the antenna does not need to be exotic, and the considerations included an "X Beam" mounted on the rear -X side of the spacecraft and a "dipole" consisting of gamma matching the solar panels as the dipole elements. Computer models showed the X Beam pattern was deflected over 30 degrees by the deployed solar panels. The solar panels proved to be difficult to feed and it was not thought wise to put RF power directly on the solar cells. The final antenna selected is a two element ground mounted Yagi. This "ZL Special" is the same type of antenna used on Oscar-13 for 145 MHz. The antenna consists of a ¼-wave whip with a single director. The director is mounted on the rear corner of the top surface and points in the -X direction and is canted up 15°. The driven element is mounted at the rear corner of the bottom surface and is canted down 15°. This antenna gives a gain of >4 dBi and its pattern is close to ideal at perigee.

Another band that has proven to be troublesome is 145 MHz. When a fixed gain antenna is used on a spacecraft in a high elliptical orbit several requirements must be met. The antenna must have sufficient gain at apogee to maintain proper signal levels. At apogee the required antenna beamwidth is 13°. The ripple in the pattern at the limb (edge) of the earth should be less than 1 dB. These requirements are easily met with an antenna gain of 15 to 19 dBic. As the spacecraft descends from apogee the field of view of the earth gets wider. The required antenna beamwidth (view of the earth) increases to more than 60° at perigee. Special care is required to design an antenna with little or no ripple in it's pattern at a beamwidth of 60° and still maintain a maximum gain of 15 to 19 dBic. The new antenna array for 145 MHz is a circular array of three folded dipoles mounted 50 to 100mm above the top surface. Computer models show a gain of 12 dBic and < 1 dB ripple in the pattern up to 60° beamwidth.

For 435 MHz an array of 6 circular polarized patch antennas has been selected. The antennas are mounted directly on the top cover panels of P3D. The elements are bonded to a 13mm thick Kevlar Honeycomb which is bonded to the top skin of the spacecraft. There are 6 skin panels with a separate antenna element on each panel. The patch elements serve as a structural stiffener for the top panels. The spacing of the array was reduced to fit on the new spacecraft structure. This reduced the gain to 15 dBic but allowed the removal of the old center element. With wider spacing the center element was required to maintain a clean antenna pattern. This allowed the 400N motor to be mounted on the top of the spacecraft.

Patch antennas can be described as a thin square of conductor material, approximately ½ wavelength on a side, closely spaced above a larger reflector plane. The center point of this active element may be grounded using a vertical conductor. While not exact, this patch radiator can be thought of as a pair of stacked dipoles, spaced by ½ wavelength and backed by a reflector. The more correct description of the antenna is that it is a pair of ½ wavelength slot antennas, spaced ½ wavelength. Active element feed points can be from the center of an edge, or inward with corresponding impedance variations. Patch antenna active elements may be of almost any shape, including round, rather than square. When properly fed, patch antennas operate with good circular polarization (CP) radiation performance. In the CP operation, all edges of the patch are actively included in the performance "equation".

When antenna users come in contact with the concept of the patch antenna, it is often in the context of those versions constructed with printed circuit board (PCB) materials and employing microstrip feed techniques. While such methods permit some rather impressive arrays to be constructed, the efficiencies encountered are often as low as 50%, principally due to dielectric losses and reduced element size caused by the material dielectric constant. Patch antennas do not need to employ high dielectric materials in their construction, hence the references herein will be to "patch" rather than "microstrip" antennas, and will use air (or space vacuum) as the dielectric.

Our tests have shown that the construction of these patch antennas requires some careful attention to fabrication methods and dimensional details. We have found that square patch active elements need to be 0.47 wavelength on each side, while the round versions are 0.54 wavelength in diameter. Close control of element size is important. Another important dimension is that of the spacing of the element from the reflector, >0.01 wavelength. Spacings of less than 0.01 wavelength result in reduced efficiency. Our need to carefully control the spacing is causing us to use an open cell low dielectric constant Kevlar honeycomb material.

With the construction methods being employed, the feed impedance characteristics are somewhat different than those of the PCB microstrip antennas. 50Ω feedpoints have been found to be located at 0.078 wavelength from the center, while a 100Ω feedpoint is located at 0.115 wavelength from the center. These are good dimensions to know, as a simple ¼ wavelength coupling line of UG-141 coaxial cable connected between quadrature 50Ω points, and with the main feed located at a 100Ω point will result in an overall 50Ω feed impedance and a circular radiation pattern for the patch. All coaxial cable feeds are terminated with the outer conductor connected to the reflector plane and the center conductor connected to the active element. The ends of the coaxial cable are located perpendicular to the reflector plane, and the outer conductor should be extended to within a close proximity to the active element.

The antenna gain of single element patch antennas, constructed as described, has been measured to be in the range of 8.5 to 8.8 dBic. With this level of element performance, useful arrays can be formed with six elements, providing overall gains of 16 to 19 dBic, depending upon element spacing.

Rules for Patch Antennas:

1. Use only air dielectric. Air (or space vacuum) has the lowest loss and a dielectric value of unity. A dielectric constant, $\epsilon_r=1.0$, makes the patch element full size which gives maximum gain. Teflon with a $\epsilon_r=2.45$ reduces the size to 64% and with no loss reduces the maximum gain by 3 dB. This is caused by the wider beam width of the smaller patch.

2. Mount patch higher not lower. The height of the patch above the ground plane should be approximately two percent of the width of the patch. With air dielectric a half wave square patch should be a minimum 0.01 wavelengths above the ground plane. Lower heights result in higher Q and high currents resulting in higher losses.

3. Design for maximum bandwidth. The bandwidth of a patch antenna is a direct function of it's height. The limiting factor is mutual H-plane coupling in a close spaced planar array. The higher the elements, the greater the spacing required between elements. Minimum edge spacing for 20 dB isolation between elements is 0.12 wavelength for a height of 0.04 wavelength.

4. Use coaxial not strip-line feed. Patch antennas and strip lines are not compatible on the same dielectric material. Strip lines prefer a high dielectric substrate and minimum height to work properly. 50Ω strip lines also require a ¼ wave transformer to match the edge of a patch.

With these rules in mind a 435 MHz six element circular patch array was designed for the Phase 3D Spacecraft. They are supported by a central grounding post and a dielectric honeycomb under each element. Each element is operated in a RHCP mode. Element center-to-center spacing is set at 0.69 wavelengths (470mm) and is limited by the size of the available top plate area of the spacecraft. The original, and most basic of these six element arrays is a hexagonal pattern. With equal power to all elements, the array is set for maximum gain. All elements are fed in phase and no phase changes are required. All elements are installed in the same orientation to maintain the in-phase radiation.

The 1.269 GHz antenna is a Short Back Fire (SBF). This antenna is two wavelengths in diameter and has a ¼ wavelength high outer ring with a ½ wavelength high post in it's center supporting a turnstile at ¼ wavelength high and a ½ wave circular reflector. The antenna has a gain of 15 dBic and has a very smooth pattern. The antenna fits well on the spacecraft and is within the negotiable volume set by ESA. This antenna also had the maximum gain per unit of area for any antenna tested.

The 2.401 GHz antenna is a 500mm dish with a gain of 18 dBic. The first prototype was built by K5SXK and weighs in at 1.3 kg, or 3 pounds for the rest of us. The feed is a turnstile backed by a reflector. K5SXK builds military-qualified antennas in his line of work and expects to deliver a space-qualified antenna ready for our coax connector. Nice Work.

The 5.6 GHz antenna could be a 250mm dish or a multi-element array. W3TMZ is working on a 5.6 GHz receiver and antenna array. The antenna would be a low profile design 250mm in diameter. AMSAT has received a 250mm spun aluminum dish from a group in Belgium. It weighs 175 grams and would have a gain of 20 dBic.

The 10 GHz antenna is now a single 20 dBic circular horn. OH7JP and his group from Finland are well along on their design. The original design using four horns with a separate amplifier on each horn has been changed to a single horn with multiple amplifiers and a waveguide feed.

Analytic Studies:

In this effort, all orbital parameters have been determined using Franklin Antonio's InstantTrack and antenna parameters using Brian Beezley's (K6STI) MNC 4.0 and Antenna Optimizer 5.03 antenna analysis software. InstantTrack provided the orbital RF range, path losses and earth size information. We have found that the MNC and AO analyses to be very useful for this effort, although the package was designed for analyzing wire antennas, and is definitely not designed to evaluate slot antennas, per se. "Substitute" equivalent wire antennas were used with MNC and AO to achieve our analytic goals. All antennas were evaluated over an infinite ground plane, which is less of an approximation with the higher frequencies. We feel that despite all of these analytic limitations for analyzing our highly specialized satellite antennas, the Beezley software has performed superbly and permitted us to achieve a very good understanding of our Phase 3D needs.

Antenna Testing:

Antenna testing is now being done at Florida Institute of Technology in Melbourne, Florida. W2KJ Mike Thursby has made available at FIT an HP 8510B complete with an antenna test chamber. We are now able to test antennas up to 24 GHz. We expect to have all the prototype antennas tested within the next few months.

A 1/3 scale model of the Phase 3D spacecraft has been constructed to permit the testing of the 145 MHz antennas using 435 MHz RF instrumentation. Tests of the six element 435 MHz array will also be done on this model, using 1.2 GHz test equipment. A 1/15 scale model was used to evaluate the 29.4 MHz antenna. A 1/5 scale model is being used to test the Omni antennas and Patch Array.

A standard base for 435 MHz patch antenna tests was constructed. This base allowed the feed points to be readily adjusted, and permitted different patch elements to be attached for test. The initial tests were conducted with a patch element with a diameter of 370mm. In fact, while close, the element size was slightly small and the resonant frequency of 439 MHz was just off of the top of the satellite band. The linear patch antenna gain is 8.7 dBi, while the CP patch antenna has a gain of 8.8 dBic. Measurements of patch circularity against a switchable CP Yagi antenna show a circularity isolation of greater than 10 dB.

The Shuttle Amateur Radio Experiment
Current Status and Future Visions

Frank H. Bauer, KA3HDO
AMSAT V.P. for Manned Space Programs

The Shuttle Amateur Radio Experiment (SAREX) is a multifaceted mid-deck space shuttle payload which is sponsored by the American Radio Relay League (ARRL), the Radio Amateur Satellite Corporation (AMSAT), and the National Aeronautics and Space Administration (NASA). The primary goal of SAREX is to pique student's interest in the science, technology, and communications fields by allowing them to talk to astronauts on-board an orbiting space shuttle. Other major facets of SAREX include ham radio DXing, technical experimentation and crew-family contacts.

Over the past three years, there has been a steady increase in SAREX flights. Table 1 depicts all the SAREX flights flown to date. As shown, the SAREX team had one flight in 1991 and three in 1992. For 1993, five SAREX flights have been manifested and three have been completed. With such a heavy schedule this year, the SAREX team has had to make some adjustments to improve our operations. As our status on the Shuttle continues to evolve (we are now manifested on over 50% of all Shuttle missions for 1993), we continue to make adjustments, as required, to improve our operations. This paper describes some of the adjustments we have made to improve our operations and provides a window to our visions of the future.

SAREX Working Group

The SAREX Working Group consists of a core group of "board of directors" that manage the day-to-day SAREX activities and provide guidance and direction to the program. Figure 1 depicts the SAREX Working Group organization. The group consists of members from the ARRL and AMSAT with Roy Neal, K6DUE, as the working group lead.

In March of 1993, several critical modifications to the working group were required due to the retirement of John Nickel WD5EEV. John's contributions as the ARRL representative at the Johnson Space Center have been far reaching. His support as part of the working group is sorely missed.

To fill the void left by John Nickel, Carl Kotila, WD5JRD, and Andy MacAllister, WA5ZIB, have been added to the working group as shown in the figure. Carl will act as a government-employee liaison and support Lou McFadin. Andy ensures that the SAREX paperwork is in order for NASA. Carl and Andy's active and insightful participation in SAREX activities will be welcomed as they become indoctrinated in the SAREX program.

AMSAT Participation in SAREX

AMSAT's primary role in the SAREX program is to foster interest in amateur space activities and to provide technical support in all SAREX endeavors. For example, AMSAT members, including Tom Clark, W3IWI, helped develop the packet radio robot. This facet of SAREX has become a cornerstone of our general QSO operations.

In late 1992, it became obvious that the SAREX team needed additional support as the transition to a frequent flyer payload accelerated. Of particular concern was the need to provide technical support to the school groups and to provide additional operations support during the

SAREX flights in the Mission Control Customer Support Room at the Johnson Space Center. To help alleviate these problems, Frank Bauer, KA3HDO, developed a SAREX Operations Team consisting of an international group of AMSAT volunteers. In addition, Rosalie White, WA1STO, requested and was granted additional staffing support in the ARRL Educational Activities Department. Rosalie's new assistant, Bob Inderbitzen, NQ1R, has provided a vital educational service to the SAREX school groups through his outstanding lesson plans and has provided help in many areas to improve SAREX operations.

The breakdown of responsibility of AMSAT's SAREX Operations Team is shown in figure 2. The team coordinates the schools from a technical standpoint and provides a representative who supports the SAREX flight operations at the Johnson Space Center during each SAREX mission. In addition to these activities, the team staffs the worldwide network of telebridge stations, they disseminate SAREX-related information before, during, and after the flight and they are responsible for the distribution of the QSL cards. The following paragraphs highlight some of the enhancements the team has made in these areas since last fall.

School Group Technical Coordination

On past SAREX missions, a few of the school groups were ill prepared to make a SAREX contact due to lack of technical information or guidance. This led to either missed or very weak contacts. In October 1992, an international operations team was formed by AMSAT-NA to significantly enhance the technical support to the school groups. Those individuals providing key support to the schools are shown in figure 3. Beginning with the first SAREX mission in 1993, each school group is now assigned a technical mentor who is familiar with satellite communications. The primary responsibilities of this mentor are to provide guidance in the school technical setup, to be on-hand for any questions or problems, and to be a conduit for vital information before, during and after the contact. In addition, technical guides, similar to the educational guideline material provided to the schools by the ARRL are distributed to the school contact coordinator. As a result of these efforts, the technical support to all school groups has been considerably enhanced. For example, all the schools on the past three flights have been well prepared and all but a small few made outstanding contacts on their first attempt. The AMSAT-NA would like to thank its SAREX Operations Team for their outstanding support and dedication in making these school contacts such a huge success.

Telebridge Enhancements

As SAREX entered an operational phase this past year, it became apparent that backups of certain mission critical systems were required. To this end, AMSAT has installed some backup telebridge stations and has trained additional operators at many of the prime geographical areas. See figure 4. To date, two new telebridge stations are operational. The backup station in Hawaii is manned by Steve Teegarden, WH6IC. In addition, Stan Wood, WA4NFY, in Orlando, Florida will carry the telebridge torch when Don Carlson, W4RDI is not available. Both Steve and Stan provided outstanding telebridge support during the STS-55 and STS-57 missions. Moreover, Steve in Hawaii has helped with crew personal contacts as required. Over the next year, AMSAT-NA intends to install additional backup stations in Texas and Southern California as well as prime stations in other parts of the world as the need warrants.

DAROME Telecommunications in Chicago has continued their outstanding support to the SAREX program by donating their telebridge communication services for all required telebridge contacts in 1993. Their services are highly appreciated and provide a vital link between the astronauts and the students.

Information Dissemination

SAREX communications to the general ham community via internet were significantly improved over the past year with the enhancements made to allow AMSAT.ORG to become fully operational. Reliable information from the SAREX Working Group can now be disseminated quickly to a world-wide audience of SAREX enthusiasts. This quick response capability is a necessary aspect of SAREX since it flies on short duration Shuttle missions.

Frequency Coordination

The SAREX frequencies chosen for 1993 have been quite successful thus far. The SAREX frequencies are shown in Table 2. The SAREX team has gotten a few minor complaints regarding the frequency selection. This is to be expected in light of the crowded nature of the 2-meter band. However, many of the parties concerned about the frequency selection in the past appear satisfied with the new compromise. AMSAT-NA will continue to monitor the effectiveness of the selected 2-meter frequencies.

1993 Flight Highlights

To date, the SAREX team participated in two highly successful flights and one marginally successful flight in 1993. STS-56/ATLAS-2 and STS-55/SL-D2, which both occurred in April, were very successful. All 18 school groups participating in SAREX on STS-56 had solid, direct contacts with the crew. On STS-55, the telebridge system was employed. All 14 school groups on STS-55 had successful contacts. SAREX contacts with several school groups on STS-55 were performed using the German payload-bay mounted SAFEX antenna. The true merits of the externally mounted antenna were obvious during these contacts since crystal clear horizon-to-horizon contacts were accomplished despite bad antenna-to-Earth orientations. SAREX on the STS-57/Eureca flight was marginally successful; primarily due to the constraints placed on the mission due to the Eureca rendezvous. A mixed bag of direct and telebridge contacts were employed on this mission. Six of the eight schools manifested on this flight talked with the Shuttle astronauts. Highlights included an outstanding 20 minute bridge contact with a group of Lake County Illinois students and an excellent horizon-to-horizon contact with a school group in Mexico City, Mexico.

Other flight highlights included the first confirmed ship-to-ship contact between the Space Shuttle and the Russian space station MIR which occurred on STS-56 on April 10, 1993. Mike Foale, KB5UAC was the Space Shuttle crew member at the microphone to accomplish this historic first. This was followed up by a 1 minute 45 second conversation with the MIR crew from the Space Shuttle Columbia on STS-55 using the externally mounted SAFEX antenna. In addition, during STS-56, Commander Ken Cameron surprised mission control in Houston when he reported that he could see them from the orbiter (via the ATV uplink). The ATV experiments on STS-56 demonstrated the utility of fast scan television as a problem-solving tool for future operations on the space station.

Externally mounted antenna

On STS-55, hams and students in the southeastern U.S. participated in a highly successful A/B antenna test using the SAREX window mounted antenna for one orbit and the externally mounted SAFEX 2-meter antenna on the next orbit. Preliminary data indicates that the externally mounted SAFEX antenna provides approximately 10-12 dB improvement in performance when compared to the SAREX antenna. This was not unexpected. The outstanding school contacts which were made using the SAFEX antenna and the highly successful antenna test confirm that the SAREX team could significantly improve its operations and minimize missed school contacts by using an externally mounted antenna.

President Clinton Endorses SAREX

During the STS-57 mission, SAREX and Amateur radio received a big endorsement from the President of the United States. While speaking to the astronauts on June 22, 1993, the President said, "I understand that later in the mission Janice (Voss) and Brian (Duffy, N5WQW) are going to be talking to school children around the world...I just want to tell you how much I appreciate the fact that you're making an educational project out of this mission. That's very important to me." Brian Duffy replied "Mr. President, we find that using amateur radio is an excellent way of communicating with children all around the world, and we're also able to excite them using space and science." After astronaut Duffy's remarks, the president continued "You have no idea--you may be on this mission creating thousands of scientists for the future just by the power of your example and by this direct communication."

Issues

The growing pains of evolving to a frequent flying shuttle payload has introduced several issues which the SAREX team is attempting to correct. These include school group selection issues, perceptions of what the SAREX program objectives represent (these vary from one person to another), operations scheduling with NASA and the lack of general QSO contacts.

While successful, from an educational standpoint, STS-55, STS-56 and STS-57 had a relatively low number of general QSO contacts. This was primarily the result of various primary payload issues on these flights. The SAREX team has spent some time this year "re-informing" the ham radio community about SAREX activities and priorities. In particular, SAREX is a SECONDARY payload with education as its prime goal. The flight crew will make random QSO contacts with hams on the ground as time permits. The SAREX team cannot and should not guarantee a large quantity of random QSOs with the crew on any specific Shuttle mission. This is asking too much from NASA and the SAREX working group.

To alleviate some of the issues generated on recent missions, the SAREX working group has developed a set of written guidelines to aid in the selection of schools and to define SAREX priorities and requirements. School group selection deadlines, requirements for school group applications, and geographically diversifying contacts on a particular mission are subjects which are included in this document. This document will provide a written backbone to help the SAREX team, NASA, and the astronauts develop a more comprehensive SAREX program.

A meeting was held in Houston on August 4, 1993 to present these guidelines and to provide NASA with an in-depth understanding of SAREX operations and priorities. Members of the working group, several astronauts, and NASA managers representing the payloads office, the public affairs office, and the education office were present at this meeting. Several NASA managers were impressed with the depth of our program; especially in light of the fact that it is all volunteer. In addition, the guidelines and schedule were well received. Based on our discussion with NASA, the SAREX team hopes to receive information regarding crew availability for general QSOs before each flight. This information will be passed along to the ham community to allow you to better gauge whether the crew will be available for a general QSO contact.

Future Flights

Two more flights are planned for 1993 and several are expected in 1994. See table 3. The next SAREX flight, STS-58, is tentatively scheduled for October 7, 1993 with ham astronauts Bill McArthur, KC5ACR, Marty Fettman, KC5AXA and Rick Searfoss (license pending), on-board. This will be a 13 day voice and packet mission. The SAREX team expects general QSO operations to improve on this flight. STS-60 is currently manifested for November 10; however, the recent delay of STS-51 will probably slip this mission into 1994. Russian Cosmonaut Sergei Krikalev, U5MIR and Charlie Bolden (not yet licensed) will use voice and packet on this flight. Jay Apt, N5QWL and Linda Godwin, N5RAX are presently manifested for the first SAREX flight of 1994. This flight, designated STS-59, will be a 9 day high inclination which will support SAREX voice and packet. Other potential missions in 1994 include STS-63 in June and STS-67 in November.

Future Visions

Several upgrades to the SAREX hardware and flight operations have been proposed by the SAREX working group. The highest priority change is the installation of a payload bay mounted antenna. The outstanding results gleaned from the STS-55 antenna test and the superb school contacts which were made using the SAFEX antenna confirm that SAREX could significantly improve its operations by using an externally mounted antenna. Once this priority is met, the flight qualification of new radios to operate SAREX on different modes and amateur bands will be undertaken. This equipment will help alleviate the severe crowding the SAREX team has experienced on 2 meter FM. Sideband operation and operation on 10 meters and 70 cm are capabilities that are being considered.

Currently, student interaction with the crew has been limited to on-orbit question and answer sessions. Several concepts are being discussed to enhance the school group involvement. Carefully planned science or engineering projects as well as geographic learning experiences are being considered for future missions. Using packet radio, SSTV or voice, the crew can provide downlink data which the students use to solve the problem which was posed. The scheduled school contact times will provide the students "windows of opportunity" to ask project-related questions and interact with the crew. Also, through careful use of the telebridge, the school groups will be able to compare notes during the flight and share the results of their projects.

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SAREX WORKING GROUP ORGANIZATION

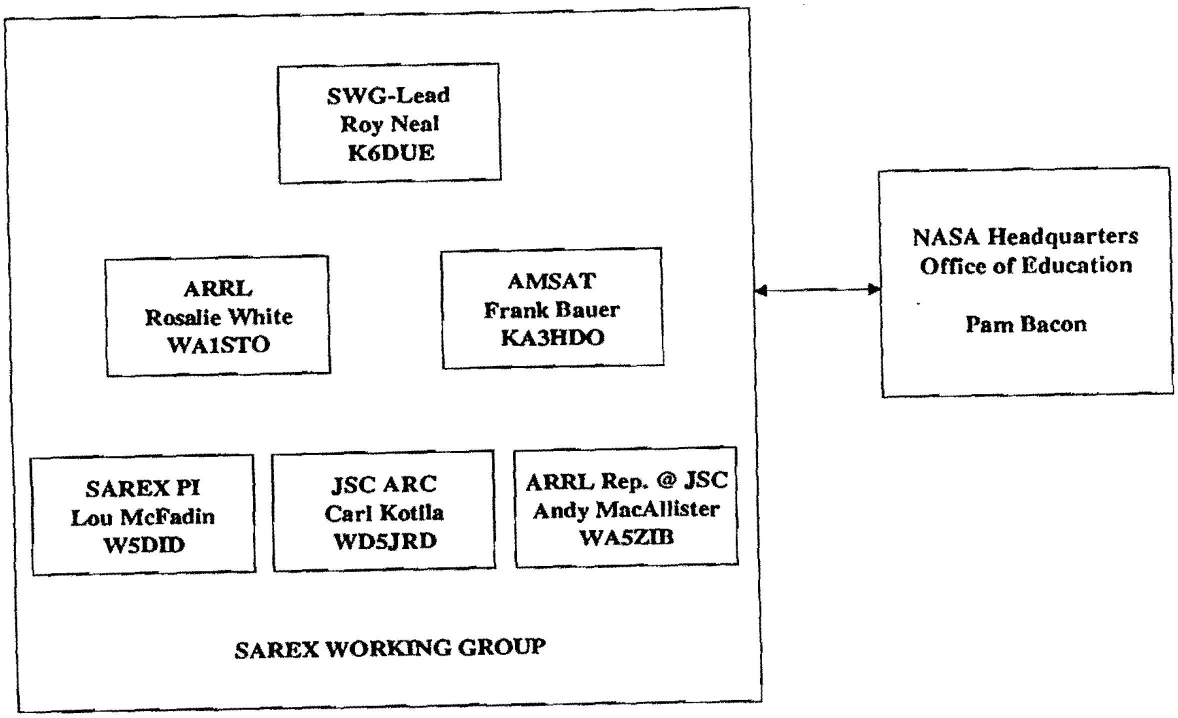


Figure 1

AMSAT SAREX OPERATIONS TEAM

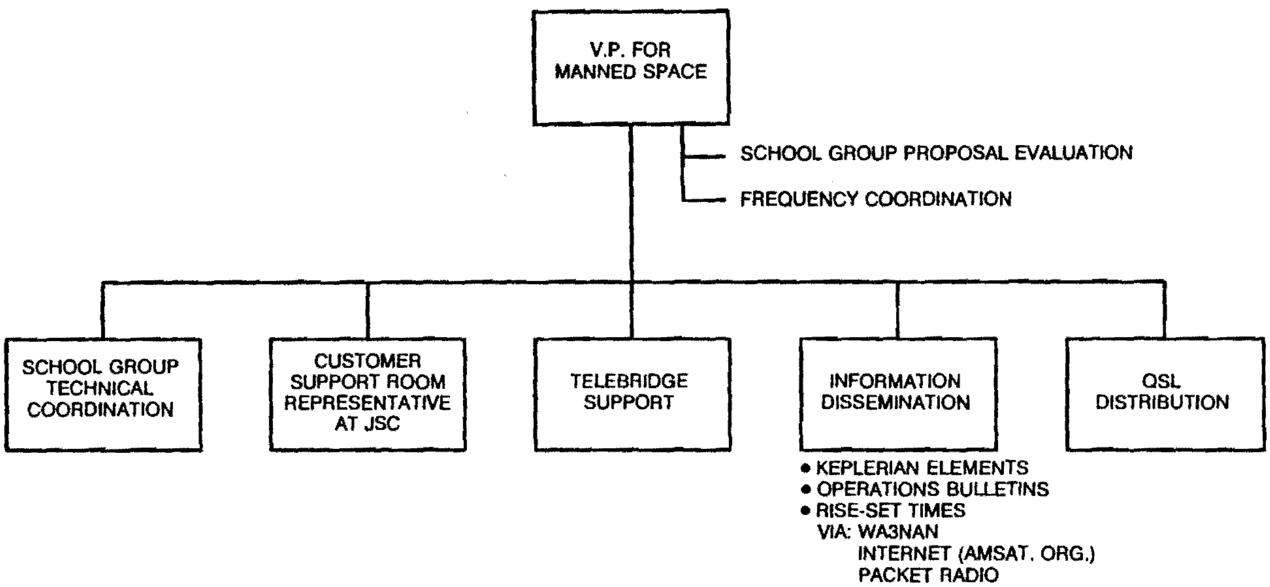


Figure 2

SCHOOL GROUP TECHNICAL COORDINATORS

WORLDWIDE/GENERAL SUPPORT
D.C. AREA AMSAT GROUP: FRANK BAUER, KA3HDO, BILL BOSTON, N3DCI, JIM GASS, N3CJN, PAT KILROY, WD8LAQ, JOHN MATTOX, N3HQL, RON PARISE, WA4SIR JOHN STOLARIK, K3CLG, HOWARD ZISERMAN, WA3GOV

U.S./HOUSTON, TEXAS
JSC ARC/CLEAR LAKE ARC: LOU MCFADIN, W5DID, GARY SHANE, WB5WOW

U.S./MID SOUTH
MARSHALL ARC: TERRY JONES, NZ8C, DON HEDINGER, N4MSN

U.S./SOUTHERN CA.
RON EARL, KERRY BANKE, N6IZW

AFRICA
HAN VAN de GROENEDAAL, ZS6AKV

AUSTRALIA
GRAHAM RATCLIFF, VK5AGR

EUROPE
DOUG LOUGHMILLER, KO5I, G0SYX

Figure 3

TELEBRIDGE GROUND STATIONS

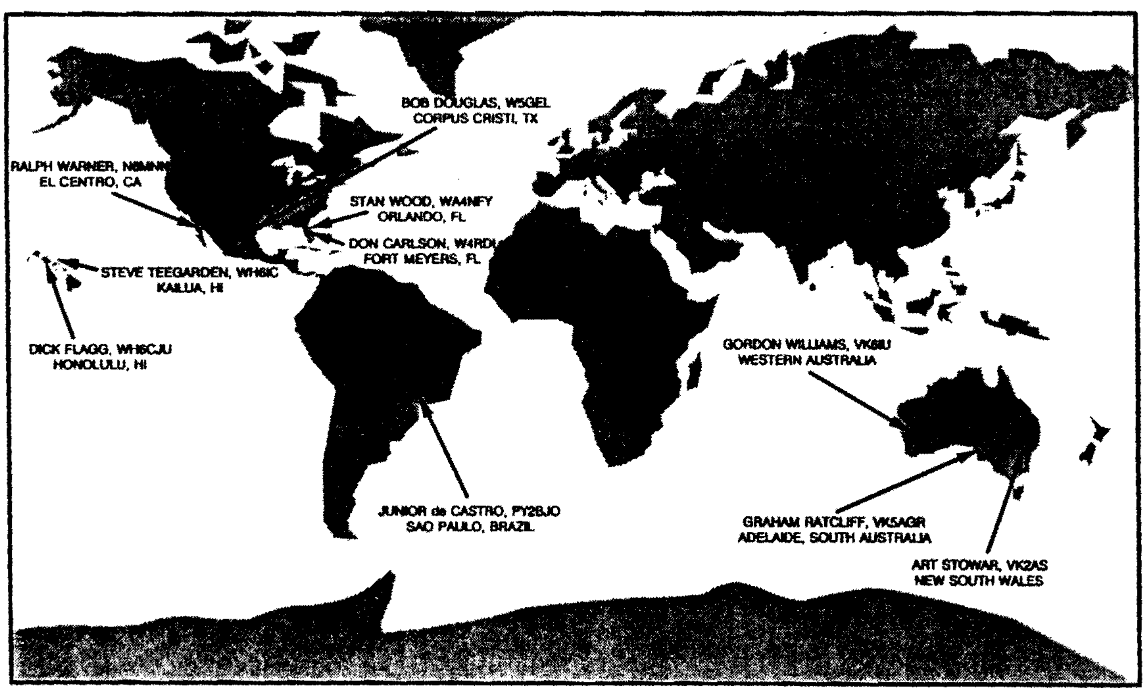


Figure 4

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

SAREX Missions Flown to Date
Table 1

		Europe	Rest of World
Voice	Downlink	145.55 MHz	145.55 MHz
	Uplinks	144.80 MHz 144.75 MHz 144.80 MHz	144.99 MHz 144.97 MHz 144.95 MHz 144.93 MHz 144.91 MHz
Packet	Downlink	145.55 MHz	145.55 MHz
	Uplink	144.49 MHz	144.49 MHz

SAREX Frequencies
Table 2

Mission	Launch	Length	Ham Crew	Inclination	Config.	Op. Modes
STS-58/SLS-2 Columbia	10/7/93	13 Day	Bill McArthur, KC5ACR Marty Fettman, KC5AXA Rick Searfoss, TBD	39	C	FM Voice Packet
STS-60/Spacehab Discovery	11/10/93	8 day	Charlie Bolden, TBD Sergei Krikalev, U5MIR	57	C	FM Voice Packet
STS-59/SRL-1 Columbia	3/31/94	9 day	Jay Apt, N5QWL Linda Godwin, N5RAX	57	C	FM Voice Packet
STS-67/ASTRO-2 Columbia	11/3/94	13 Day	Ron Parise, WA4SIR	28.5	TBD	Not yet Manifested

Future SAREX Flights
Table 3

SAREX Shuttle Mission Operations -
From a Payload's Point of View

Lou McFadin W5DID
Philip Chien KC4YER

SAREX, the Shuttle Amateur Radio EXperiment, has flown several times on recent Shuttle missions. From the outside, it may appear that the same experiment is flying each time, but the truth is rather different. Each mission has its own particular challenges, and variations.

The space Shuttle is an extremely versatile platform for many different functions. It can deploy satellites, serve as home for a week, or longer, Spacelab mission with many experiments within the Shuttle's cargo bay, or rendezvous with a satellite. Different types of Shuttle missions present different problems for the SAREX team. Unlike the OSCARs, the Shuttle's Keplerians change quickly over time, and it's attitude can place our antenna in an unfavorable attitude. Careful planning ahead of time, experience from previous missions, and many nerve wracking, last-second plans have made all of the SAREX missions to date a success.

The Shuttle astronauts get the most attention during a mission, but it wouldn't be possible without the help of hundreds of personnel at the Johnson Space Center in Houston, Texas, and other personnel around the world. The primary control for the Shuttle is from the Flight Control Room, better known as "Mission Control". A couple of dozen engineers man consoles, including the flight director, capcom, flight dynamics officer, flight activities officer, and payloads officer. The Capcom, always an astronaut, passes messages between the Shuttle and the rest of the flight controllers. The flight dynamics officer is responsible for any Shuttle maneuvers or changes in it's attitude, the flight activities officer is responsible for planning the astronaut's time-line, and the payloads officer represents each of the payloads to the flight control team - including SAREX. The Payloads officer is supported by the Customer Support Room (CSR), a separate facility where each of the payloads has an expert available if there's a question about that payload's operation.

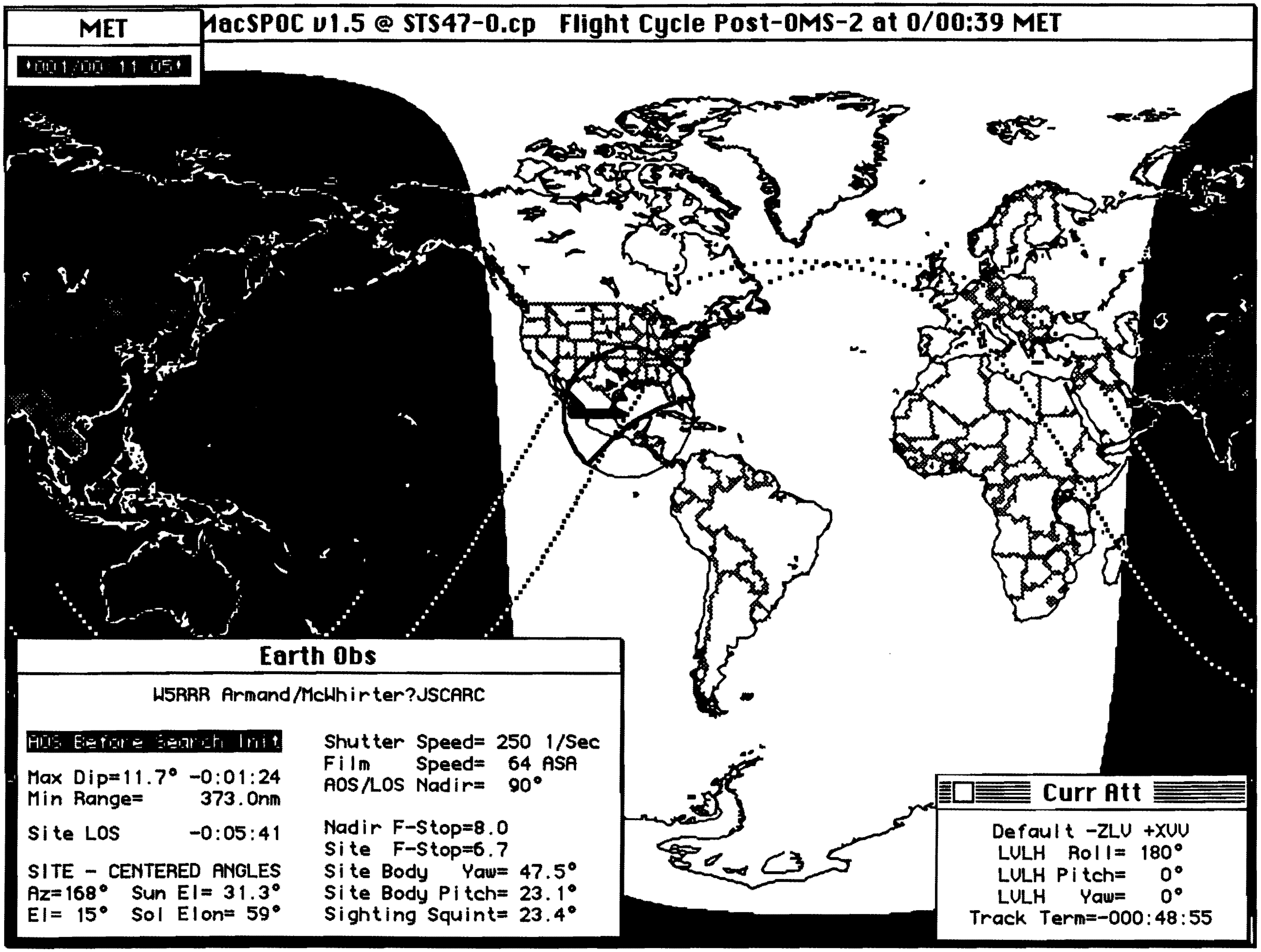
During SAREX missions, the JSC Amateur Radio Club and AMSAT tries to have a member available during each of the scheduled SAREX activities (e.g. preplanned school contacts, family contacts, setup and stowage), and to prepare the schedule for the crew's activity each coming day. The team monitors the Shuttle's status, and keeps abreast of changes in the Shuttle activities which can affect SAREX ops. Typically a handful of hams participate in CSR operations. In addition, hams at the Goddard Spaceflight Center and various worldwide relay stations participate, especially with the preplanned school and family contacts.

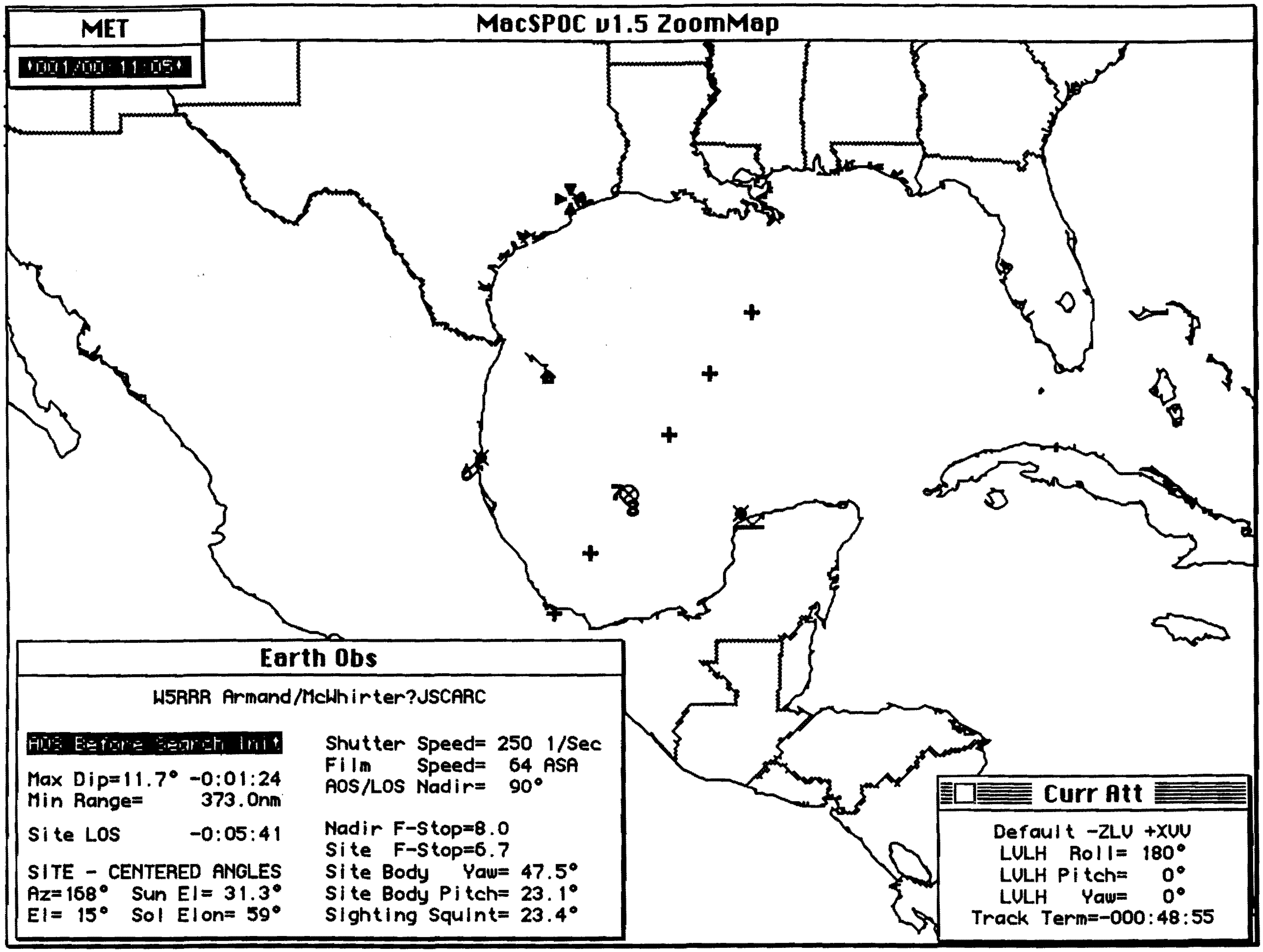
The flight dynamics group supplies us with the Shuttle's state vector, a set of mathematical quantities which defines the Shuttle's position in space. Typically the state vector is supplied in the M50 format, the Shuttle's distance from the center of the earth in a three-axis system, it's velocity in all three axes, and the time. While the M50 format is a more accurate technical means for describing the Shuttle's position and velocity, most Shuttle tracking programs use the more familiar six classic Keplerian elements which describe the Shuttle's orbit. Gil Carman WA5NOM has written a program which performs the iterative process to convert M50 format into the more traditional 2-line elements format.

SAREX has obtained the use of a Macintosh Powerbook 170 on which we use two excellent satellite tracking programs in the CSR; MacSPOC by Dan Adamo, and Orbitrak by Bill Bard. Both are available as shareware programs. The DOS program Graftrak, by Joe Bijou, is also used on a Compaq notebook computer.

Each Shuttle mission carries several laptop computers, typically Grid Laptops modified for spaceflight. Among other functions the SPOC (Shuttle Portable Onboard Computer) program tracks the Shuttle's position, locations of ground tracking sites, and emergency landing locations. On several missions, MacPortable and Powerbook computers have been flown. Dan Adamo wrote the MacSPOC program as a derivative of the SPOC program, adding additional crew-requested functions including a simulated view out of the window with recommended camera settings for earth observation photography. The MacSPOC program has been used aboard three Shuttle missions, and Dan has proudly stated that his program was 'beta-tested' by astronauts in orbit. The MacSPOC program will accept orbital elements in either M50 or Keplerian element format.

Unlike most satellite tracking programs MacSPOC has additional functions which make it extremely useful for our needs. The program will calculate the Shuttle's attitude, including where each of the windows is pointed. Dan has been gracious enough to add a function showing the SAREX antenna's ground coverage. Appropriately, the icon indicating the location window perpendicular is a small house with a radio antenna! This information is extremely important for recommending to the crew which window to place the antenna in. The antenna does very little good if it's pointed up towards the stars! MacSPOC also includes look up charts for the Shuttle's planned attitude maneuvers, burns, and calculations for the predicted orbits after each burn. The program is versatile enough to calculate a predicted state vector for a future event - accounting for all of the burns and attitude changes in between. This way a school or station can be given a set of predicted parameters well in advance of the actual contact. MacSPOC is an excellent tool for helping design a SAREX time-line and monitoring a Shuttle or MIR mission. Figures 1 and 2 show MacSPOC screens for a theoretical school contact in Houston, Texas via the W5RRR ground station.


MET
001/00:11:05
MacSPOC v1.5 @ STS47-0.cp Flight Cycle Post-OMS-2 at 0/00:39 MET
Earth Obs
W5RRR Armand/McWhirter?JSCARC
AOS Before Search Init
Max Dip=11.7° -0:01:24
Min Range= 373.0nm
Site LOS -0:05:41
SITE - CENTERED ANGLES
Az=168° Sun El= 31.3°
El= 15° Sol Elon= 59°
Shutter Speed= 250 1/Sec
Film Speed= 64 ASA
AOS/LOS Nadir= 90°
Nadir F-Stop=8.0
Site F-Stop=6.7
Site Body Yaw= 47.5°
Site Body Pitch= 23.1°
Sighting Squint= 23.4°
Curr Att
Default -ZLV +XVV
LVLH Roll= 180°
LVLH Pitch= 0°
LVLH Yaw= 0°
Track Term=-000:48:55


MET
001/00:11:05
MacSPOC v1.5 ZoomMap
Earth Obs
W5RRR Armand/McWhirter?JSCARC
AOS Before Search Init
Max Dip=11.7° -0:01:24
Min Range= 373.0nm
Site LOS -0:05:41
SITE - CENTERED ANGLES
Az=168° Sun El= 31.3°
El= 15° Sol Elon= 59°
Shutter Speed= 250 1/Sec
Film Speed= 64 ASA
AOS/LOS Nadir= 90°
Nadir F-Stop=8.0
Site F-Stop=6.7
Site Body Yaw= 47.5°
Site Body Pitch= 23.1°
Sighting Squint= 23.4°
Curr Att
Default -ZLV +XVV
LVLH Roll= 180°
LVLH Pitch= 0°
LVLH Yaw= 0°
Track Term=-000:48:55

Orbitrack is a more conventional Macintosh satellite tracking program, using elements in 2-line NORAD format. It can track many satellites and ground stations simultaneously. Orbitrak produces excellent quality ground track maps. We will often examine potential schools passes with maps showing the Shuttle's predicted path.

In addition to the Macintosh tracking programs, we have an MS-DOS computer running Graftrak. Graftrack is available as a crew optional software item - if a crew member is interested in a satellite tracking program - even on missions where SAREX isn't a payload, it's made available on the crew's laptop computer. Other good MS-DOS satellite tracking programs include SatTrac, Quicktrack, and Tracksat.

Each night, while the crew sleeps, a revised time-line is planned for the next day. If necessary, a page or two is included for SAREX. Typical information includes updated Keplerian elements for the crew to use on their computer for both the Shuttle and Mir, and updates for upcoming school contacts. SAREX provides this information to the payloads officer six hours before the crew is scheduled to wake up, typically in the middle of the night. The flight activities officer is responsible for transmitting the information to the crew via a flight-qualified fax machine or modem.

Precise tracking is not required during most SAREX missions. On typical missions updating the Keplerains once a day is adequate for all but the most narrow beam antennas. For Shuttle missions which perform very few maneuvers, for high quality micro-gravity experiments, the initial Keplerian elements after the Shuttle achieves orbit are often adequate to last for the entire flight! On the other hand, for a mission which requires a rendezvous with another spacecraft the keplerains are updated after each Shuttle maneuver.

W5RRR publishes the Keplerian elements on the Johnson Space Center Public Affairs Bulletin Board System. The BBS number is (713)483-2419.

AMSAT distributes the elements through a variety of sources including packet networks, shortwave transmissions (via the Goddard Spaceflight Center's club WA3NAN and ARRL), and through the Marshall Spaceflight Center's Spacelink BBS at (205)895-0028.

A large percentage of NASA's queries during SAREX flights is for information on SAREX operations - what frequencies will the astronauts be using, when are they going to be on the radio, etc. The Johnson Space Center Public Affairs Office is supposed to handle these queries, but many times the SAREX team has to handle questions which are too technical. In addition, reporters are often interested when SAREX makes a significant first for the space program, such as the direct contact between the Shuttle and Mir on STS-56.

Besides 'routine' SAREX operations, unplanned events happen on a much too regular basis. Some contacts are not successful on the first try due to a variety of reasons. Since SAREX is a secondary payload, it doesn't get as high priority as many of the crew's other activities. If there's a problem with the mission's primary payload, then the crew will try to fix that problem, if necessary postponing the contact until later in the mission. In many cases, the Shuttle's attitude may be in a bad position, where none of the window positions will produce a good contact with the ground station. Whenever possible the SAREX team tries to inform the school or person being contacted about these problems ahead of time. Often the problem cannot be anticipated, such as an incorrect frequency setting or hardware problem. Whenever possible we will try to schedule a backup pass and it's almost always successful. In one unusual case, the Trumansburg High School needed three tries to talk to the STS-55 mission. During the first attempt, the crew was not able to hear the ground station. For the backup attempt, the antenna cable came loose. Fortunately, on that mission a second antenna, part of the German SAFEX experiment was available, and the contact was successful on the third try. While it was extremely frustrating for the school to encourage the students to stick it out, it was an excellent highly successful contact with the students talking to the Shuttle for an extremely long high quality pass.

SAREX is also available as a backup communications method to the Shuttle's onboard com systems. Normally the Shuttle transmits data to the ground through the Tracking Data and Relay Satellite System (TDRSS), a pair of geosynchronous relay stations. During the STS-47 mission the Shuttle lost communications with TDRS-West. The crew was in no danger but had no way of communicating with Mission Control. The flight control team realized that there was a scheduled SAREX pass coming up, and asked the SAREX CSR team to relay a message up to Jay Apt, N5QWL, via Australian Andy Joyce VK4KIV in Melbourne. Immediately after establishing contact with Andy, Jay asked him to make a long distance phone call to the states, not realizing that the CSR was already patched in with a conference call. Jay informed the ground of the Shuttle's status. Andy relayed that the problem was a ground problem and that no further action was necessary. A couple of seconds later contact was restored with TDRSS.

All of the effort is certainly worthwhile when we see the results. Every school which has participated in the SAREX program has become more educated about the space program, communications, and amateur radio. Many schools have started amateur radio classes and space clubs because of SAREX. SAREX was the very first Shuttle payload to fly on all five of NASA's Shuttles. Future flights are being planned for the next several years and new schools are constantly submitting applications for educational contacts. There are over 150 schools waiting for their chance to participate. Thousands of hams, with no direct connection with the space program, have talked to the astronauts in orbit, and many more have worked the packet computer.

DEVELOPMENT OF A PORTABLE MODE S GROUNDSTATION

Ed Krome KA9LNV (ka9lnv@amsat.org)
1023 Goldfinch Dr.
Columbus IN 47203

Satellite Mode S is a fascinating mode of operation. With its 2401 MHz downlink, it is leading edge technology, yet accessible to any satellite buff willing to try it. Its popularity has been increasing rapidly, with new stations appearing almost daily. The crew up there is friendly and always eager to help new ops get started and swap info about what works best. It's quiet and uncrowded. Since mode S operation on AO-13 requires the same uplink (70cm) as does mode B, most active satellite ops already own most of the gear required. 2401 MHz is a downlink, requiring only an antenna, preamp and downconverter. Many ops have quite good success with only a single 8 foot long loop yagi; a tiny antenna indeed. Mode S is a fun band.

The attendant small antennas, always the most cumbersome part of a satellite station, brought up the question of just how small a portable station could be put together.

FIRST ATTEMPTS

This project has been evolutionary rather than revolutionary and will continue to be so. To date, it has been through several iterations, each getting more transportable and more satisfactory. The first attempt at a portable downlink was to lug the home station around. This consisted of a single loop yagi, a preamp, an S band downconverter and a Kenwood TS-430S transceiver. Worked, but not very convenient or pretty, And that assemblage didn't include any uplink gear at all. Since the Kenwood can't run full duplex, a completely separate 70 cm transmitting arrangement was required. The whole mess started to resemble packing for a family vacation.

ANTENNAS

A particularly vexing part of the original station was the antenna. I built an 8 foot loop yagi so it could be taken apart into two 4 foot sections. But it still was rather a pain to transport and could be easily damaged, and really didn't provide the level of performance I desired.

Although I had used loop yagis for several years, I had always been interested in dish antennas; in particular, the concept of a stressed dish. For those not familiar with stressed dishes, there is a rather amazing physical principle that says that if you anchor a thin beam at one end, then pull the other end at a right angle to the beam, under very small deflections, the bend that the beam will assume is a parabola! Cool. That's mechanical engineer's talk for a rather incredible phenomena. So, I built one.

The original stressed dish was an assemblage of 18 inch long 5/16 oak dowel rods radiating from a drilled oak hub, with a 3/4 inch dowel rod center post glued through the middle. The end of each dowel was tied to a common point on the central dowel rod with 25 pound test "casting" fishing line. This line is braided Dacron and doesn't stretch, so once you get things adjusted correctly, they will stay put. The feed was simplicity itself; a short helix built from #12 house wire. G3RUH has published details on how to make small helix feeds on Internet and in the AMSAT Journal (1). I have built versions from 3 to 6 turns and all work fine. The completed antenna frame was covered with 1/4 inch mesh hardware cloth, which had been cut into pie-shaped segments and wired to the dowel arms of the dish with some overlap. I connected a GaAsFET preamp directly to the helix feed. This assemblage was then put up on my tower, nestled between a pair of 432 yagis. Performance was simply amazing. I had never been able to extract data from the AO-13 S band beacon before, but now it worked fine. QSO's were armchair copy. This was some antenna. But it still wasn't exactly portable. In fact, it was quite the opposite. Just trying to carry this multi-dimensional thing, bristling with sharp edges of wire mesh, up the tower was quite a challenge. After all, I do like to hold on with more than one hand when I climb.

The design basically consisted of 8 wire mesh wedges suspended between 8 short dowel rods. Well, why not put the dowels in the middle of the wedges instead of at the edges? Then each 5/16" dowel with its attached mesh wedge became a single piece plugged into a hole drilled radially in a wooden hub. The trick was to get the wedges so they assume the desired shape and support each other. So I first plugged 4 wedges into the hub at 90 degree intervals. Then I pulled each of the 4 wedges into shape with fishing line. Then I inserted the remaining 4 leaves. Since the first 4 were stressed to shape, they were out of the way of the next 4. Then these 4 were each pulled into shape with the fishing line. Since each wedge was cut with 3/4 inch of overlap to its mating part on each edge, the second group of 4 tended to mate well with the first set and hold a pretty good shape. It even looked like a dish. Of course, this didn't make a perfect dish, but small deviations to true form (1/10 wavelength, or 1.3 cm (1/2 inch)) mean almost nothing to the overall performance of the dish. Even fairly large deviations only cause the performance to deteriorate a few dB, and in practice, really don't seem to have much effect. Just to stabilize the whole thing, I used a few pieces of wire to tie the edges of the wedges together. After assembling the dish surface itself, I slid the feed into place and secured it with a hose clamp. Instant antenna!

Ah, but is it portable? Sure is. When the ribs with their attached wire mesh wedges are removed from the center hub, they lie flat. The wedges, ready to go, can be easily stacked in the bottom of a suitcase and take up less than an inch of height. The center hub and 3/4 dowel center post are carried separately. To make the antenna easier to assemble in the field, I screwed very small eye hooks into the end of each radial arm. Each rib-forming piece of fishing line was tied solidly to a hole in the center mast on one end and to a small S-hook on the other. After the initial effort to tie off the right length of line to get each rib bent to the correct shape (which should be done with the bare rib alone before the mesh is attached), reassembling is simply a matter of plugging the dowel rod and mesh wedge into the hub and hooking the S-hook to the appropriate rib eyebolt. You can mark or color code the ribs and lines to insure correct reassembly.

Be careful when you build your dish, but don't be too critical. It is amazing how far you can deviate from true form and still have a functional dish. I have built small dishes with f/d ratios from .5 to .85 and all have performed satisfactorily.

RECEIVER

Once the antenna problem was solved, the next most cumbersome piece was the HF transceiver. Nice piece of gear, but a bit much for field work. And not full duplex, either. Review of amateur literature for the past few years turned up a variety of interesting receiving ideas. Small superhets, direct conversion, even a regen or two. I have some experience with direct conversion receivers, having built a few NE602 based designs. They are simple, compact and functional, but don't offer much dynamic range and are rather easy to crush. Recognizing that this receiver would be part of a full duplex system and would be in close proximity to a fairly powerful transmitter (even if it was on a different band) sounded like a less than satisfactory situation.

A different approach has been published by Rick Campbell KK7B (developer of the "no-tune" transverters that are so popular on the microwave bands) (2,3). This approach recognizes that the weakest part of a direct conversion receiver is not the RF section, but the mixer. His design work placed a large emphasis on proper mixer termination and really low distortion audio amplification. Campbell has published two versions of his direct conversion approach, one a "straight" approach called R1 and the second a "single signal" approach, called R2. The straight version mixes the RF with the Local Oscillator in a double balanced mixer, which is terminated in a diplexer filter (which passes the audio bandwidth and terminates everything else in 50 ohms). The diplexer is followed by bandpass filters and 100 db gain of very low distortion audio. This design has one rather odd (typical of direct conversion) characteristic; you can hear each signal twice, once on each side of zero beat. For SSB, you tune the one that sounds like something human. Works great, but does make for a lot of signals in the passband. This setup appears well suited for the less crowded bands.

Campbell's second approach is a direct conversion receiver that gives only one signal instead of mirror images of the same signal. This scheme is quite a bit more complicated, and essentially uses 2 identical mixer/diplexers followed by audio phase shift amplifiers which are identical except for a 90 degrees of phase difference between them. The 2 identical mixers are fed RF from a splitter from the antenna. Each mixer is fed a separate LO signal split from a single LO, but 90 degrees out of phase to each other. The 90 degree shifted signal is referred to by a magic word; "quadrature". These phase shifts result in unwanted image cancellation and reception of only a single signal. If you want to switch to the opposite sideband, you reverse one of the phase shifts. Sounds complicated but works great. The articles are must reading.

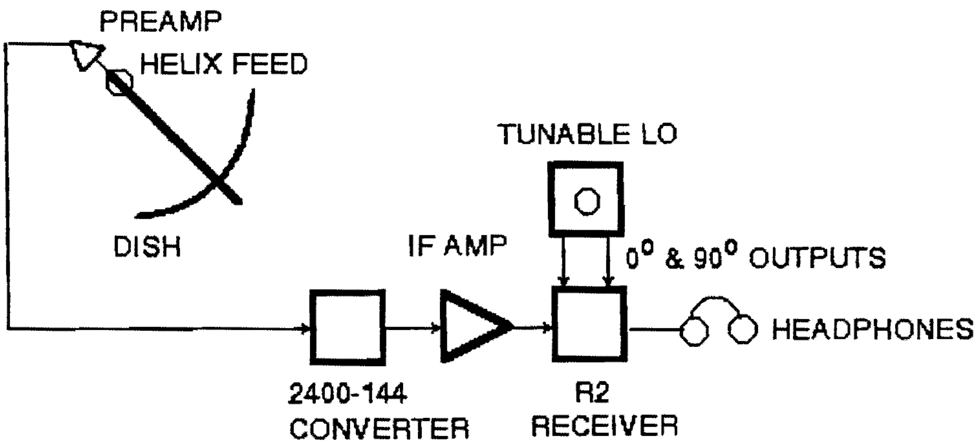
Since Campbell's articles showed some really small radios, I gave them a try. Fortunately, Campbell has beautiful circuit boards available for reasonable cost. So after debating the merits of dead bug breadboarding, I ordered one of each board.

The boards are quite compact and easy to build. One really unique thing about this type of receiver is that there are no frequency-sensitive components on the circuit board. A board is suitable for use on any frequency within the frequency range of its mixers.

My initial thoughts were to build the unit as a direct conversion receiver for 2.4 GHz. Wow, 2400 MHz to audio in one step. Then a small problem reared its ugly head. To receive a signal, you have to provide the board with an LO equal to the frequency you want to receive. To tune it, you tune the LO. And to use the single signal version, you have to split and phase shift the LO by 90 degrees. Tuning the LO could be done with a crystal oscillator based UHF source mixed with a stable VFO, but accurately phase shifting a 2.4 GHz signal started to sound rather daunting. Scrap that one.

So I took the easy way out. I built the single signal direct conversions receiver, with a tunable LO and phase shifter for 144 MHz. This was used as the IF behind a normal 2.4 GHz to 144 MHz downconverter. Campbell published a hetrodyne type tunable LO in QST (4); I built something similar, dead bug breadboard style and it works fine. A note on phase shifter construction; build a tunable version (such as a Wilkinson divider followed in one leg by a tunable shift network) since in order to adjust the image suppression of the receiver, it is necessary to go back and forth between adjusting the audio phase shift and the LO phase shift. And it makes a huge difference to the performance of the radio. I used very closely matched components (< 1/2 %, matched with a borrowed RLC bridge) and the unit worked with little adjustment. But, when I started tweaking the phase shift components, unwanted sideband suppression rapidly improved from <10 db to at least 40 db.

And the first time I connected the small homebrew dish with preamp, Down East Microwave downconverter, and the 2" x 5" x 6" receiver, I heard AO13 mode S just fine! QSO's on small homebrew gear is quite a kick. This is a satisfactory mode S portable station.



2400 MHz PORTABLE RECEIVER

KA9LNV

AND SMALLER STILL...

Although my interests are really in homebrew gear, I tried a piece of commercial equipment in order to make things even smaller. I borrowed an SSB Electronic 2.4 GHz downconverter from W9FMW, and mounted it directly at the feed of the dish. Since the SSB converter has a GaAsFET front end, it worked nicely without an external preamp. This replaced the preamp and downconverter previously used. Mounting the DEM downconverter directly at the dish feed will also provide satisfactory results, but it really needs the improved noise figure and gain of a preamp.

THE NEXT STEP

As I said at the beginning, this is to be an evolutionary project. The next stage will be to eliminate the downconverter. Build a direct conversion receiver for 2.4 GHz that mounts at the dish feedpoint and has a headphone output. Since, as previously mentioned, the biggest problem with this approach is the need to phase shift the LO, a better bet is to use the R1 receiver board and tolerate the image signals. Though the population is increasing on mode S, there aren't usually enough stations to make this a severe handicap. Although this device has not yet been built, I am collecting parts for it and expect to have some results in the near future. It will be published in the AMSAT Journal.

TRANSMITTING

Transmitting on 435 MHz was handled in a similar method to reception. KK7B has also published and supplies circuit boards for a tiny phasing-type SSB/CW exciter (5). Like the R1 and R2 receivers, the basic board is not frequency specific. Frequency of operation is determined by the LO. As with the single signal R2, two LO signals are required with a 90 degree phase shift between them. The board was easy to build; the tunable LO somewhat more complicated. I used a 448 MHz crystal controlled oscillator (I happened to have a 100 MHz crystal that functioned nicely at its 7th harmonic of 112 MHz. Two doublers and an amp provided 10mW (+10 dbM) at 448 MHz. This was mixed with a buffered FET VFO (identical to the one used on the 144 MHz LO but operating at 12 MHz) to provide 436 MHz output. Filters and amps got rid of the unwanted mixing product and provided +13 dbm for the splitter/phase shifter.

With this LO arrangement and its built-in MMIC RF amp, the exciter provides a massive 3 mW of good sounding SSB or CW on 436 MHz. Getting to required power levels can be approached from a number of ways. I used a little 70 cm amplifier I built a few years back that uses an MRF 911 to drive an S-AU4 "brick" hybrid amplifier (6). This provides a few watts output to a commercial amplifier. Although I use a Mirage D24 (2 watts in, 40 watts out) with an input attenuator (use what you've got, right?), this driver amp will drive a Mirage D1010 to 100 watts out. Another approach would be to use a brick such as the M57786M to replace the MRF 911/S-AU4 amplifier. While I am not familiar with this device beyond a catalog listing, this brick is rated to produce 7 watts out for 2 mW in.

Generally, an uplink system is full of tradeoffs. The requirement is that some minimum EIRP is required to access the bird. This can either be done with a small antenna and large amount of RF power or a large antenna and less power. Do you want to carry a larger antenna or a larger amp? If the intended use of this station will require battery power as in a Field Day installation, secondary power sources are heavier than antennas. So use a small amp and a larger, breakdown antenna. I built a 13 foot long K3RIW-type 70 cm antenna that breaks down into 4 sections. This is pretty small and is quite rugged. Use of 40 watts uplink power is usually adequate. Note that this antenna is single plane polarized. Though this is detrimental in terms of performance, it is a lot easier to carry an antenna that breaks down and stores flat than one that looks like a porcupine. Alternatively, you could simply plan to remove the second set of elements from a circularly polarized yagi for transportation. This still needs original thought.

AND SO...

This article is really intended more to wet a person's appetite than to be a construction article. I do hope that it will help inspire ham experimenters to try new modes and ideas in improving the state of our interests. I intend to continue to evolve the mode S groundstation. Stay tuned!

Notes:

1. J. Miller, "A 60cm S-Band Dish Antenna", The AMSAT Journal, Mar/Apr. 1993, pp. 7-9

2. R. Campbell, "High-Performance Direct-Conversion Receivers", QST, Aug, 1992, pp. 19-28

3. R. Campbell, " High-Performance, Single-Signal Direct-Conversion Receivers", QST, Jan. 1993, pp. 32-40

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5. R Campbell, "A Multimode Phasing Exciter for 1 to 500 MHz", QST, Apr. 1993, pp. 27-31

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MANAGING OSCAR-13

James Miller G3RUH

3 Bennys Way
Coton, Cambridge
CB3 7PS
England
e-mail: g3ruh@amsat.org

Abstract

The Oscar-13 satellite is 150 kg of spinning tri-lobed chassis. Outwardly it's covered with solar panels, inwardly it's filled with batteries, a control computer, navigation sensors and associated interface electronics. In addition there are four linear transponders used for long range SSB voice and CW amateur radio communications. The management objective is to ensure that the former equipment is controlled in such a way as to ensure the most efficient use of these transponders. A member of the Phase 3 management team for nearly a decade, the author describes how it's done.

1. AO-13 AS A CONTROL SYSTEM

It is instructive to view the management of Oscar-13 in terms of a feedback control system, figure 1. Objectives, which are tempered by known disturbance factors, are used to formulate a control strategy. The strategy is implemented by means of commands transmitted to the satellite.

The spacecraft itself responds in a deterministic way to the commands and environmental disturbances, but in a random way to the much smaller unknown factors, mainly drag effects. This determinism is fortunate, since it means outline plans can be formulated several years in advance, and potential problems anticipated very early.

The satellite tells us about itself via the telemetry beacons, and the received data is then subject to interpretation. This analysis of the actual (as opposed to expected) spacecraft performance can then be compared with the original objectives, and the control cycle repeats.

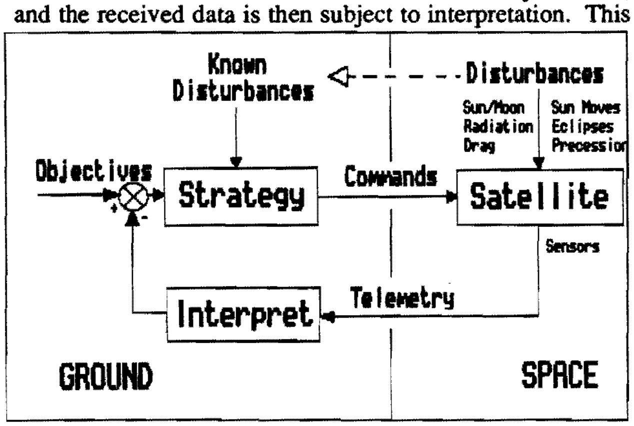


Figure 1. A satellite can be thought of as an element in a control loop.

In figure 1, factors on the right hand side are only accessible via radio links. The left hand side is represented by pieces of paper, telemetry decoders, computer analysis programs, telephone, fax, e-mail and of course command stations or managers.

From a practical point of view, having people as an integral part of the control mechanism introduces little degradation because the system dynamic is very slow indeed, measured in days rather than milliseconds. Thus it is sufficient to check out the telemetry no more than once a week or so - although for the author it is, by choice, a daily operation.

So this review paper takes that model as a guide, and the various topics will be discussed in this context:

- Objectives
- Disturbances
- Control Strategy
- The Oscar-13 Satellite
- Telemetry
- Interpretation
- Telecommand

2. OBJECTIVES

The AO-13 control objectives are remarkably concise:

- Healthy battery charge
- Optimise orientation
- Optimise transponder availability
- Publish information

These factors are interlinked. The primary task is to keep the battery healthy, otherwise there could be no transponder usage. But this requires the satellite's orientation with respect to the Sun and users on Earth to be controlled in the best way.

This in turn dictates which transponders should be on during which part of the orbit, because some of the antennas have a more narrow beamwidth than others. With the demise of the 435 MHz transmitter in May 1993 this requirement was somewhat simplified because both remaining transponders, mode-B and mode-S can be operated simultaneously for long periods.

A healthy battery is one that a) retains a net positive power balance, and b) does not drop below the threshold of 12.6 volts at any time; fully charged is 14.5 volts.

The preferred satellite orientation is that which points the antennas at the Earth when the satellite is at maximum distance, or apogee. However this ideal can only be achieved for 20 weeks of the year, and at other times up to 60° of off-pointing is required. This is no great disadvantage, since the satellite's range during the best part of these periods is still substantial, giving good Earth coverage.

3. DISTURBANCES

In the control sense, there are several factors which change the satellite's circumstances and require action if the objectives are to be realised.

Known Factors
- Sun's annual movement
- Eclipses of the Sun by Earth and Moon
- Orbital precession

Unpredictable
- Random torques
- Radiation effects
- Failures

3.1 Known Factors

Oscar-13 is spin stabilised at typically 25 r.p.m. In principle it points towards the same spot in the heavens all the time, just like a gyroscope. Therefore from the satellite's point of view, the Sun is continuously moving around at a rate of 1°/day, and consequently sunlight strikes the solar panels at a slowly changing angle.

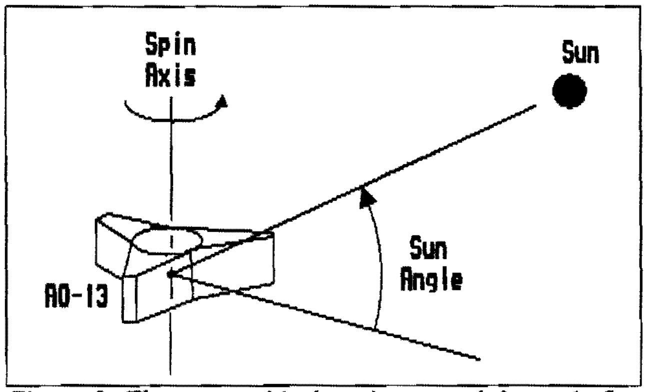


Figure 2. The most critical environmental factor is Sun Angle, defined as illustrated.

At best, the Sun is perpendicular to the spin axis, and gives maximum illumination. At other times it can be up to 45° off axis, resulting in Cos 45° = 0.71 or 71% illumination. This represents the safest minimum with the mode-B transponder ON for half an orbit.

When the Sun's position lies close to the satellite's orbit plane, Earth casts a shadow across the satellite's path. When the satellite then passes through this point it is cut off from sunlight, a condition known as eclipse and the battery receives no charge. Oscar-13 experiences eclipses for typically 20 minutes per orbit most of the year at perigee. For a few weeks eclipses occur at apogee, and can last nearly three hours. Short eclipses can easily be accommodated by the battery, long ones cannot, necessitating transponder closedown for part of the orbit.

Occasionally the Moon interposes between Sun and satellite, and this too needs to be anticipated. Periods can be a few minutes and a partial obscuration, to a total eclipse of several minutes and an overall encounter lasting an hour or more.

While the spin axis orientation is fixed in space, the orbit plane is not. It drifts very slightly. The plane rotates around Earth's equator at -0.17°/day, and the apogee/perigee line moves round the orbit plane at 0.07°/day (in 1993). So the spin axis direction, with which the antennas are coaxial, as seen from the orbit plane appears to drift slowly by a degree or two per week. This calls for occasional correction.

3.2 Unpredictable factors

The forgoing known factors can all be explicitly accounted for in the management plan. There are however some less predictable effects. As the satellite swoops past Earth at perigee, even though the altitude is well over 500 km in 1993, it receives a slight buffeting. This shows up as a) a steady fall in spin rate (-0.06 r.p.m./day in 1993) which is consistent over time, and b) a random wander in spin axis direction by as much as 1°/month. This might seem to be a trivial matter, but the whole basis upon which measurement of the spin axis direction is founded is its property of gyroscopic invariance, so considerable judgement is needed when interpreting sensors' data.

There is also the effect of radiation. This is detectable as "hits" on the flight computer's memory, but this is Hamming-code protected, and so self correcting. Hits on the computer itself appear to have resulted in just two software crashes in the 5 years since launch. In the longer term, solar panel output will degrade, but presently this effect is not really discernible.

3.3 Failures

There have been (up to 1993) only two failures aboard Oscar-13. The RUDAK digital module refused to boot up properly immediately after launch, despite a year's exhaustive on-air testing from a water tower in Ismaning, Germany. For a short while it responded to short test programs, but soon that ceased also. No explanation has been found; a cracked PCB trace or IC failure is suspected.

The 435 MHz transmitter failed abruptly on 1993 May 19, thus eliminating mode-L and mode-J operation. Tests with large EME antennas and DSP techniques have so far not heard the exciter stages, but this work continues. [2]

4. CONTROL STRATEGY

Given the mission objectives and environmental influences, a strategy or plan has to be drawn up to realise these goals. This is by far the most time consuming job in AO-13 management. Factors to be considered are:

- Solar illumination vs attitude
- Attitude drift
- Squint plots
- Schedule planning
- Magnetorque simulation

To examine these factors the command stations use a suite of analysis programs evolved by the author since 1984.

4.1 Solar Illumination vs Attitude

The most important influence on Oscar-13 is the Sun angle. This is the angle the Sun makes with the satellite's spin equator. See figure 2. Maximum illumination is received when this angle is zero, while if it were 90° Sun and spin axis would be coaxial, and there would be no illumination at all.

The spin axis direction has to be controlled so as to maintain a favourable Sun angle at all times. To investigate the value of Sun angle as a function of spin axis direction, also known as "attitude", program ILLPLAN is used, and figure 3 shows a typical screenshot.

Spin axis direction is conventionally defined in terms of an attitude "longitude" around the orbit plane, starting at perigee direction = 0°, apogee direction = 180° and so on, whilst direction out of the plane is called attitude "latitude". Figure 3 tabulates latitude at the left hand side, and longitude across the page, so the presentation is map-like.

For any combination of attitude longitude/latitude a number is displayed, which is the Sun angle that will be experienced. If that number exceeds ±45° a +++ or --- is displayed instead; this indicates a no-go zone due to low illumination. If outside ±60° a blank is shown. At those attitudes the on-board navigation sensors will fail as they cannot see the Sun. The blank area is of course the direction of the Sun; its longitude Saz and latitude Sel is printed at the top.

By pressing the < or > keys this table can be instantly indexed backwards or forwards by 7 days, and so provides a dynamic cartoon film of Sun angle vs attitude prospects.

The nominal Earth-pointing-at-apogee condition is longitude 180°, latitude 0°, i.e. the middle of the chart. In the example illustrated this would result in a +++ or no-go condition. So the satellite would have to be oriented either to the left or the right of centre, for example at longitude 210° or longitude 120°. The choice is made from considerations of squint angles for northern and southern hemisphere users (see section 4.3), and favours 210°. In this example the no-go zone moves vertically up the diagram some 1° per day, and allows a nominal 180°/0° spin axis direction to be restored on July 11th.

By liberally exercising this program a sequence of orientations can be chosen as much as two years in advance which will guarantee favourable attitude and Sun angle combinations.

4.2 Attitude Drift

A program used in conjunction with the forgoing is called ATTHIST. Once an orientation of the satellite has been achieved it is left untouched for as long as possible. Reorientations are time consuming, and confusing for users. A typical analysis is shown in figure 4.

Given an initial orientation this gives a week by week breakdown of key data, in this case the familiar Earth-pointing-from-apogee condition longitude 180° latitude 0°. The Sun angle is of greatest importance, and is seen to start at +36°, fall through zero, reaching the nominal limit of -35° in late September, dictating a re-orientation.

Other parameters of interest are the percentage solar illumination (100 Cos SA), the Sun's position in longitude (Saz) and latitude (Sel), and the familiar keplerian elements argument of perigee and RAAN. An understanding of the Sun's position is essential in management as it influences the ease or difficulty of attitude measurement via the on-board sensors, though it is of no importance from the user perspective.

4.3 Squint Plots

Once an attitude schedule has been fixed, driven only by Sun position constraints, the next task is to devise a transponder mode-schedule. [14]

By far the most important quantity in Oscar-13 communications is known variously as the pointing or squint angle. This is the angle between the spacecraft's antennas and the user. See figure 5. If this angle is large,

1994 Apr 18 [Mon] SEL= -33.8 SAZ= 158.9 WP= 338.2 RAAN= 257.5 IN= 58.0

LA\LO	260	250	240	230	220	210	200	190	180	170	160	150	140	130	120	110	100	90
15	-17	-9	-1	7	14	21	27	33	37	40	41	41	38	34	29	23	16	8
10	-15	-6	2	10	17	25	31	37	42	45	+++	45	43	38	33	26	19	11
5	-12	-4	5	13	21	28	35	41	+++	+++	+++	+++	+++	43	37	30	22	14
0	-9	-1	7	16	24	31	39	45	+++	+++	+++	+++	+++	+++	40	33	25	17
-5	-6	2	10	18	27	35	42	+++	+++	+++			+++	+++	44	36	28	20
-10	-4	5	13	21	29	38	+++	+++	+++					+++	+++	39	31	23
-15	-1	7	16	24	32	40	+++	+++						+++	+++	42	34	26

Figure 3. The spin axis direction has to be controlled so as to maintain a favourable Sun angle at all times. To investigate the value of Sun angle as a function of spin axis direction, also known as "attitude", program ILLPLAN is used.

DATE	ALON	ALAT	SA	ILL %	SEL	SAZ	Arg P	RAAN
1994 Jul 11 [Mon]	180.0	0.0	36.4	80.5	50.9	199.9	343.8	242.9
1994 Jul 18 [Mon]	180.2	1.0	29.8	86.8	57.4	206.7	344.3	241.7
1994 Jul 25 [Mon]	180.3	2.0	23.1	92.0	63.4	216.3	344.7	240.4
1994 Aug 1 [Mon]	180.5	3.0	16.5	95.9	68.5	230.6	345.2	239.2
1994 Aug 8 [Mon]	180.7	4.0	9.8	98.5	71.7	251.2	345.6	238.0
1994 Aug 15 [Mon]	180.8	5.0	3.1	99.9	72.0	276.1	346.1	236.8
1994 Aug 22 [Mon]	181.0	6.0	-3.6	99.8	69.3	298.1	346.6	235.6
1994 Aug 29 [Mon]	181.2	7.0	-10.3	98.4	64.5	313.7	347.0	234.4
1994 Sep 5 [Mon]	181.3	8.0	-17.0	95.6	58.5	324.1	347.5	233.1
1994 Sep 12 [Mon]	181.5	9.0	-23.8	91.5	51.9	331.3	348.0	231.9
1994 Sep 19 [Mon]	181.6	10.0	-30.6	86.1	44.9	336.5	348.4	230.7
1994 Sep 26 [Mon]	181.8	11.1	-37.4	79.5	37.6	340.4	348.9	229.5
1994 Oct 3 [Mon]	181.9	12.1	-44.2	71.7	30.2	343.6	349.4	228.3

Figure 4. ATTHIST. Given an initial orientation this gives a week by week breakdown of key data, in this case for the Earth-pointing-from-apogee condition longitude 180° latitude 0°. The Sun angle is of greatest importance, and is seen to start at +36°, fall through zero, reaching the nominal limit of -35° in late September, dictating a re-orientation. Other parameters of interest are the percentage solar illumination (100 Cos SA), the Sun's position in longitude (Saz) and latitude (Sel), and the familiar keplerian elements argument of perigee and RAAN.

communications are poor quite regardless of anything else. So a study of squint angle forms the next stage of the planning process.

Some of the spacecraft antennas have a narrow beamwidth, notably the 1269 MHz receive which is a 5 turn helix, and the 2400 MHz transmit, a 4 turn helix. Their -3db beamwidths are of the order of ±20°, so there is little point in seriously exercising them when signals arrive or depart at angles worse than this.

On the other hand, there are also omni-directional whips for 145 and 435 MHz, and these must be used sideways on and at short range.

With this in mind program SQPLOT is used to determine the pointing angles as a function of time through each orbit for a representative 10 day period. This can be done for a typical user at 45°N or 35°S, and for any specified satellite orientation.

A typical plot is shown in figure 6. Squint is the vertical axis, while the horizontal is mean anomaly in 1/256th orbit period. Superimposed on the plot are candidate periods for mode-L and mode-S operation. (Since the demise of mode-L, that time is now allocated to mode-S).

In this way a mode switching schedule can be devised, and is eventually published in the familiar format.

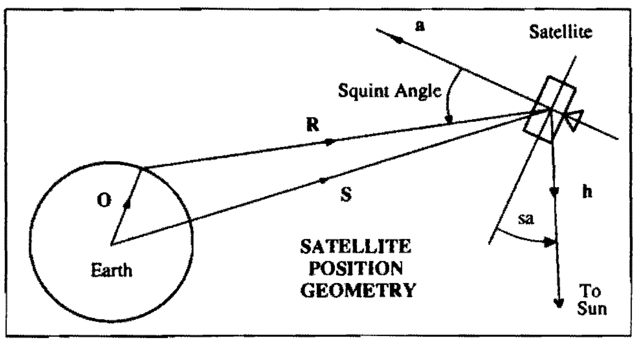


Figure 5. Squint is the angle between the spacecraft's antennas and the user.

```
L QST *** AO-13 TRANSPONDER SCHEDULE *** 1993 May 10 - May 31
Mode-B  : MA   0 to MA 130 !      Omnis MA 250 - MA 60
Mode-BS : MA 130 to MA 180 !<- S transponder; B trsp. is ON
Mode-S  : MA 180 to MA 190 !<- S transponder; B trsp. is OFF
Mode-LS : MA 190 to MA 195 !<- S beacon + L transponder
Mode-JL : MA 195 to MA 210 !           Alon/Alat 210/0
Mode-B  : MA 210 to MA 256 !  Move to attitude 120/0, May 31
Please don't uplink to B, MA 180-190. Interferes with mode S.
```

4.4 Magnetorque Simulation

Re-orientation of the satellite from one spin direction to another is achieved by an on-board system called a magnetorquer. Wound around each of the three spacecraft arms is a large solenoid. These three coils form the rotor of an electric motor; the "stator" is the Earth's magnetic field. Commutation is provided by the on-board computer which switches current through the coils sequentially in synchronism with the spin.

When the Earth's magnetic field lies on the satellite's spin equator we have a pure motor, in that spin rate can be increased or decreased or simply maintained. If it lies off-equator then the resulting non-coaxial torque allows the spin direction to be changed as well.

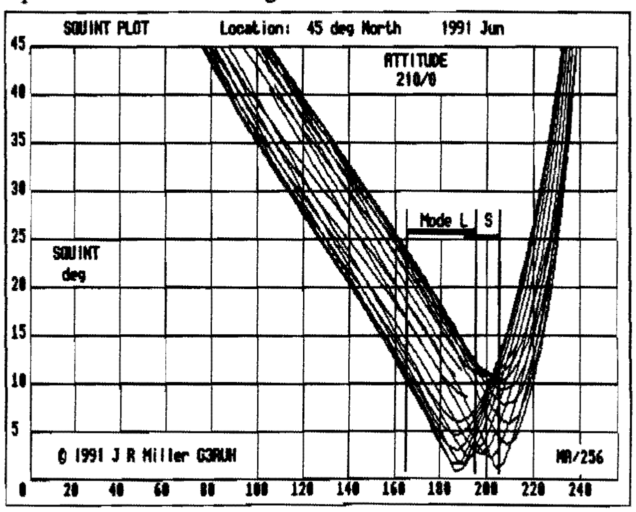


Figure 6. Plots of squint angle as a function of MA are used to devise the transponder mode schedule.

Magnetorquing is strongest when the Earth's magnetic field is strongest, and so only takes place at perigee encounter, essentially within MA = ±10. During fly-by the field also changes greatly in direction, and this ensures a rich profile of torques can be generated. Typically a movement of 5° can be achieved per perigee pass. However during eclipses, the spacecraft is deprived of its reference direction the Sun, so magnetorquing is impossible at that time.

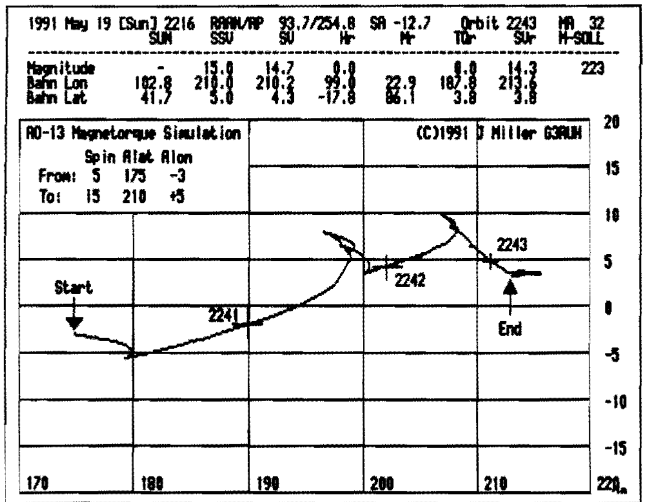


Figure 7. Prior to actually commanding a magnetorque, a ground based simulation is essential to find out how many perigee's worth of torquing is required, the impact of eclipses and to investigate trade offs between spin rate and re-orientation rate. Also, the spacecraft's Earth modelling is a simplification, and simulation can account for this.

Program MAGSIM output is typified in figure 7. Once again the orientation coordinate system of orbit plane longitude and latitude is used. As the simulation progresses the interim orientation is plotted. Each perigee instant is marked. This example has been exaggerated for clarity.

Across the top of the screen a running display of the most important numbers is maintained. The first line gives time in utc, keplerian elements RAAN and argument of perigee (AP), Sun angle (SA), orbit number and MA. The quantities below the line are columns containing certain vectors expressed in orbit plane (German = Bahn) coordinates. SUN is the Sun's direction, SSV and SV are target and present spin vector as from the spacecraft's on-board magnetorquing algorithm, whereas the column SVr is the real spin vector determined by simulation. Hr, Mr and TQr are the Earth's magnetic field magnitude and direction, spacecraft magnet direction and resultant torque (**TQr** = **Mr** x **Hr**). M-SOLL is the angle on the spin equator between the magnet direction and the Sun. The flight computer uses this to commutate each of the three coils at the right moment.

Over the years this simulation has been refined and calibrated to the point where complex reorientations can be planned and executed with considerable confidence. Errors amount to only 0.2 r.p.m. and a degree or two after a dozen perigee passes and a net movement of 60°. These errors are mainly due to short term variations in the Earth's magnetic field. Finally the program automatically generates the 7 number command sequence that is to be sent to the Oscar-13 on-board computer.

4.5 Other planning programs

ECLIPSE calculates the time and duration of eclipses by the Sun, and is used to determine when temporary changes to the transponder schedule have to be made. MOONECL does the same thing for the Moon. SMOOTH13 takes many sets of Nasa keplerian element sets and smooths them, resulting in a secondary set of elements that is free of the short term luni-solar variations and measurement noise that is so readily apparent [5]. About 6 month's past data, typically 20 sets, is processed at once. The smoothed set is used by all the management programs, rendering them consistent and accurate. The set is also converted into Oscar-13's on-board computer format for direct uploading.

5. THE OSCAR-13 SATELLITE

The spacecraft comprises a number of subsystems [1,3] including:

- On board computer or IHU
- Transponders B, S, (J and L failed)
- Solar/battery power system
- Sun and Earth sensors and SEU
- RUDAK-1 (failed)
- Propulsion system (spent)
- Telemetry system and beacons
- Telecommand system

The on-board computer or IHU (integrated housekeeping unit) orchestrates spacecraft activities. Based on a Cosmac 1802 processor it has 32k of radiation hardened RAM, and input/output interfaces for analogue and digital services. The flight software turns the transponders on and off as directed, switches antennas, monitors the battery systems and navigation sensors. Finally it generates telemetry and accepts telecommands from the ground.

6. TELEMETRY

This is transmitted continuously; there are text bulletins in CW and 50 baud RTTY, but the most important data is sent as PSK at 400 bps or 50 bytes/s. This rate was selected (in 1978) because the system fundamental timing is a 20 ms clock, and it is also properly matched to the limited beacon power using popular ground station receive antennas.

Data is sent in 512 byte blocks, preceded by a 4 byte sync code, followed with a two byte CRCC or checksum and lasts 10.24 seconds. Blocks, interspersed with a few seconds of idle code hex50, consist of engineering data and plaintext messages alternately. A complete description of the telemetry can be found in [3].

Decoders have been available since at least 1984 [6,7]. Audio enters one end, RS232 data comes out the other and the data can be displayed on virtually any PC. This is a routine no-skill operation enjoyed by perhaps as many as 500 operators. Taking telemetry is not the exclusive domain of command stations, and never has been.

The information available is:

- General status
- Navigation
- Power
- Temperature
- Messages

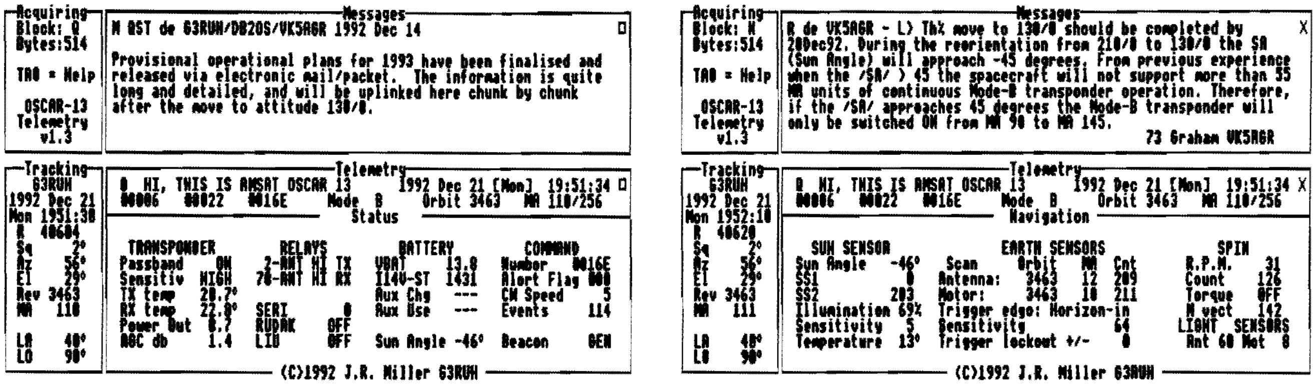


Figure 8. Typical screens from the author's display program. The message blocks are displayed in sequence as they arrive, and can be saved to disc or printer. The lower window can be cycled between Status, Navigation, Power and Temperature data. Windows showing a small square in the top right corner arrived uncorrupted; those with a cross failed their CRCC checksum test and therefore contain errors. One is apparent in the message that begins "N de VK5AGR ".

7. INTERPRETATION

Once telemetry has been received it can be analysed in detail if required. This is particularly important during a re-orientation, to ensure that nothing is going wrong, and goals are being achieved. Effort goes mainly into studying:

- Whole orbit data WOD
- Battery state
- Attitude determination
- General monitoring

7.1 Whole orbit data

There is a facility to dwell on one telemetry channel and sample it at any interval from 1 to 256 MA counts until 384 points have been collected. This means that more than a whole orbit's data is acquired each time, so "WOD" is a slight misnomer. The data is telemetered in one of the message blocks.

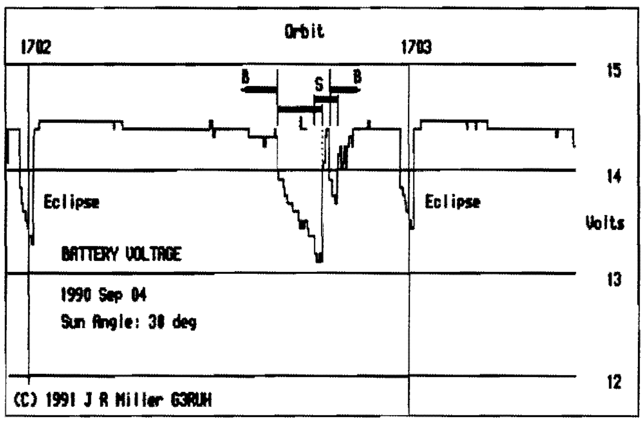


Figure 9. A typical dwell would be on the battery voltage. Here the 384 points of numerical data have been plotted using program WODDISP and give a profile of 1½ orbits activity. This plot has been annotated to show which transponders were in use, and to highlight perigee eclipses.

The heavy mode-L loading is apparent. The danger threshold is 12.6 volts, and though not reached, shows why mode-L time was relatively restricted.

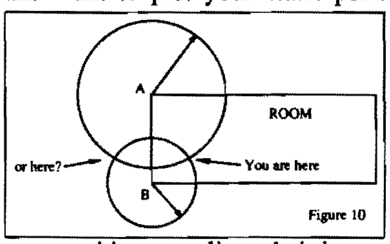
Frequent plots such as this have enabled the command stations to predict the exact battery condition under all conditions of transponder loading and solar illumination, and so maximise the facilities on offer at all times.

7.2 Attitude Determination

Oscar-13 carries two optical sensors which are used to determine the satellite's attitude. They are mounted on the end of one arm, and as the satellite spins they scan the spin equator for their respective targets. The Sun sensor measures the Sun angle, (see figure 2), while the Earth sensor responds when the Earth comes into view, generally within the hour or two around perigee.

The art of position finding is centuries old. The principles are much the same whether you are surveying the backyard or aiming a satellite. All you need is two or three objects whose position IS known. You make an observation about each of them. Then you plot your position on a map; it's the only place that could give rise to those observations.

A simple two-dimensional analogy will make this clear. You have a map of a room, you are somewhere in the room and want to plot your exact position on the map. The obvious way to do this is to measure the distance to a known point, say a corner, and then the distance to a second known point. Then draw arcs of these distances about each point, and your position must lie at their intersection. See figure 10.



Of course two circles intersect in two places, and you need to resolve this. Frequently the alternative is unreasonable, but you could easily measure the distance to a third point.

It's just the same with measuring a satellite's position. You have a map of the sky. You are on-board the satellite and want to plot the spin axis direction on the map. So you measure the angle between the spin axis and two known points in the sky. These could be a star, the Sun or the Earth.

On the map one draws the positions of the known objects,

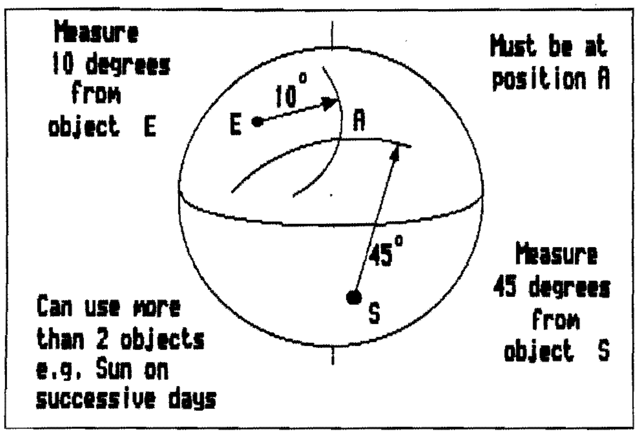


Figure 11. By measuring the angles between a spacecraft axis and two objects, intersection of two arcs as shown locates the direction of that axis.

and draws the two arcs. The spin axis direction must lie at their intersection. The ambiguity can be resolved with the help of a body in a third position, or by some reasonableness criterion. This is illustrated in figure 11.

As indicated earlier, Sun and Earth sensors measure the angles for this purpose. Figure 12 shows the resulting plot. The "map" is in orbit plane coordinates, that is longitude 0 to 360, and latitude -90 to 90. A Mercator style square map (e.g. like figure 7) is very clumsy to work with; a spherical presentation is more appropriate since we are entirely concerned with angles rather than distances.

The measured data is superimposed, and although two intersecting arcs would suffice to determine the spin axis direction or attitude, in practice one takes a number of measurements over several days. To make this clearer, figure 13 shows the centre magnified x4. At this scale it can be seen that the data is indeed slightly noisy, hence the need for confirmatory measurements.

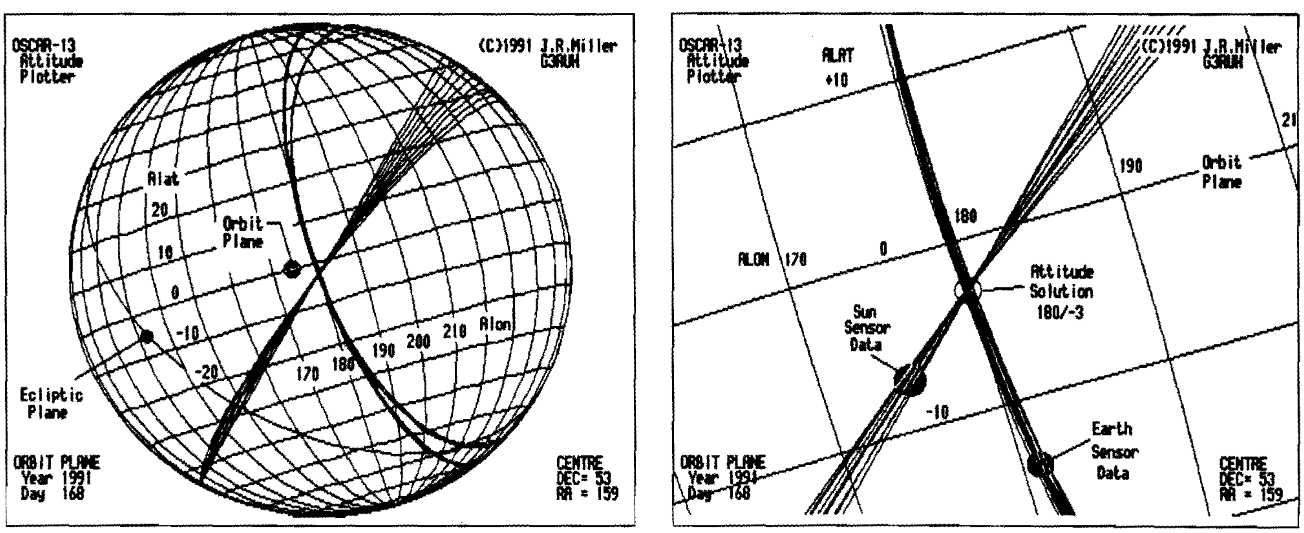
The program which generates these plots is called ATTPLOT, and takes as its input date/time and value of Sun and Earth sensor measurements. It takes 4 seconds to compute and draw. Recently the author discovered a means of measuring squint or pointing angle from observations of the S-band beacon doppler shift [8] (the antenna is mounted eccentrically), and this data can also be input and plotted.

Another program called ATTFIX takes the same data set as the plotting program, and computes the least squares solution numerically that is depicted in figure 12 graphically. This is useful for analysing the fine structure and jitter properties of the Sun and Earth sensors, and indeed has been used to calibrate the mounting axis of the Earth sensor itself. The telescope axis has been found to be misaligned by about 2.5° upwards, i.e. toward the antennas, and its two beams are separated by 10.14° rather than the specified 10°. These may seem like insignificant amounts, but small uncertainties in measuring the spacecraft attitude take a disproportionate amount of time (i.e. days) to resolve.

Sun sensor data is quantised to 1 part in 256. This equates to about 1° resolution. Thus a spot measurement is likely to have up to ±0.5° error in it, as well as added random noise. The whole orbit data collection facility helps resolve this. Figure 14 shows the Sun sensor data gathered over a 12 day period. The quantisation and random noise is clearly apparent. A least squares fit is drawn through the data, and allows extraction of extremely accurate values of Sun angle.

Using this technique, it has been found that the spin axis direction, which by gyroscopic principles ought to be a rigidly fixed direction, does have a tendency to wander over a period of a month. This is attributed to the present (1993) low perigee height.

The many techniques developed for Oscar-10 and Oscar-13 attitude determination have been published, and the interested reader is directed to the references [11,12,13]; [15] is outstanding.



Figures 12 & 13. Oscar-13 attitude determination with program ATTPLOT. The "map" is in orbit plane coordinates, that is longitude 0 to 360, and latitude -90 to 90. Data from Sun and Earth sensors is plotted. Fig. 13 shows the central portion magnified x4.

8. TELECOMMAND

Oscar-13 is a computer in space; its keyboard and screen merely happen to be on Earth. Thus one composes instructions on the ground, transmits them to the spacecraft, and watches telemetry for the response. This round-trip takes about 30 seconds.

Just as a home computer will be running a program that creates an environment (perhaps BASIC), so Oscar-13 is running a language/environment called IPS, Interpreter Structure for Processes. [4]

8.1 IPS Interpreter

The IPS interpreter offers a plain language environment not unlike FORTH. Instructions are accepted, parsed, compiled and then executed.

- Essential Primitives are provided. e.g.
  Arithmetic 0...9 # + - * /
  Relational = < > <> etc
  Logical NOT AND OR EXOR BIT
  Peek & Poke bytes, words, fields
  Manipulate stack (Push Pull Swap Dup)
  FOR...NEXT DO...WHILE REPEAT...UNTIL
  An 1802 assembler

- All other objects defined by user
  Variables & Constants
  Functions/Procedures/Routines

Here are two examples of commands; entering `2 3 +` would result in the response `5`.

The command sequence `: SQUARE DUP * ;` defines a new function which will be compiled and ready for global usage. So a subsequent command `9 SQUARE` would result in the response `81`.

8.2 Software Installation

- First the flight computer is reset.
- Next a very short self testing loader is uplinked
- Then the IPS interpreter is uploaded (only 7200 bytes)
- Finally the flight routines are uplinked (36 kbytes).

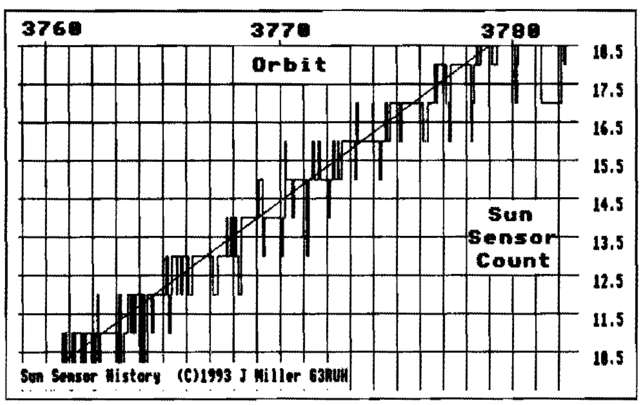


Figure 14. Sun sensor data is quantised to 1 part in 256. This equates to about 1° resolution. Thus a spot measurement is likely to have up to ±0.5° error in it, as well as added random noise. A least squares fit is drawn through the data, and allows extraction of extremely accurate values of Sun angle.

When the flight routines are running they serve simultaneously:

- 20 ms loop analogue multiplexer)
- 20 ms clocks) Machine code
- Telemetry buffering)
- Spacecraft control. Interpreted and then compiled code.

8.3 Flight Routines

This is approximately 10 pages of plain language, and is compiled as it is received by IPS. It then totals about 16 kbytes including buffers etc.

At the highest level it is organised around a chain. Calling this is the very last command sent:

```
0 EINH SERVICE    ( Battery service, watchdogs )
1 EINH BAKEN-ST   ( Beacon sequencer  )
2 EINH NAV-ST     ( Navigation )
3 EINH MEL-ST     ( Memory errors )
4 EINH UL-ST      ( Transponder scheduler  )
                  ( 5 - spare )
                  ( 6 - spare )
7 EINH MODE-S-ST  ( Mode-S control )
```

The program is "merely" cycling around these eight tasks. Each is defined elsewhere, and of course invokes other definitions. For example, item 2 on the chain, "Navigation start" is defined below, and calls in turn NAVIGATION, SENSOREN and TRQ-ST:

```
: NAV-ST  NAVIGATION SENSOREN TRQ-ST ;

: NAVIGATION   Z-ALT @B Z @B <> DUP Z-MARKE !
  JA? Z @B DUP Z-ALT !B =0
      JA? RECTAS @ KO + RECTAS !
          PERIGA @ KW + PERIGA !
      DANN ORTSDATEN MAGNET @B
      JA? A-CONTROL
      DANN
  DANN ;

: SENSOREN Z-MARKE @
     JA? #447 @ SS>BETA BETA !
         #44D #44F JE I 6 + @B
         JA? 0 I 6 + !B Z @ I !
         DANN 2 +NUN
     DANN ;

: TRQ-ST Z-MARKE @
    JA? E-FLAGS @ #14 UND >0  Z @
        MZEITGRENZE @ = ODER
        JA? 0 M-EIN !
        DANN Z @B 32 + #FF UND 64 < M-EIN @
             UND 1 UND MAGNET !B
    DANN ;
```

8.4. Commanding

Day to day commands are required to update Message blocks (which can be read on the beacons in PSK, RTTY and CW), invoke magnetorques, check sensors, invoke WOD data collection, change transponder mode schedules and so on. Occasionally `0 TRANSPONDER` is needed!

Commanding is a very small part of Oscar-13 management. It is not always straightforward. The 435 MHz command uplink is interfered with by radar, and man-made noise invariably ruins 145 MHz downlink telemetry, especially at poor pointing angles and at maximum range. Mode-B commanding is tiresome at best.

Fortunately the 1269 MHz uplink is still available and needs only a few watts e.i.r.p., and the 2400 MHz S-band downlink is very strong on compact antennas [9,10] and error free. So provided the mode-S facility is exercised daily, which it is, an excellent command link is assured.

8.5 Reliability

Crashes are very infrequent. One initial load, and five reloads have taken place as follows:

8.6 Coding

The COSMAC 1802 IPS interpreter was designed and implemented by Dr Karl Meinzer DJ4ZC [4] in the late 1970s. The flight software was also written by Dr Meinzer, and has been edited and added to by Peter Gülzow DB2OS and the author.

Load	From		To	Total Commands	Life Days	Rate Comms/day	Crash Notes
1	1988 Jun	-	1989 Oct 09	1173	480	2.44	•
2	1989 Oct 09	-	1989 Oct 28	390	19	20.53	rt
3	1989 Oct 28	-	1989 Dec 10	224	43	5.21	•
4	1989 Dec 10	-	1991 May 13	759	519	1.46	pt
5	1991 May 13	-	1992 Jan 29	248	261	0.95	rs
6	1992 Jan 29	-		612	570	1.07	(*)
			Total	3406	1892	1.80	

Notes
- • reason unknown - probably radiation hit on CPU
- rt after intensive RUDAK testing; probably an induced mistake
- pt investigation of navigation coding error induced a "poke" with its address and data transposed.
- rs reset command inadvertently sent.
- (*) as of 1993 Aug 21

A reload uses 70 commands.

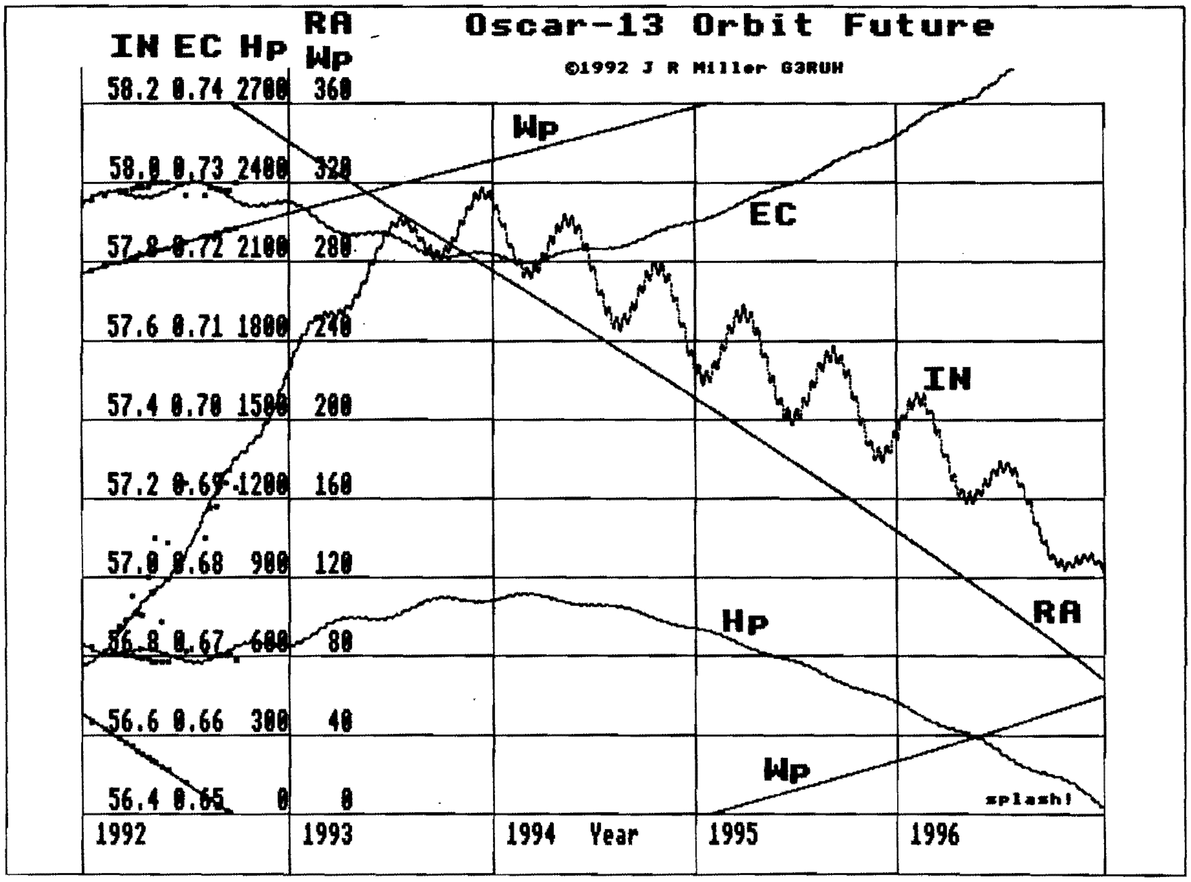


Figure 15. The orbit is slightly unstable in that the eccentricity oscillates. In 1996 perigee passes will strike the atmosphere causing the orbit to decay rapidly. This has been documented by several authors; [5] contains a full bibliography. Hp is perigee height.

9. THE FUTURE

Oscar-13 management has essentially stabilised, and a regular diurnal rhythm is well established. The spacecraft is "calibrated" to a high degree, and is extremely reliable.

It is now well known that the orbit is slightly unstable in that the eccentricity oscillates, figure 15. In 1996 perigee passes will strike the atmosphere causing the orbit to decay rapidly. This has been documented by several authors; [5] contains a full bibliography. It will be an interesting period.

10. CONCLUSION

Many command stations have contributed to Oscars 10 and 13 management at one time or other. These include DB2OS, DJ4ZC, DK1YQ, G3RUH, VE1SAT/VE6, VK5AGR, W0PN, W3GEY, ZL1AOX. Many more potential command stations work or have worked behind the scenes. Some have pulled out to work on other satellites or in other fields. For some their work is over (e.g. RUDAK specialists), or they simply retire. A thousand or more hours a year is a lot to give.

The present day command team consists of DB2OS, VK5AGR and the author G3RUH. Having a transmitting station in each hemisphere is important, but geographic location is otherwise irrelevant. In fact it is quite possible to have non-transmitting command stations, since others can do the actual uploading.

The core team is in daily and immediate contact via telephone, fax and e-mail. Contact with the user community is via similar routes, the post and by listening to the transponders. All significant decisions are made jointly, and by common consent can be vetoed by the others.

Anyone can do this job if they show the level of commitment typified by the people whose callsigns are listed above. These folks are self-motivated, self-trained, self-starting and self-sustaining.

There is absolutely no "how-to" manual, and no training course. They have a strong inquisitive streak, and an ability to work things out from scratch unaided. There is no glamour, and no "power". Far from it. They do it because it is interesting.

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CREDO

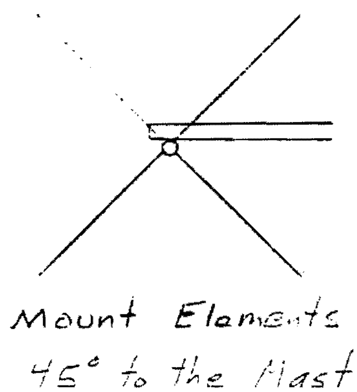
Discovery is easy; the difficulty is to acquire what we discover. - Roberto Gerhard, composer 1896-1970.

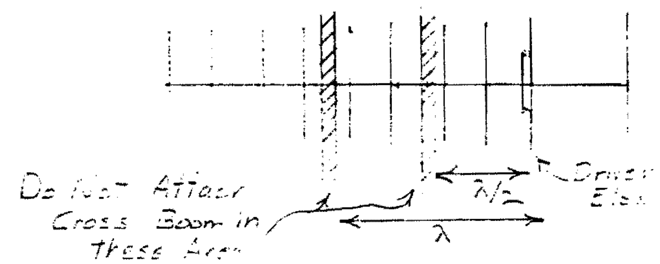
Using Metal Booms to Support AMSAT Antennas

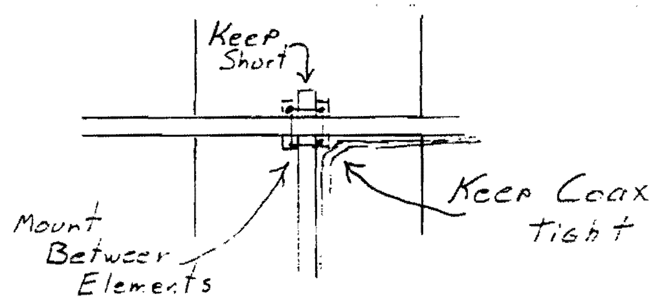
Kent Britain WA5VJB

With a little care, your really can support your Crossed Yagi Circularly Polarized antenna on a metal support boom!!!!

The Antenna Range Experiments also showed why many amateurs had mixed results trying this before.







Just mount the antenna with the tips of the elements as far from the support boom as possible. Saw off any excess cross boom, and avoid mounting the boom 1/2 or 1 full wavelength from the Driven Element. Run the coax back down the antenna and along the boom keeping the radius small, but not so tight as to damage the coax.

As an umpire for the Central States VHF Society's Antenna Contests, I have a 432 through 24,100 MHz Antenna Range. The range was set up on 435 MHz and a 2.2 Wavelength DL6WU Yagi was used as the test antenna. The DL6WU is the basis for virtually all todays' high performance Yagis.

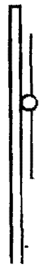
Antenna gain was measured with a metal boom protruding from the antenna in various configurations each 1/8 wavelength along the boom.

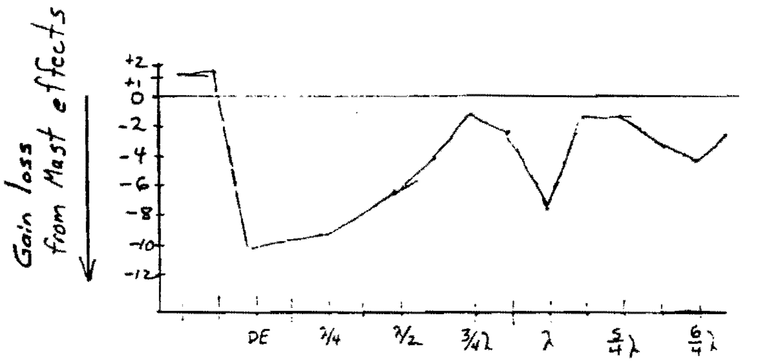
As boom approaches the element, there is coupling between the element and the boom. The net effect is to make the element appear longer. This increases the SWR of the Antenna and disrupts the pattern. IF I had used a perfectly optimized 435 MHz antenna, then any changes would have reduced gain. Well, my 10 year old Yagi wasn't as tweaked as I thought it was. From some of the other measurements, it was easy to tell it wanted the Reflector, D3, D4, D6, and D9 slightly longer.

DATA

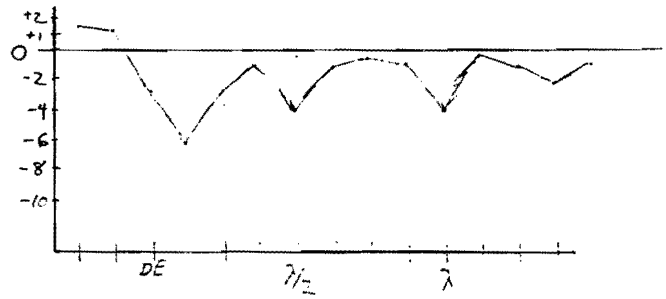
Mounting: **Gain Change:**

Boom Completely through the Yagi:

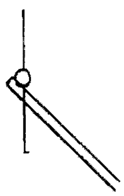


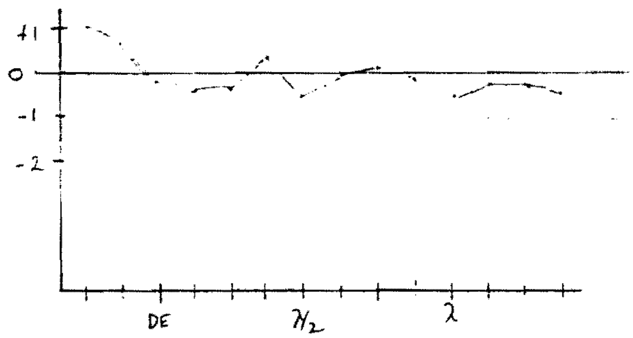


Boom 1/2 way through the Yagi:

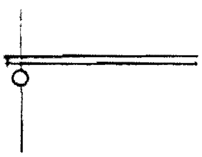


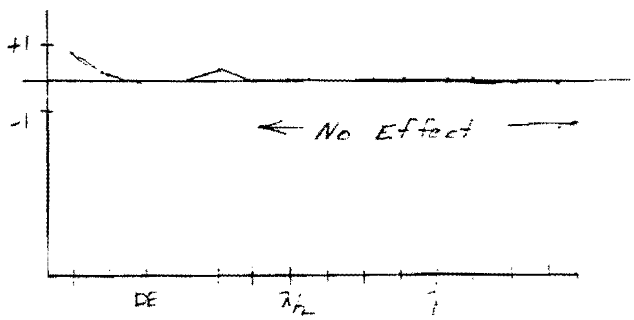
Boom 45 Degrees to the Elements:



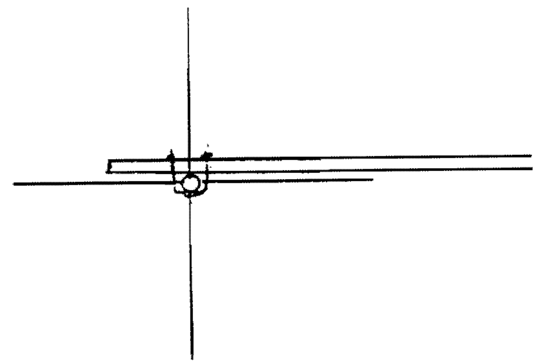


Boom 90 Degrees to the Elements:





Conclusions:



If mounted in this manner, one plane of the antenna could see as much as a 10 dB loss in gain. The antenna circularity would be nil.

Just by keeping the tips of the elements away for the boom, the antenna gain change (and it's Circularity) is about a tenth of a dB.

A boom mounted a 1/2 wave multiple from the driven element affects the impedance of the driven element. This changes the SWR of the antenna. You could rematch the antenna Driven Elements to compensate, but it's simply easier to mount the boom somewhere else.

The high SWR areas at 1/2 wave multiples are fairly sharp, and only 3 or 4 inches wide. So on a 2 Meter antenna, just don't clamp the cross boom 38-42" or 80-84" in front of the Driven Element. Mechanical balance problems would eliminate worrying about farther points.

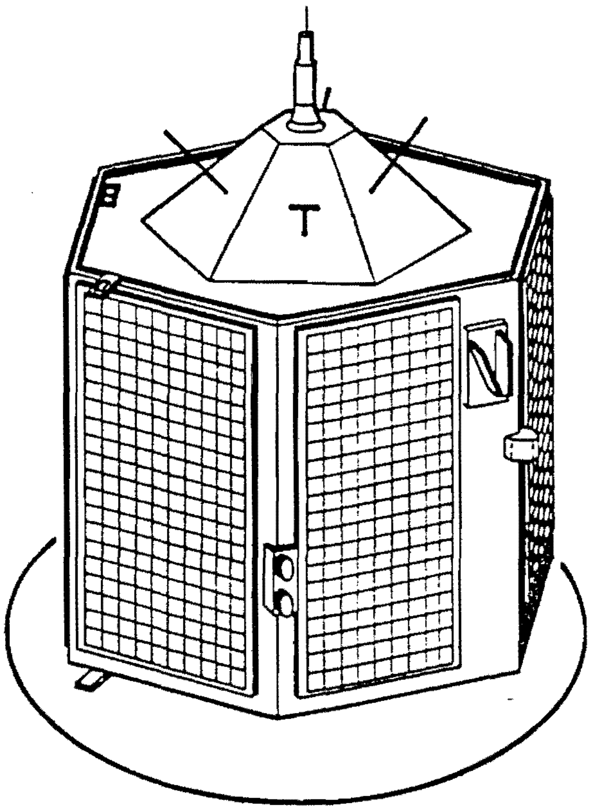
Coax is a conductor, so the coax itself can distort the antenna pattern. The Coax could be run through any of the nulls without distorting the antenna pattern. The support boom is already in a null, so by simply running the coax along the support boom you are not distorting the antenna pattern. In most installations this will be a shorter run of coax giving you a better system.

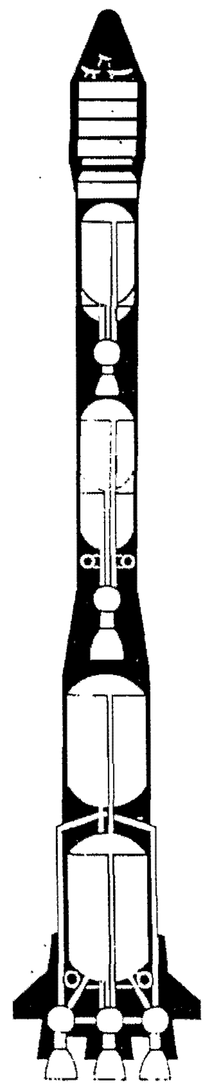
STRONGER, SIMPLER, CHEAPER and less LOSS. Just avoid the pitfalls cnes centre national d'etudes spatiales

R.A.C.E.

SUP'AERO

Project





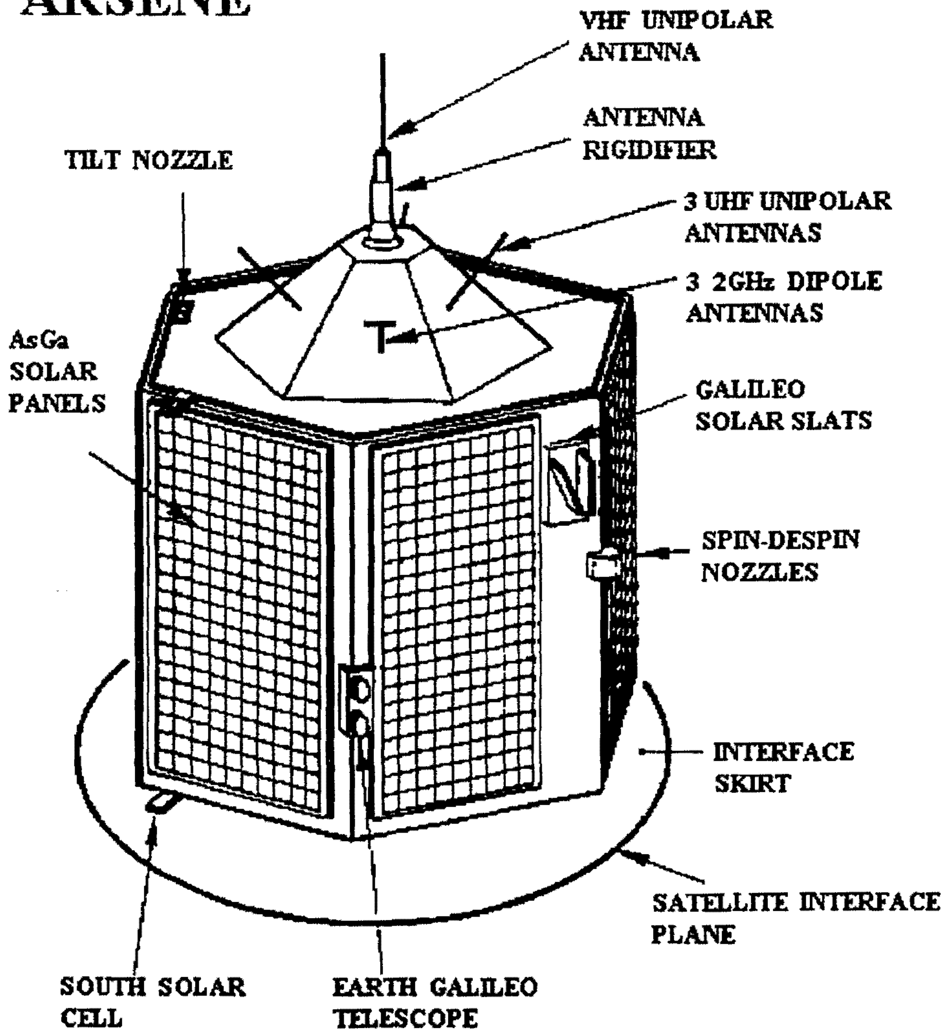
ARSENE

SATELLITE DE TELECOMMUNICATION POUR LE SERVICE RADIO-AMATEUR

ET

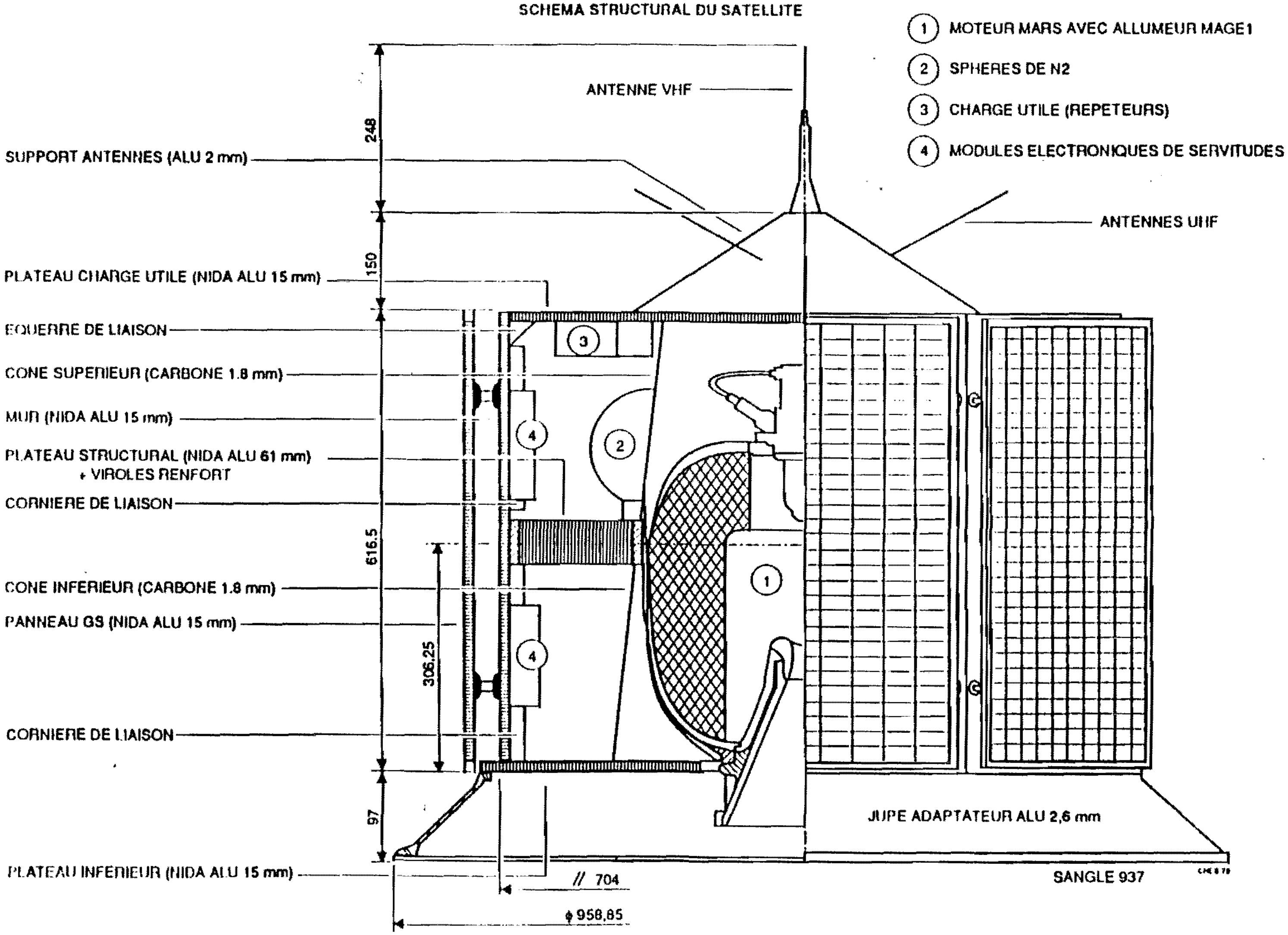
L'ENSEIGNEMENT DE L'ESPACE

ARSENE



VHF UNIPOLAR ANTENNA
ANTENNA RIGIDIFIER
TILT NOZZLE
3 UHF UNIPOLAR ANTENNAS
3 2GHz DIPOLE ANTENNAS
AsGa SOLAR PANELS
GALILEO SOLAR SLATS
SPIN-DESPIN NOZZLES
INTERFACE SKIRT
SATELLITE INTERFACE PLANE
SOUTH SOLAR CELL
EARTH GALILEO TELESCOPE

SCHEMA STRUCTURAL DU SATELLITE



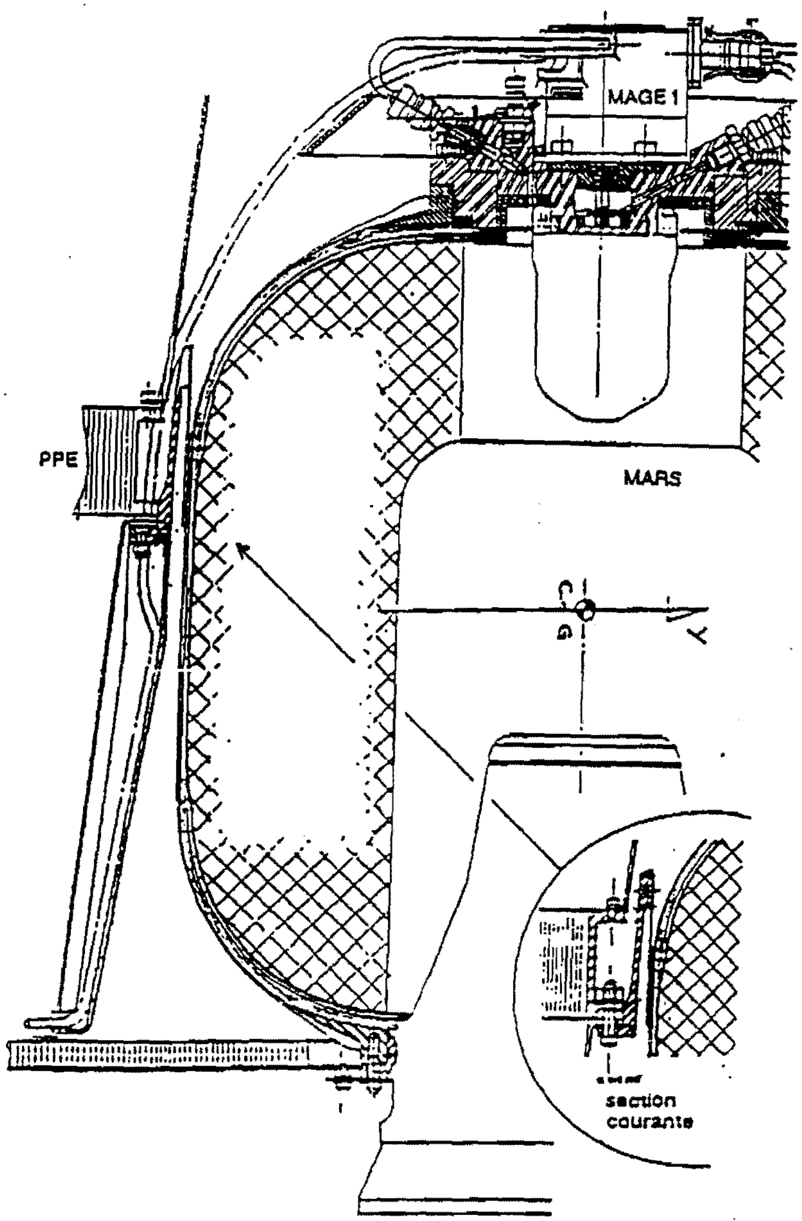
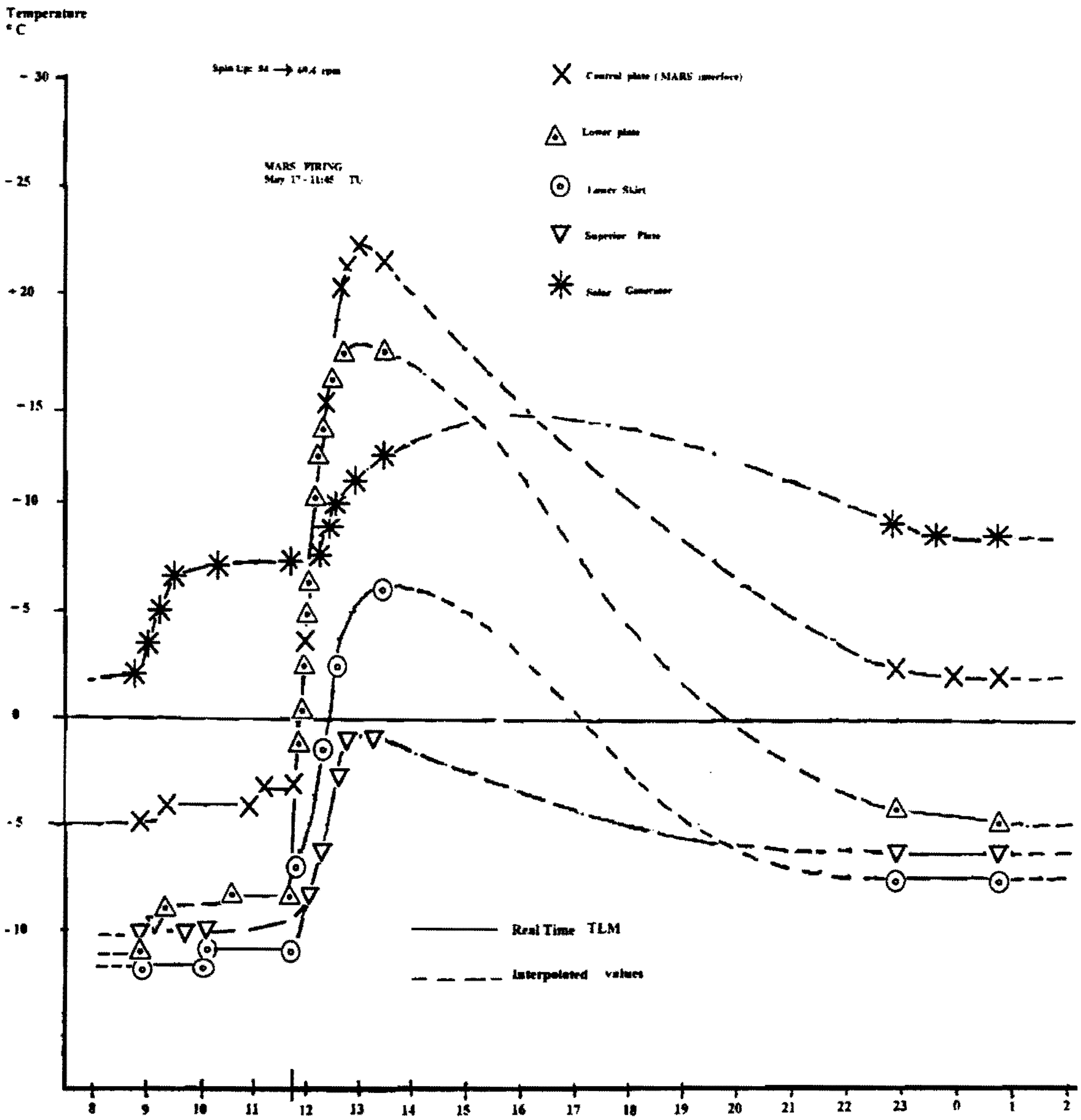
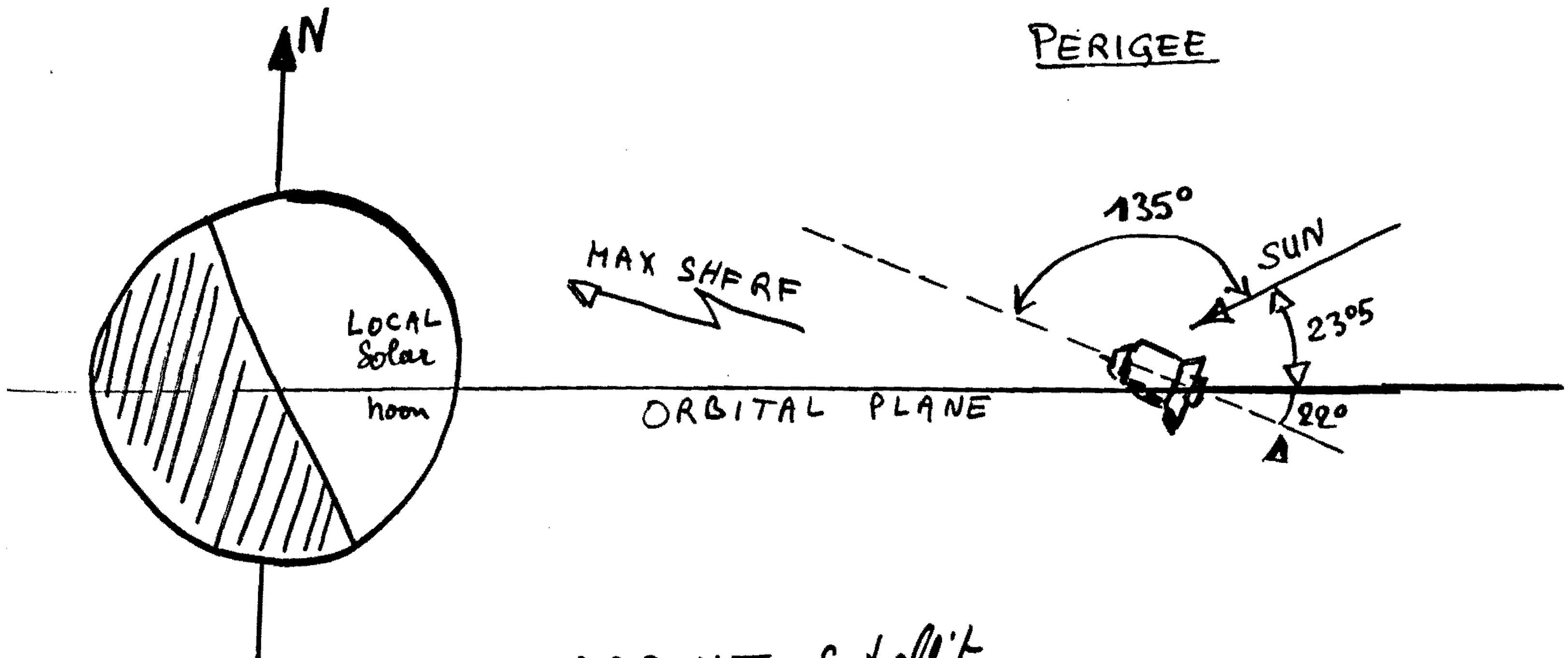


FIG 3 - MOTEUR D'APOGEE, INTERFACE MECANIQUE

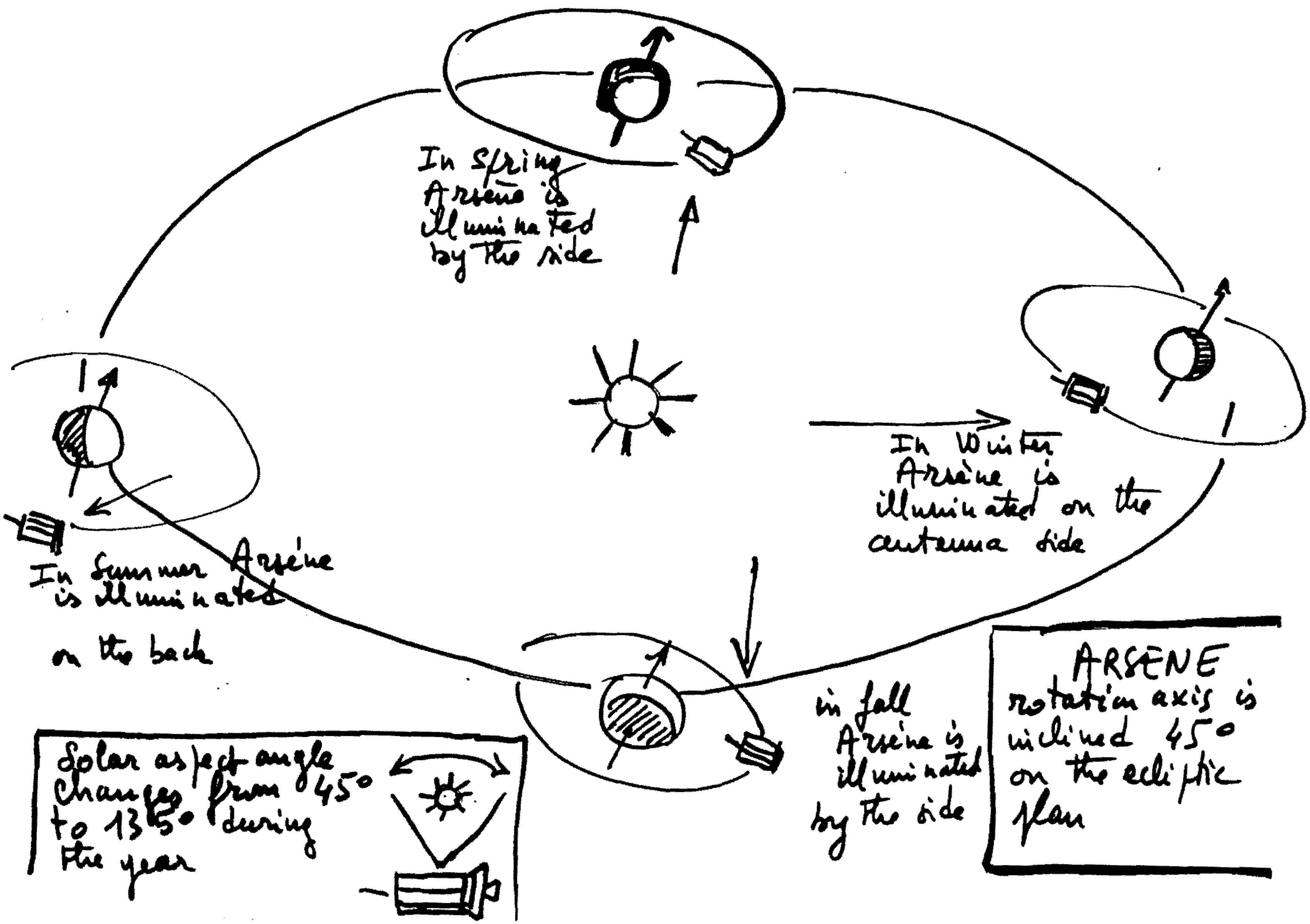
ET POINTS DE CONDUCTION

ARSENE TEMPERATURE EVOLUTION
AFTER MARS APOGEE MOTOR FIRING





ARSENE Satellite
in summer
at 12:00 solar time


In Spring Arsene is illuminated by the side
In Winter Arsène is illuminated on the antenna side
In Summer Arsène is illuminated on the back
in fall Arsène is illuminated by the side
Solar aspect angle changes from 45° to 135° during the year
ARSENE rotation axis is inclined 45° on the ecliptic plan

UNAMSAT-1 EXPERIMENT MODULE
TSFR

by

David Liberman, XE1TU
UNAM/AMSAT

UNAMSAT-1 is a microsat built in the Universidad Nacional Autonoma de Mexico, UNAM and the TSFR or Module 4 is occupied by the hardware required to perform the science experiment proposed for this mission. This paper gives a description of this hardware as well as a more detailed description of the experiment.

Meteors have been in the field of interest of scientist and radio amateurs for a long time. Scientists are concerned with meteors because they represent the matter in the Universe that doesn't necessarily emit any type of radiation. For this reason, they are considered part of the "Dark Matter" that composes the Universe.

In a sense, some of them could be the only messengers coming from outside the Solar System. Of course, many come from inside the Solar System. From earth, the escape velocity of the Solar System is close to 72 km/h, and that should also be the velocity of an object falling to earth and coming from outside the Solar System. This is the parameter we intend to measure with UNAMSAT-1.

We know that when a meteorite enters the atmosphere it will suffer great ionization due to the friction with the molecules of the atmosphere. It has been reported that there are basically two types of ionization produced. One is from molecules of the meteor itself that will become part of the trail left behind by the meteor and the other, probably due to a very strong emission of ultra-violet light by the body of the meteor, the ionization of atmosphere molecules, which recombines very fast and seems to be present only in the vicinity of the meteor itself.

A radio wave bounced from the trail (named the "trail-echo") can give, through its intensity, an idea of the kinetic energy of the meteor. The wave bounced from the ions surrounding the meteor (named "head echo") will produce a Doppler frequency displacement due to the velocity of the meteor relative to the satellite.

The instrumental requirements are a pulse transmitter, a receiver with the capability of tuning plus or minus the expected Doppler shift of the echo, a control circuit and a power conditioner for the transmitter, plus the corresponding AART. Let me describe each of these devices.

The power required is calculated considering the path loss from the satellite to the meteor trial. Then an analysis of the scattering of the incident wave is done, but only the back-scatter component is considered, to calculate the power returning to the satellite. Again, a path loss from the fraction of power back-scattered in the direction and at the distance of the satellite is accounted for. This yields a power requirement at 40.997 MHz of 70 watts peak. We decided to add a safety factor and the transmitter was built for 70 W RMS.

The parameters used to calculate the back-scattering considered that we should be able to get echoes from meteors producing 10^{12} ions per meter of trajectory as a minimum. This number of ions is also the limit to consider the trial under-dense or over-dense. The over-dense trial has more than 10^{112} ions per meter and can be considered a perfect electrical conductor. So we calculated the total loss of the signal to allow us to see the over-dense meteors. In general, there is no relation between the mass of the meteor and its kinetic energy. A meteor of 1 gram at a high velocity will leave a trial equal in ionization density as a bigger meteor with much less velocity.

The efficiency of the transmitter had to be as large as possible to avoid generating too much heat. Jan King advised that we should try to use a mode F final amplifier.

We built an exciter frequency controlled by crystal with 220 mW and the transmitter was built with only two transistors. The measured power is 70 W RMS and the efficiency from D.C. to R.F. is 92%. A large amount of testing has been performed and the transmitter looks very stable and "well behaved".

The receiver is based on a suggestion made by Tom Clark, W3IWI, and is basically a GasFet preamplifier, a double balanced mixer, a bandpass filter, an I.F. amplifier, a phasing network producing +90 degrees and -90 degrees to a summing amplifier, all of this for each of the side bands. The mixer uses a sample of the crystal oscillator of the exciter, so no corrections are required to obtain the true Doppler shift.

The control circuit for this module is based in the 68HC805B6. It controls the pulse duration by reading 4 bits in the AART for low duration and 4 bits for the high duration. The duration can be controlled between 1 msec and 16 msec and the pulse repetition rate from 1 to 16 sec between pulses. The same micro-processor has an A/D converter that digitizes the echo and has a serial output to send this information to the main CPU on the satellite for further processing.

The module has several thermistors that will allow us to know, via telemetry, the temperature of many points in the module. There is also a watch-dog timer made with a counter and a gate ("and") that will reset the microprocessor in case the pulse tries to stay high for more than 16 msec.

The transmitter and the receiver are connected to the same antenna through a hybrid circuit with more than 26 dB isolation. The receiver uses the same signal sent to key the transmitter to blank its preamplifier and the I.F. during transmission to avoid overloading.

The antenna's supports were modified to allow for the additional antenna for 41 MHz. In Module 1 of the microsat, we have an antenna coupler and a coaxial line of ½ wavelength to connect the other half of the canted dipole.

The HC805 can be reprogrammed from the ground by using one of the HDLC lines going to one of the PSK transmitters. The memory in this "micro" is big enough as to hold several versions of the controlling program and even several copies of each version. Through the same HDLC line we can record the starting address so we can use a different version of the controlling software at will.

The digitized echo (64 bytes) will be send to the main CPU where further processing will take place, like a Fast Fourier Transform, and comparison between consecutive echoes to determine if there has been a Doppler shift. If the shift is within certain limits, it will be put in a file that will be retrievable by all amateur users, so they will also be able to determine the velocity of the meteor. Each meteor will be placed in a different file along with the time information that will allow us to know when and were the event took place.

Finally the power supply. It represented a good engineering problem as the transmitter will require 10 amps on the 10 volt bus line when transmitting the pulse. Due to the duty cycle, we decided to build a switching power supply that will charge 16 tantalum capacitors of 330 uF to a voltage of 40V. requiring only 50 mA for a very short time (about 0.5 sec). This way the 10 V bus line doesn't even know that the satellite is sending 70W RMS pulses.

Another interesting engineering problem was to make all that fit in the TSFR, but we succeed with no small effort and it looks very nice. It has been tested many times and we are very confident that it should perform in space according to expectations.

VOXSAT
VOice eXperimental SATellite

Gustavo Carpignano, LW2DTZ
AMSAT ARGENTINA Vice-President
M.Rosas 2044
1828 Banfield
Buenos Aires
Argentina

Abstract

In January of 1990, four microsats were launched from Kourou european space port. One of those microsats was the Lusat packet satellite, brother of Pacsat. Lusat was made totally made in United States, except by the CW beacon equipment that was made by an Argentine team.

All the mechanicals, hardware and software of those birds were made out of our country, but we learned a lot from our North American colleagues.

Nearly two years ago, a team of satellite enthusiast designed a simple payload with the idea to launch it from the MIR space station, but some financial aspects didn't make that possible. But a launch opportunity to be included inside a big Russian satellite as a secondary mission did appear. With that objective, the team started to work to make all the necessary changes.

1.0 Mission General Description.

The VOXSAT satellite is aimed at educational and researching problems and also at popularization of the space techniques among people of the Earth. Signals from the satellite can be received as short audio messages on Earth by VHF-FM receivers with a simple antenna. The process of receiving of messages is possible right from teaching classes Houses of Science & Technics Creative Work Laboratories, as well as from other places.

The satellite is working out by Amsat Argentina with the help of Amsat Russia, the Centre of Space Communication of the House of Science and Technical Creative Work of Youth, the Adventure Club and Compas-R ltd company.

The satellite will also include an FM crossband repeater with a uplink in 70 cm band and downlink in 2 m band.

The satellite is to be put in orbit by a rocket and the payload will be inside a big russian satellite. It's active existence depends of the power supply sources available.

The orbit will be circular with inclination of not less than 55 degrees, with a height of 700 km.

2.0 The Board Hardware.

Description

A receiver for fixed frequency operation in the 435-440 MHz range for audio uploading from Earth command stations.

A receiver for uplink to crossband repeater on 435.100 MHz FM.

A transmitter for 145.825 MHz fixed frequency, with 2W-power, FM, deviation is 3.5 kHz for Digital Voice recorded downlink and FM repeater downlink.

A transmitter for 145.995 MHz frequency with 2W-power, FM for telemetry downlink.

The digital-analog converter blocks.

The electronic memory block.

The on board computer.

The telemetry system.

Power Supply System.

2.1 Power supply

The power will be received from the big russian satellite and will be regulated in accordance of the payload need.

2.2 The Electronic Memory Block

The basic idea of the transformation is to sample the input analog signal and convert it to digital for recording in memory, and also to perform the inverse transformation. The system will divide the signal in sectors and in samplers, and verify the level of each portion of that signal. This level is thus converted into a digital value that can be loaded in the memory. For the signal reproduction, a circuit will read the sequence of digital values stored and transform it across an integrator, that acts as a filter, for duplication of the original signal.

For the A/D and D/A we will use new chips designed by ISD, Inc. Those chips have the capability to load a analog signal 20 seconds long with a S/R best of 35 dB, to 3 dB and 3 KHz of the bandwidth, and a distortion best of 2 % at 1 KHz.

The digital signal is loaded in a EEPROM memory of 128 kB, and retention the information is for ten years and 10,000 read/write cycles.

The possible damage made by the radiation in some cells of the memory will result in low fidelity, contrary to that of a RAM system where a simple bit error can be catastrophic.

We will use six circuits in serial, that will give two minutes of storage for the transmission of bulletins.

2.3 Telemetry system.

Since the control and the environment is supplied by the principal mission of the Russian satellite, the needs for VOXSAT telemetry are very little. Therefore, only a small amount of telemetry information will be transmitted about the operating parameters. Those will sense the principal analog and digital signals about the payload itself.

The telemetry will be send via a packet radio beacon by using UI frames, that do not needed ground station acknowledgement. A possible format of the analog data to be measured is shown below.

VOXSAT HI 080 070 060 050 040 030 020 010 PC16

THE VALUES OF THE CHANNELS FROM 1 TO 8
HAS THE TELEMETRY VALUES

NUMBER	DESCRIPTION	UNIT
1	Russian sat input voltage	Volts
2	Regulator source output	Volts
3	Transmitter output power	mW
4	Total current	mA
5	Temperature	C
6	Transmitter temperature	C
7	Transmitter current	mA
8	Receiver sensibility	mV

2.4 On-Board Computer

The on-board computer consist in a MC146805 microprocessor and auxiliary CMOS circuits. It has eight analog input and eight digital outputs. Furthermore, it has six digital input/output ports for control of experiments, eight Kbytes of ROM and eight Kbytes of RAM.

The circuit has a watchdog timer to reset the microprocessor in case of a fault. The ROM-stored programs lets the satellite transmit it's data in HDLC packets.

3.0 Structure.

The VOXSAT support structure has the purpose of containing the satellite blocks, and isolate thermally and mechanically from the big satellite. The structure was made of thin aluminum that made it very light and strong.

On the other hand, the structure is used for the effective shielding of the radio signals that VOXSAT makes, with respect to those of the Russian satellite systems.

ACKNOWLEDGMENT

I would like to thank Leonid Labutin, UA3CR; Eugeni Labutin, RK3APR and Sergei Samborov, RV3DR for their help to make this project possible.

DOVE PROGRESS REPORT AND FUTURE OPERATION

Jim White, WDØE

Member, Microsat Command Team

ABSTRACT

This paper contains a report on the efforts to recover DOVE from previous hardware and software problems and return it to 145.825 MHz MHz operation, including limited voice transmissions. The original design and operational objectives for DOVE are reviewed first. Previous operation and problems encountered are summarized. The steps necessary to recover from these problems and put DOVE back into operation on two meters are discussed. Particular attention is given to the development of methods and technology to exercise the voice synthesizer and digitizer. Finally, the possibilities for future operations to provide educational opportunities are reviewed.

MISSION OBJECTIVE

Dr. Junior DeCastro, PY2BJO, envisioned a satellite that would speak to young children and students around the world. They would be able to receive its transmissions using simple receivers and antennas. The satellite would transmit messages of peace and greetings from the world's children to their peers. It might also speak its telemetry and other information designed to engage children and stimulate their interest in science in general and space science in particular. When not speaking, the satellite's data transmissions would be receivable with widely available low cost equipment. He named this satellite DOVE (Digital Orbital Voice Encoder).

HISTORICAL PERSPECTIVE

Chronology of events

DOVE was built and launched with PACSAT, WEBERSAT and LUSAT in January 1991 and became DOVE OSCAR 17 (DO-17). Its transmitter came on and began sending ASCII telemetry (TLM) and short text broadcasts soon after launch. The software in use at that time was the same as used in the other Microsats.

During further software development the two meter transmitter became stuck in an on condition. It was rescued by W5UN who used his high ERP EME capability to force a signal into the two meter command receiver. This was accomplished near the end of eclipse when the transmitted power dropped low enough to reduce receiver desensitization.

Following its recovery, DOVE was used by Chaminade College Prep physics students during the 1991-92 school year for projects in their classroom. Dave Reeves of Chaminade has developed a number of curriculum packages that use DOVE to teach science principles.

In late 1991, software was developed to test DOVE's voice capability. It was successfully loaded and turned on in the summer of 1992. The speech consisted of a very simple test phrase that did not take full advantage of the voice synthsizer capabilities, but did prove the hardware in module 4 was working. After a few days the voice messsage became garbled. The cause was unknown at that time, and for safety DOVE was reset back to the on-board Read Only Memory (ROM) software (MBL) and the s-band transmitter turned on.

Hardware description

Module 4, the so-called TSFR (This Space For Rent) module, contains an AX.25 packet encoder, the SC-02 voice synthesizer (now called the Artic Technologies 263A), a digital to analog (D/A) converter, a Motorola 68HC11 processor with 32 K of RAM and a ROM (figure 1). The ROM contains a loader used to place programs and data into the 68HC11 RAM. The 68HC11 in this module communicates with the V40 main processor via the internal 4800 baud bus.

Module 4 also contains the s-band transmitter, which has an output of .8 watts on 2401.220 MHz. The s-band antenna is a monopole mounted on the +Z (top) surface of the spacecraft near one of the sides. The receivers in DOVE are for command and control only. There are two transmitters, both on 145.825 MHz. The second one is a backup. Power output is adjustable to control battery charging as with the other Microsats. However, because the transmitter is not on continuously, and because it is more efficient than the 70 cm Microsat transmitters, the power budget is nearly always positive and the transmitter is typically run at 4 watts. Transmitter B is slightly more efficient than A and so is normally the one in operation. When the transmitters are switched, the sense of the circular polarization changes. Module 4 communicates with the V40 CPU via the standard Asyncronously Addressable Receiver Transmitter (AART) board that is used in all Microsat modules.

DOVE is presently spinning at the same rate it has since shortly after launch, about 21 seconds per revolution. This spin rate can be easily determined by timing the fades of the s-band signal.

Design issues

The primary design issue with DOVE is that its receivers and transmitters are in the same band. This means that when a transmitter is on, DOVE cannot receive a command from the ground. This issue has necessitated elaborate software timers and watchdogs to assure the spacecraft doesn't again get hung in a state with a transmitter locked on. If that were to happen with the transmitter power at 4 watts, the power budget might be enough negative to allow the satellite to be rescued again. However that is by no means certain. Additionally it is not clear the batteries could survive another continually negative power budget episode. If it were to get hung in a state with a transmitter at a lower power level, resulting in a break even or positive power budget, the satellite would be lost because commanding would be impossible.

When in normal operation, the duration of the transmitter-off periods is controllable by adjusting the rate at which TLM is gathered and transmitted. It is possible to send the spacecraft a command to gather telemetry at a rate so fast that the transmitter remains on continuously. This could also result in loss of the mission because it takes about 5 seconds with the transmitter off for the satellite to receive the command to change the telemetry rate or perform a reset. The telemetry cycle time limit is about 11 seconds. However, this limitation has not constrained operation. During 1992 the author sent over 100 telemetry rate change commands to the satellite to facilitate experiments by students at Chaminade College Prep, without a problem.

There is an additional hardware design constraint that has not yet hampered operation, but will make it difficult to exercise the D/A digital voice synthesis capability of DOVE. The speed of data transfer to the D/A is not fast enough to support pure digitized voice at a rate the would provide reasonable quality. It has been suggested that a form of adaptive pulse code modulation could be used to overcome this constraint.

Hardware issues

DOVE has suffered some hardware failures that have made the fulfillment of its mission problematical. During 1992 it was discovered that the AART in module 4 was not responding to messages from the V40 CPU. During subsequent testing it was determined that this AART was receiving and acting on all messages, but not sending a response. This problem was responsible for the hung transmitter problem, and several subsequent software crashes that took DOVE off of two meters. The normal Microsat software must assume, for the safety of the satellite, that if an AART does not respond within a few milliseconds, something very bad has happened. This causes a safety shutdown of all systems, commonly called a "screech". To work around the problem with DOVE, system level Microsat software had to be modified to never expect a response from module 4. While dangerious, this technique has worked so far, and we have no choice but to continue to operate this way if the mission is to continue.

The carrier suppression of the s-band transmitter failed completely, apparently at launch. The first time it was turned on it was discovered that the modulation is about 20 dB below the carrier. Thus it is quite easy to hear the s-band carrier, but difficult to hear the modulation. A receive system capable of about 40 dB overall signal to noise ratio is necessary to detect the flags and packets beneath the carrier. Recently, DSP technology has been applied to this problem as noted further below.

The Microsat Boot Loader (MBL) ROM in DOVE that controls basic spacecraft functions after a reset command is received hangs at times, usually after a few weeks of operation. When that occurs MBL stops sending telemetry packets regularly and does not respond to commands. Recovery from this can be accomplished by sending the spacecraft a "fire code" reset. However, this reset turns off all transmitters so it is necessary to immediately command MBL to turn on the s-band transmitter to avoid serious battery overcharging. This is somewhat dangerous because if the wrong command is sent and one of the two meter transmitters is turned on instead, the mission would be in jeopardy for reasons previously presented.

During the extended periods DOVE has been operating with only the s-band transmitter on, its batteries have been continually overcharged. It is not clear what long term effect this will have on the operation or life of the satellite.

ACTIVITIES DURING THE PAST YEAR

A number of activities have taken place during the past year or so aimed at recovering DOVE and restoring it to operation on two meters. Harold Price, NK6K, obtained from Bob McGwier, N4HY, the hardware and software Bob had been using to work with DOVE. This included a prototype Microsat CPU board, the prototype DOVE voice module board, and some s-band equipment. Harold obained additional equipment needed for the effort. The author purchased an Artic Technologies 263A (SC-02) development system and he and his son Tim (N0ISE) spent much of the Christmas 1992 holiday learning the system and developing better sounding voice phrases for the SC-02.

Bob Diersing, N5AHD, developed software to translate the voice data files from the Artic development system into data files that could be incorporated into the program run by the DOVE 68HC11 processor. He also designed and built an IBM-PC compatible I/O board using the Artic 263A. In order to test the 68HC11 program in an environment more like that of the actual DOVE speech module, a 263A chip was interfaced to a Motorola 68HC11 development board. Additionally, he created software to merge voice data files and a 68HC11 program, and produce output in a form suitable to loading into the satellite by ground command software. Testing and development of this hardware and software continues.

The MBL ROM hung and was reset in July 1993 by the author using the s-band receive capabilities of Bill McCaa, KØRZ. Bill's equipment is able to hear the modulation under the carrier very well. Additionally, using the tracking notch filter feature of the JPS NIR-10, Bill has been able to receive the modulation well enough to decode some MBL telemetry packets. As this paper was being written, he had not been able to decode the longer acknowledgment packets because the high Doppler shift rate of the s-band signal makes it necessary to step the receiver at a 100 kHz or 200 kHz rate. Every time the receiver steps during a packet, that packet is lost because the PSK modem misses at least one bit.

Harold tested the process of loading a Read and write Memory (RAM) resident MBL routine using Bill's receive capability. This was found to work, but has the disadvantage of requiring lengthy long distance phone calls and the availability of two stations for a mutually visible pass.

In August, ground testing of the RAM based MBL routine turned up unacceptable software problems, and so, while it was loaded, this code was not started.

RECOVERY PLAN

At the time of writing (mid August) the plan for the recovery of DOVE was as follows.

- Reset MBL again if necessary. If it does not respond to commands or attempts to load packets it will be necessary to reset it again.

- Develop a new RAM resident simple loader that cycles the two meter transmitter and sends acknowledgments (acks). It will also do a memory wash to protect itself and the module it loads. This will prevent the software "rot" problem with the old modified RAM MBL. Rot is the term used to describe what happens when software errors are introduced by radiation disturbing memory bits. This is a very short program and will be loaded from s-band using either NK6K or KØRZ receive equipment. Existing ground software will be modified to handle this simple loader.

- Load this RAM loader and thoroughly test its operation.

- Load the operating system. The operating system "Kernel" will be loaded using the simple RAM loader and two meters.

- Load a housekeeping task (PHT) module that includes the same voice test code used last year. Use the simple RAM loader. This will allow us to assure the hardware in module 4 is still working. The problem that caused the voice to become garbled after a few days has been found and fixed.

- Test the proper operation of the Kernel and PHT by listening to the s-band transmitter. Normal PHT TLM and information packets should be sent. Stay in this mode for a few hours to assure the software and hardware are stable.

- Turn on two meter transmitter. This will return DOVE to limited operation. Normal PHT ASCII telemetry will be sent, with the two meter transmitter cycling on and off.

- Using the loader in PHT, load the operating modules (three) including a more elaborate housekeeping task (PHTX).

- Test the voice briefly to assure hardware is working. While the voice test could be left on, the quality of the voice in that software is poor and does not represent what the satellite is capable of. Hence the plan is to turn it on only long enough to test the hardware, then turn the voice off.

- Do quick WOD check to assess health. We need to assess the health of all the hardware onboard as quickly as possible. Whole Orbit Data (WOD) collections on the power system will be done to determine the general health and allow us to set the appropriate power targets. During this period, the s-band transmitter will probably be turned off.

- Full WOD survey. Richard Howlett, VK7ZBX, has been added to the DOVE command team. He will do a full WOD survey and analyze the results against previous WOD collections. We will likely invite others to participate in this analysis. The results of this activity will determine the overall health of all spacecraft systems and facilitate a decision to proceed with further development, or dictate a change of plans.

- Make DOVE available for student and interested party WOD collections. After the WOD survey is completed, assuming all is well with the hardware, we should be able to accommodate requests for WOD collections and dumps from students or interested groups. The emphasis will be on education, in keeping with DOVE's overall mission. VK7ZBX will coordinate these activities using the internet. He will accept requests for WOD, command the satellite to perform the WOD collections and dumps, and work with student groups on analysis. Students can collect the WOD directly in their classrooms and labs.

- Make DOVE available for short text broadcasts. The 200 character text broadcast capability has been used in the past for short messages to interested groups (including a demonstration to the FCC commissioners). This capability will again be available.

- Fully ground test modified software containing several new features. The test hardware will be moved from NK6K to the author and a complete and thorough test of software presently under development will be carried out with ground based simulators. This is likely to take several weeks.

- Load the new software via two meters. This software can be loaded by the author using a two meter half duplex capability. Unless software or hardware problems cause a crash, further new versions of the software can be loaded in this fashion. A return to s-band-only operation will not be necessary.

- Using the new capabilities of this software, carefully adjust the power control algorithms in the housekeeping task software. An additional mission safety feature is the ability to establish by command a power "floor" for the two meter transmitter. When set to the proper level this will reduce the chances of a transmitter lock-on at a break even or positive power budget.

- Test the voice capabilities of the new software. These are described below.

- Adjust the transmission intervals of the various informational messages to reduce downlink channel time used by less important data packets. A further description is below.

- Turn s-band back on for testing. It is likely the s-band transmitter can be operated along with the two meter transmitter. If testing shows we have the power budget, s-band will be left on to provide a test signal for stations working on their s-band equipment or DSP demodulation techniques.

OPERATION WITH PRESENT SOFTWARE

With the housekeeping task software that will be initially loaded it will be possible to run thetwo meter transmitter at full power (4 watts). As noted above it should also be possible to run the s-band transmitter. Full ASCII telemetry will be available, with no change from previous formats. Existing telemetry decoding programs that still handle the original ASCII Microsat telemetry format will continue to work (including TLMDCII). Existing WOD reduction programs may work as well, if they can handle ASCII. A release of WB9ANQ's WOD2SS that adds this capability should be available soon after DOVE begins sending WOD. The ability to collect and dump up to 6 orbits of WOD will be available. Two hundred character text messages will be available. As noted above, the hardware in module 4 can be tested with the short SC-02 phrase that was active briefly in 1992.

SOFTWARE UNDER DEVELOPMENT

The software under development will provide several additional capabilities. We will be able to tune the power control algorithm to adjust for most efficient operation. This is an important feature recently added to AO-16, but is not likely to provide much advantage to users of DOVE because we can run the two meter transmitter at maximum power already. However, it may be possible to tune the power control software to more carefully manage battery charging and prolong battery life. It may also be necessary to do some tuning to obtain enough power to run the s-band transmitter full time.

We can adjust the intervals at which various information packets are transmitted on the downlink. We anticipate the BCRXMT message will be turned off. The text broadcast message will be sent more often if there is new information or a bulletin associated with a special event, less often if it contains only routine status information.

WOD collection capability will be reduced to one orbit of data. It has been found that collecting more than one orbit provides little additional useful data and uses up a great deal of time unnecessarily. Using just one orbit of data at a time it is possible to start a collection at the beginning of one pass, then stop the collection, start the dump, and collect the entire set of data on the next pass. Analysis can be done prior to the third pass (if available) and another collection started then. Given stations available to do the commanding and collection, up to three collections a day can be assembled and analyzed.

The text broadcast capability has been expanded to 800 characters. This should allow more flexibility in what can be sent including things like:

- Special event messages
- Messages from PY7BJO (DOVE's owner)
- Messages from education groups and students
- Operating information
- Mix of all of these

The major new feature is an expanded capability to exercise the SC-02. The software has the ability to send the phrases outlined below. They must be developed and tuned using the 263A development system on the ground.

- A greeting in English. Presently this is planned to be "This is DOVE in space"

- Up to three greetings in other languages in round-robin format. Each time the sequence of voice phrases is played, the next phrase in this set of three will be heard (figure 2). From one to three can be included in the set. None of these phrases has been developed at present.

- One of two phrases tied to a TLM channel trigger value. The present software speaks either "I am in the beautiful sunlight," or "I am in the cool darkness," depending on the amount of current from the solar panels.

All of these phrases can be changed and the new ones uploaded with command software under development. We can also change the telemetry channel and the trigger value that the last two phrases are keyed to. We estimate it will take about two good passes to completely replace a set of phrases.

A few possibilities for new phrases tied to telemetry are listed in figure 3. We would like to hear ideas for additional phrases, meaningful to young childern, that DOVE might speak.

It should be noted that phrase development presently requires the development system from Artic, along with a good understanding of the language involved, phonetics and phonemes. Assuming those requirements are met, a 5 or 6 second phrase requires several hours to develop and adjust. At present only the author has the hardware and software required, so new phrases are not going to be produced quickly. Discussion is taking place about creating a simple and inexpensive development system to make it possible for others to create phrases. Once new phrases are developed they can be loaded into DOVE quickly and easily, without the need to load new software.

EDUCATION OPPORTUNITEIS

Once DOVE is back on two meters it can be used for a variety of education related activities. Among those are measurements and demonstrations of:

- The speed of light
- Doppler shift
- Distance of the satellite from the sun at various seasons
- Centripetal acceleration
- Gravity
- Orbits of satellites
- General information about satellites or communication satellites
- How temperatures change in a satellite
- How power from solar panels changes during an orbit
- The form and alignment of the lines of force in the earth's magnetic field
- The force of photons on differently painted surfaces in space

Additionally, DOVE can be used by amateurs as a stepping stone to other satellites. After receiving DOVE using normal terrestrial packet equipment and/or simple receivers, the next step can be AO-21 or FO-20.

FUTURE OPPORTUNITIES

The software presently under development can provide the capabilities described above. We can more throughly utilize the synthesized voice by speaking phrases tied to a variety of telemetry channels. The longer text bulletin messages can be used in ways previously described. We can run the s-band and two meter transmitters simotaniously. We could even add flexibility in the use of the SC-02 with more and possibly longer phrases. However, more could be done.

With additional software development the D/A converter could be exercised. This would provide significantly better voice quality and potentially some sound effects. Longer phrases could also be played through the D/A. Voices or sounds recorded on the ground, including students' voices, could be digitized, uploaded and played. Multiple messages could be loaded and played back serially, alternately, or even randomly. One or more could be in the transmit sequence while others were being loaded. However, extensive software will be required to implement this feature. Code would have to be written for the V40, the 68HC11, and ground computers, to perform APCM or some similar compression technique. Both spacecraft and ground software would have to be developed to allow large files to be uploaded quickly. A adaptation of an inverted Pacsat Broadcast Protocol has been discussed. Even with that capability a group of dedicated ground stations would be required, because uploading digitized sound files several tens of kilobytes long would take several passes.

We have developed new software to make the process of loading all software from scratch much easier and more automatic. S-band receive is needed only for the initial pass or two of the process. Whatever else happens with DOVE in the future, loading after a software crash or reset should not be a roadblock to progress.

The potential for DOVE to more fully achieve its originally envisioned mission could be further enhanced with some additional volunteer effort. One of the objectives of DOVE was to bring science, technology and satellites into the classrooms of very young students including those in developing countries. Receiving equipment is very hard to obtain in those countries, no mater how interested and dedicated a teacher or administrator may be. A group of volunteers could produce an inexpensive kit to use in such classrooms. It could be made available at very low cost, or even at no cost if a group or club was willing to donate the necessary time and material. Such a kit might consist of the following items:

- receiver
- antenna kit
- tracking material (OSCAR Locator?)
- curriculum material
- DOVE facts sheet and drawings
- information about other amateur satellites

The receiver could be made available either as a kit or in assembled and tested form. It would need to receive 145.825 MHz MHz only and need not be complex. It should be able to run off of a variety of power sources, including a battery. The antenna could be a simple ground plane or monopole and be an easily assembled kit. A short feed line would be needed, with connectors already attached. This equipment should be all that is needed to hear the DOVE voice transmittions.

The other items in the list would be enhancements to the package that would facilitate the educational value of the satellite. Simple pass prediction material and devices like the OSCAR Locator could be used to learn about the fundamentals of orbits and better schedule activities around DOVE passes. Curriculum material could be included that would outline classroom activities leading to an understanding of science, physics and mathematics principals. A DOVE fact sheet and drawings would start students out on a road to learning about what makes up satellites and how they work, and would help them relate the telemetry phrases they hear to what is happening inside and outside the satellite. Information about other amateur satellites would stimulate further curiosity and potentially generate new hams.

Material could be produced in several languages to facilitate direct use by students in many countries. Once the program is going, more student groups could exchange information about their activities through the AMSAT Education Newsletter and potentially contribute material to the package.

Equipment and material of this nature could also be used with other education oriented satellites now being planned or build, including one scheduled for launch in 1994 that will also operate on 145.825 MHz MHz.

SUMMARY

With the successful development and implementation of the software and implementation steps outlined in this paper, DOVE will again be operational and fulfilling much of it intended mission. Hardware problems that have slowed the achievement of this goal have been creatively worked around with software and technology. It is our expectation that DOVE will remain on the air, transmitting on two meters, as long as there is interest. Further evolution of the mission will depend on the level of interest expressed by the amateur radio and education community.

There is much work to be done. New and enthusiastic volunteers have made progress to this point possible. There is plenty of room for additional dedicated people to contribute. It is certainly possible to add digitized voice to the mission if skilled people step forward and volunteer their time.

DOVE has a bright future, sharing 145.825 MHz MHz with other education related amateur satellites, and bringing the excitement of technology and space to young people world wide.

ACKNOWLEDGMENTS

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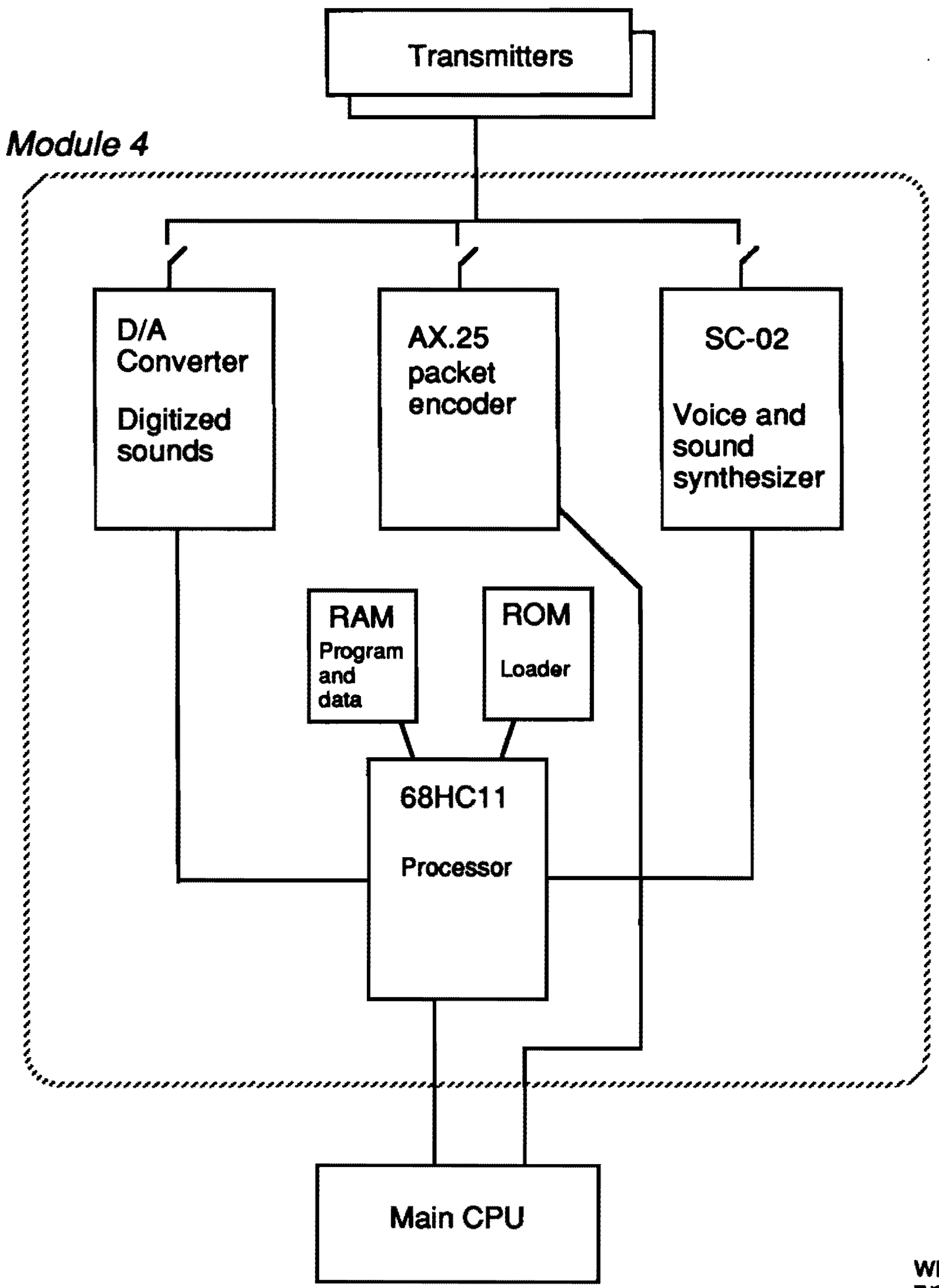
Figure 1

DOVE VOICE MODULE BLOCK DIAGRAM



WD0E
7/93

Figure 2

DOVE TRANSMISSION SEQUENCE

DATA	VOICE		
ASCII Telemetry and text message	English greeting/ID	Language 1 greeting ↓ Language 2 greeting ↓ Language 3 greeting	Telemetry true phrase - OR - Telemetry false phrase

- One or all phrases can be replaced in 1 or 2 passes
- If a greeting isn't present it is skipped
- Telemetry channel tested, and test value, can be changed by command
- Length of TLM and Voice segments can be changed (power budget considerations)
- S-Band transmitter may be on full time

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8/93

Figure 3

POSSIBLE NEW PHRASES RELATED TO TELEMETRY

Panel temperature: **My skin is warm/My skin is cold**

Array voltage: **It is light around me/It is dark around me**

Array voltage: **My power is from the sun/My power is from my battery**

Array voltage: **I am moving South/I am moving North**

+Z array current: **My top is up/My top is down or My top is pointed into space/My top is pointed at earth**

Battery voltage: **My battery is fully charged/My battery is low**

Various panel currents: **My left side(right side, front, back) is in the sun/My left side is in shadow**

Transmitter temperature: **My transmitter(voice) is hot/My transmitter is cold**

Battery temperature: **My battery is cold/My battery is warm**

+Z array temperature: **My top is cold/My top is warm**

Transmitter A power output: **You are hearing my transmitter number 1/You are hearing my transmitter number 2**

<u>With further software work:</u>

Particle impact detector: **I have been hit x times by meteorites in the past y minutes**

BCR currents and a little math: **My batteries are charging/discharging**

STATUS block that counts down the command watchdog: **It has been x days since I have received a command**

Some 20-20 hindsight:
A Slightly Different View of WeberSat

by
Bob Argyle, kb7kcl
Weber State University

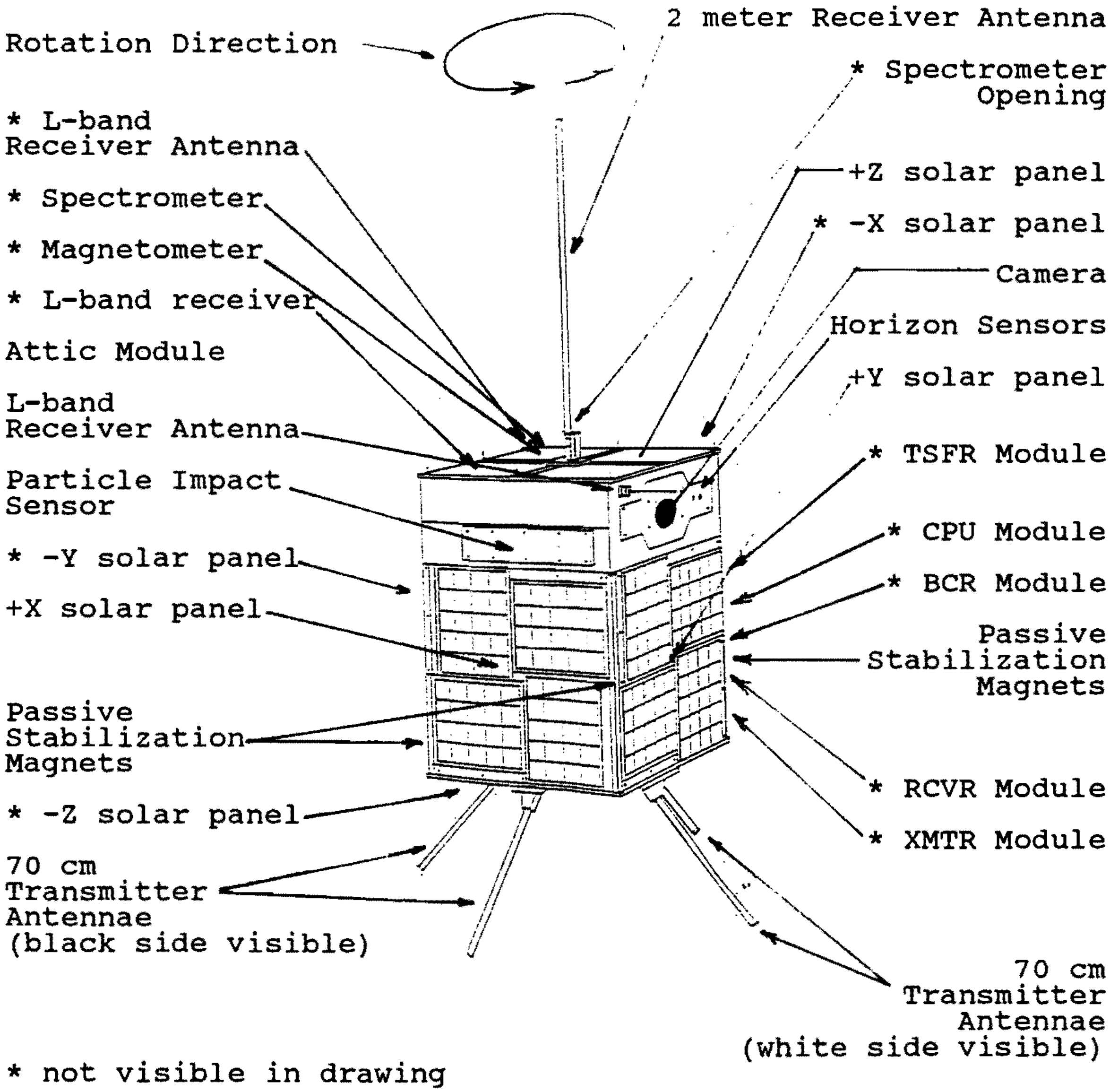
Abstract

Webersat/OSCAR-18 is a 12.25 kilogram experimental low-earth-orbiting satellite, one of the four Microsats launched 1:35:30 22-Jan-90 (UTC) into an 800 km sun-synchronous polar orbit. It has over three years of successful operation so far. Among its experiments are a color video camera, spectrometer, flash digitizer, horizon sensors, particle impact detector, flux gate magnetometer, and the usual Microsat telemetry. This paper gives an overview of the present operational status of major systems. Rather than a rosy review of what works, the problems encountered and suggested changes for future designs are offered. We learn from mistakes.

Introduction

For the purpose of this paper, Microsat specifically refers to Pacsat/Amsat-OSCAR-16, DOVE/OSCAR-17, Webersat/OSCAR-18, Lusat/OSCAR-19, Itamsat (to receive OSCAR-28 (?) upon orbital operation), and other satellites in design or under construction based on the Amsat Microsat bus, and may be used, uncapitalized, to refer to any spacecraft small and light enough that one can hold under one arm while opening a locked door with the other, without fear of dropping it. I've done exactly that. A thirty kilogram satellite is too big to be a microsat. This size and weight imply a certain simplicity in the satellite.

The construction of Microsats has been described in detail elsewhere. To summarize, there are five modules. Interconnection between modules is through a 25 wire bus. The modules are controlled by a serial interface. The satellite may be assembled from its component modules, or disassembled, in less than a half hour. The modules are respectively transmitter (XMTR), receiver (RCVR), battery charge regulator (BCR), computer (CPU), and "this space for rent" (TSFR). Each module is 183 mm long by 199 mm wide by 40 mm high (BCR, 43 mm high) internally. Webersat has an added "attic" 75 mm high containing a Canon Ci-10 color video camera, impact sensor, magnetometer, L-band video receiver, spectrometer, and horizon sensor.



Note: This array labeling has been derived experimentally. Some disagreement over array labels exists in the literature and the engineering drawings.

figure 1: Webersat perspective view, face and axis labeling

Rotation studies

Webersat, like the other Microsats, has 4 canted turnstile antennas mounted on the -Z face, which are painted black on one side and white on the other. On Webersat, they are mounted so that the left side of spacecraft (in the usual orientation of +Z on top) has one or two black sides visible and the right side has one or two white sides visible (see Jackson, "Camera", figure 2). If a visible-light photon strikes a white side, it reflects, and if it strikes a black side, it is absorbed. Given equal numbers striking each side, and that the elastic collision on the white side impacts more momentum than the inelastic collision on the black side, a net momentum is imparted around the Z-axis, causing a counter-clockwise rotation when viewed from the +Z surface (+Y +X -Y -X). It achieved this spin direction in October of 1991. The bar magnets line up the Z-axis along the earth's magnetic field, but leave the satellite free to rotate around the Z-axis. As the satellite revolves around the earth, its Z-axis stays aligned with the magnetic field, causing two tumbles per orbit. The +Z axis points earthward over the (magnetic) southern hemisphere, the -Z over the northern hemisphere, leaving the X and Y axes to point earthward only over the magnetic equator. Noticeable horizon foreshortening appears at about 30 degrees inclination in the magnetically aligned Z-axis, even if the Y-X pointing is accurate.

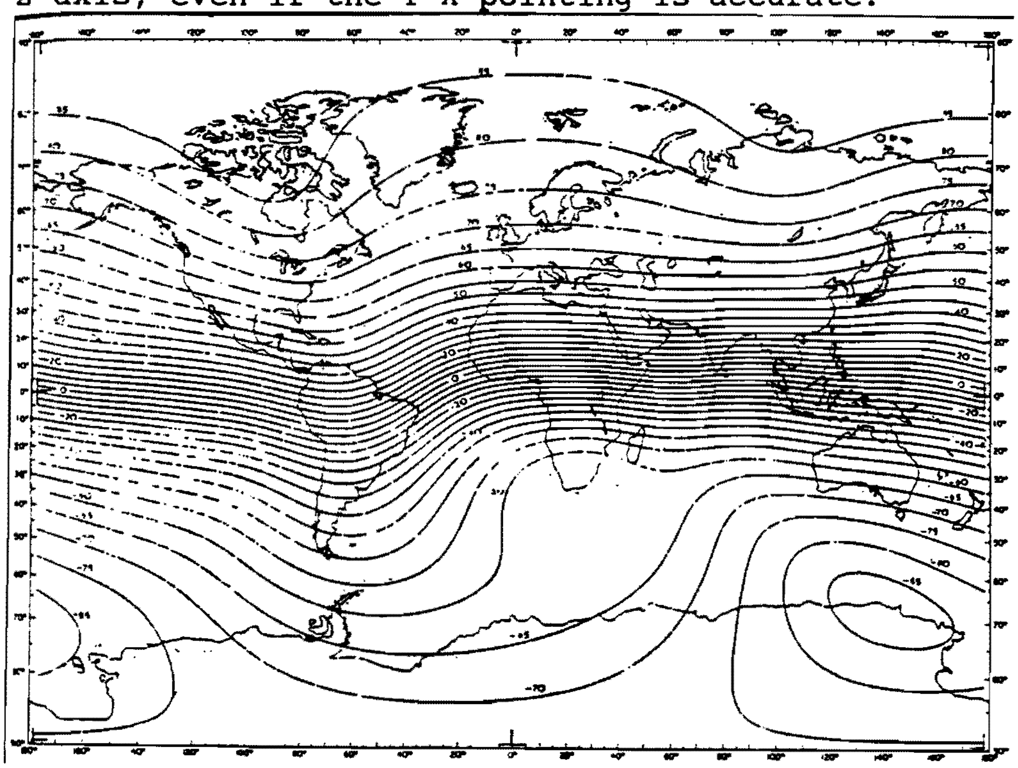


figure 2: Magnetic inclination of Z-axis (1965 IGRF)

From the periodic nature of the +Z-array current, it may be reasonably suspected Webersat is not rotating around the Z-axis. An early unpublished study of the spin rate by the author included finding the axis of rotation, and its precession, by taking the direction cosines from the solar panel currents. The cross-product of the vectors would give the spin axis. The angle between the vectors divided by the time interval would be the rotation, and the precession rate and magnitude would be calculated from the spin axis changes. This gave a precession an order of magnitude faster than the spin rate. This result is not simply unpublishable, but its interpretation unprintable. Attempts to understand the motion were put on hold for quite some time.

Due to the addition of the "attic," Webersat is slightly longer along the Z-axis, and has a greater moment of inertia along that axis, than along either the X or Y axes. If we label the long axis of a cooked strand of spaghetti the Z-axis, we note it also has its greatest moment of inertia along that axis. If we now try to rotate the spaghetti about that axis, we see that the spaghetti tends to convert that rotation into a rotation about either the X or Y axis. If we'd used our noodle, we'd have realized Webersat would show the same effect.

In summary, Webersat "wants" to rotate about any but the Z-axis, but the magnets won't let it. It converts the momentum from the solar propeller into a coning motion, or "Weber-Wobble". The period of the wobble is about 70 seconds. The period of rotation is (August 1993) about 4 minutes, and has varied erratically from 2 minutes to 25 minutes. The spin slows gradually, as predicted by the motion model (Smith, "expanded"), but shows occasional sudden increases. The magnitude of wobble diminishes with increased spin rate. The reason for the spin rate increases is unknown, but was related in at least one instance to a geomagnetic storm. Curiously, this increased rate was in the same direction, opposite the stable rotation since achieved.

Recommendations: If adding modules to the Microsat stack, add them to the +X and -X sides beneath the solar panels, not to the +Z side. This will retain the magnetic stabilization and spin properties of the other Microsats, at a slight cost to the ease of assembly. An additional benefit would be added view angles from the +Z and -Z surfaces, allowing, for instance, a camera pointing out the +Z or -Z face to view aurora australis and aurora borealis respectively.

WeberWare 1.3's telemetry decoding programs calculate the rotation rate around the Z axis. However, as the wobble and rotation changes from orbit to orbit, probably according to Webersat's passage over the magnetic poles, predicting where the camera will be pointing down is problematic. While Weber is assembling a database of telemetry, taking the array currents and extracting the spin, tumble and wobble to form a predictive pointing model, awaits an eager Math student. When a major perturbation of the motion occurs, some alert should be raised so the cause may be found.

It has been noted that the satellite spins opposite to a Crookes' Radiometer, that the spin rate varies, and that a Crookes' radiometer is not wholly evacuated. Perhaps variations in spin rates are related to an interaction between the normal photon torque and the Crookes' radiometer torque from whatever varying atmospheric density exists at 790 km. A possible experiment to measure this density is suggested: have a 3-axis stabilized satellite carry Crookes' radiometers in the usual pressure vessel, a fully evacuated vessel, and a vessel open to the atmosphere, with sensors to measure the speed and direction of rotation. How to manufacture these radiometers to survive launch and then operate in micro gravity is a remaining problem.

Orbital changes

Webersat's orbit has changed since launch by a slight descent (795.0 km to 781.9 km), a change in inclination (98.7129 degrees to 98.6216 degrees), and a movement of its orbit plane relative to the sun. Shortly after launch, the satellite had 100 nodal orbits in a week plus about 8 minutes, with the highest elevation pass at about 11:30 am local standard time. In the summer of 1992 the satellite had 100 nodal orbits per week, so that one week's schedule was almost identical to the next. Now the satellite passes are 4 minutes earlier than the previous week's, with the daytime highest elevation pass about 12:12 PM local standard time. Sun-synchronous orbits are most stable in the plane of the sun (Smith, "personal"), so this time is not expected to change much. This time also implies that night passes occur centered about midnight.

Impact sensor

The impact sensor consists of an array of piezo-electric transducers or "microphones," mounted on the +X surface of the attic. An additional sensor is located inside the body of the attic. Each sensor has circuitry to convert any signal above a certain threshold to a pulse. If a pulse comes from the external sensor, and no pulse comes from the internal sensor within a certain time period, a

4-bit counter (0 to 15) is incremented. The counter resets to 0 from a count of 15. Due to the constraints of the interface, the output of the counter is converted to an analog voltage, 0 to 2.55 volts, which is then sampled with the telemetry, to give an expected reading of 0 to 255 in steps of 17. Like all real world results, the actual results are somewhat different. The sensor converts in the range of 54 to 208 (including some noise) in steps of 9.5.

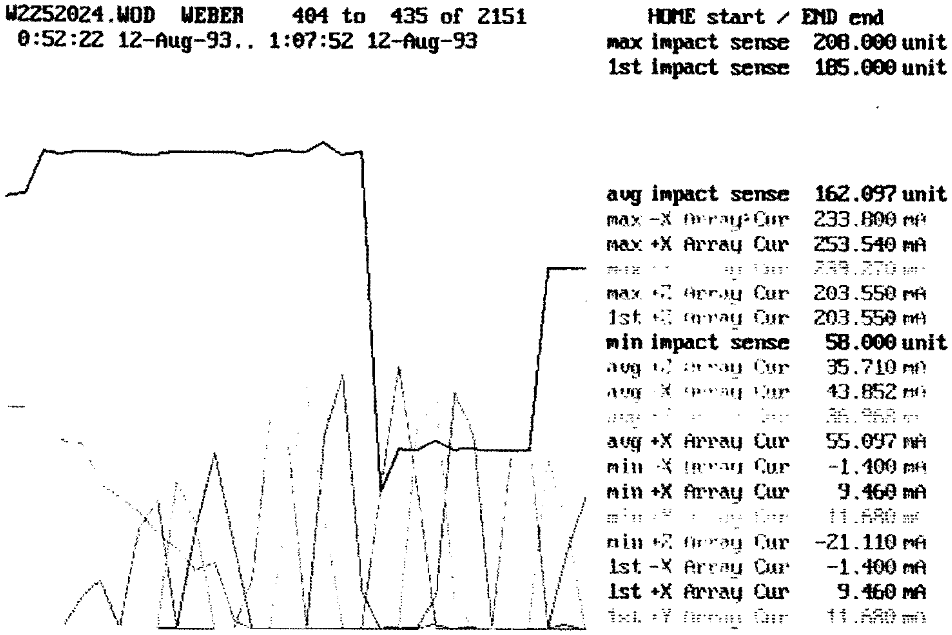


figure 3, impact sensor output, WeberWare 1.3 WOD_GRAF.EXE

Despite the internal sensor preventing counting, the possibility of thermal creaking exists. Analysis of a recent collection taken during the Perseid meteor shower gave this relation between an impact counter event (a change in the count greater than 9) and the array illuminated: 10 events where the -X is most illuminated, 2 events where +Y is most illuminated, 2 events where +X is most illuminated, 3 events where +Z is most illuminated, 1 event where -Z is most illuminated. Therefore, thermal creaking by expansion of some object on the -X side, or by contraction of an object on the +X side, is a significant possibility. The impact sensor did not receive thermal coating, and would have a different cooling characteristic than the attic module itself.

Geologists have noted that earthquakes have a different wave form signature than impacts or explosions. An impact or explosion produces waves that have motion in the direction of the wave propagation, pressure or P-waves, while earthquakes, a slippage of one part of the earth past another, produce waves that have motion orthogonal to the direction of propagation, shear or S-waves. Similarly, a slippage of one part of the satellite frame past another part should produce S-waves, while impacts should produce P-waves. Measuring these waves on a satellite would require many sensors and a dedicated digitizer for all sensors simultaneously.

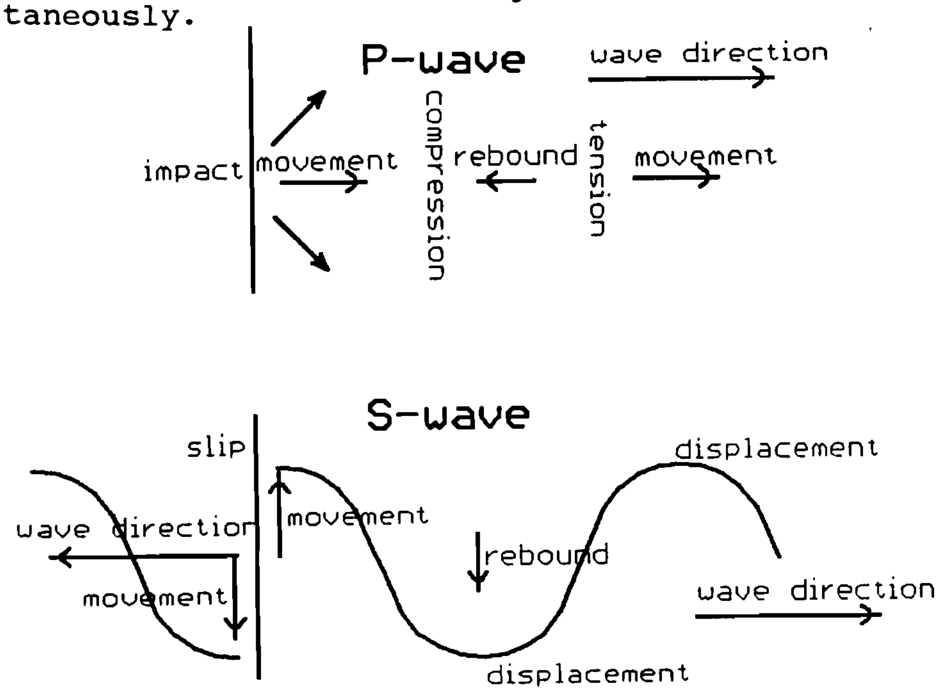


figure 4, P-waves and S-waves, impacts vs. thermal creaking

Recommendations: While the easiest way to eliminate thermal creaks would be to make the satellite solid, this would eliminate the advantages of modularity and the 30 minute assembly time. The P-wave versus S-wave distinction, while able to use the entire satellite as a detector, is probably more complex, and power hungry, than the results would justify on a microsat. Some method of making the sensor plate(s) acoustically isolated from the satellite, yet have the attachment able to withstand launch, is probably best. Perhaps the solar panels themselves could be wired as sensors.

Magnetometer

The Webersat fluxgate magnetometer was designed by Dr. Mario Acuna of NASA and further developed by Dr. Robert Summers.

Webersat had one or more of its stabilization magnets in the wrong orientation when the magnetometer had its compensation magnet installed. The magnet was installed off axis of the magnetometer coils, but this did not indicate an error at the time because the magnetometer could sense a very small magnet being moved 12 or so feet away in almost every direction. At this writing (August 1993) the X-axis is always 255. The Z-axis averages 72, the same value and variation both axes read when the device is powered down. However, when the satellite has low rotation and high wobble, such as in the spring of 1991, the X-axis of the magnetometer displays occasional activity.

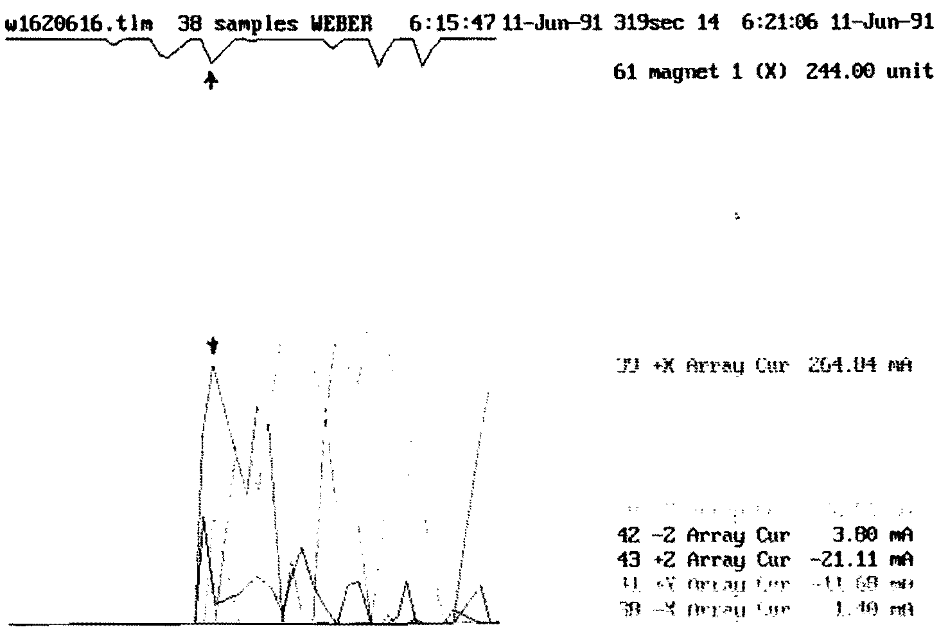


figure 5: magnetometer and array current graphs. Text data are for Sample 14, 319 seconds after data collection began. Horizontal scale is 2.5 sec/pixel. Vertical scale is 0..255 raw units.

What we'd do differently: The time constraints of the launch campaign rule out the obvious answer of "be more careful." No magnetic stabilization implies either unstabilized, or some other sort of stabilization at added expense in weight and control. Even the simplest stabilization, gravity gradient, requires some care in deployment, and takes the satellite out of the microsat class (as defined in this paper). Some sort of programmable range and scale was ruled out by the constraints of the interface (4 wires: 5V, ground, and two analog signal outputs). A non-saturating magnetometer would be less sensitive and probably non-linear at the extreme ranges, but, unless the interface constraint is changed, is probably the best solution.

Horizon sensor

The horizon sensor is composed of two visible-light photodiodes (Siemens BPW21) aimed through holes in a field-of-view restrictor (FOV). Illumination of each photodiode is though a 1.25" long 1/8" diameter hole in an aluminum block. The two holes are parallel to the Z-plane and are at 79 degrees to the +Y surface, in opposing directions. The divergence between the center of each field-of-view is 22 degrees.

The original concept of the horizon sensor was that reflected light (or sunlight) would generate a current in a photodiode. Due to the large dynamic range of the light, and uncertainty about the light level calibration, a logarithmic scale was needed, so the current would go through a diode and generate a voltage proportional to the logarithm of the current, varying with temperature and junction size:

$$V = k\ T\ d\ s\ \ln(I / Io)$$

Voltage across junction = Boltzmann's constant * temperature in Kelvin * constant function of doping * constant function of junction size * natural log of (current through diode divided by recombination current).

The many orders of magnitude change in produced current between direct sunlight, reflected earth, and deep space would produce a difference of a few tenths of a volt above a 2.5 volt floor. This voltage would require amplification, and inversion, to the range 0 to 2.5 volts. The dark reference level would vary with the 5 volt supply, not considered a problem. The original concept would have a schematic like that shown:

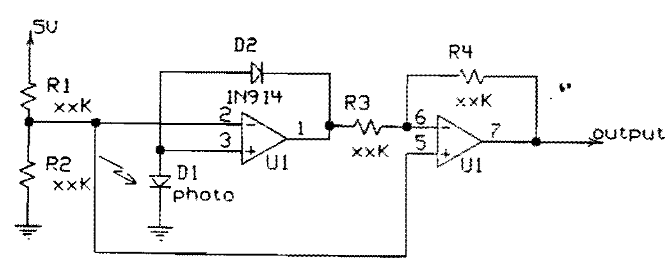


figure 6, original horizon sensor concept, 1 of 2 channels

Somewhere between the original concept, the SPICE model, and the prototype, the circuitry was constructed as shown (figure 7); a difference easily overlooked when under time pressure.

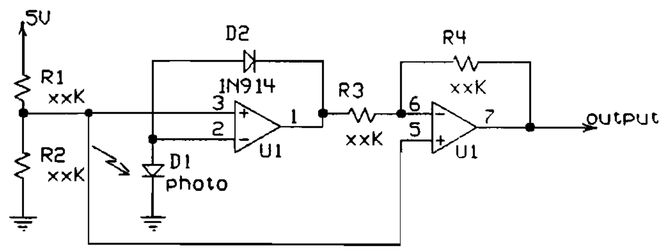


figure 7, original horizon sensor circuit

However, the circuit did respond to light, and that was all that was needed. The output of the first stage varied between 0 and 2.5 volts, so the second stage of amplification and inversion was removed. The flight circuit is as shown in figure 8.

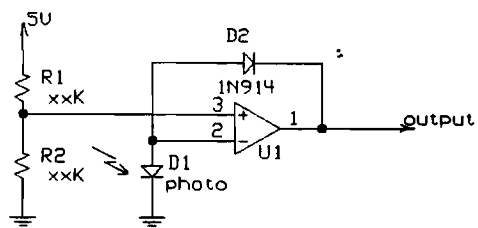


figure 8, horizon sensor flight circuit

Each photodiode has a 10 degree field-of-view, with 22 degrees between the centers of the fields of view, and when both photodiodes are illuminated, the only object large enough to illuminate them both would be the earth, if no significant reflection occurred from the sides of the FOV tubes. The FOV was not anodized, and so significant reflection does occur. The logarithm diode is reverse biased. Yet, the sensor does yield useful signals; despite being visible-light photodiodes, the sensors can detect the some IR from the earth at night and yield rotation data. During the day, the earth and sun are both detected, with the sun being detected most often.

What we'd do differently: for night usage, sense infra-red rather than visible light, and place the sensors other than in the Z-plane so they more often intercept the earth. Anodize the FOV for less reflections, and build the

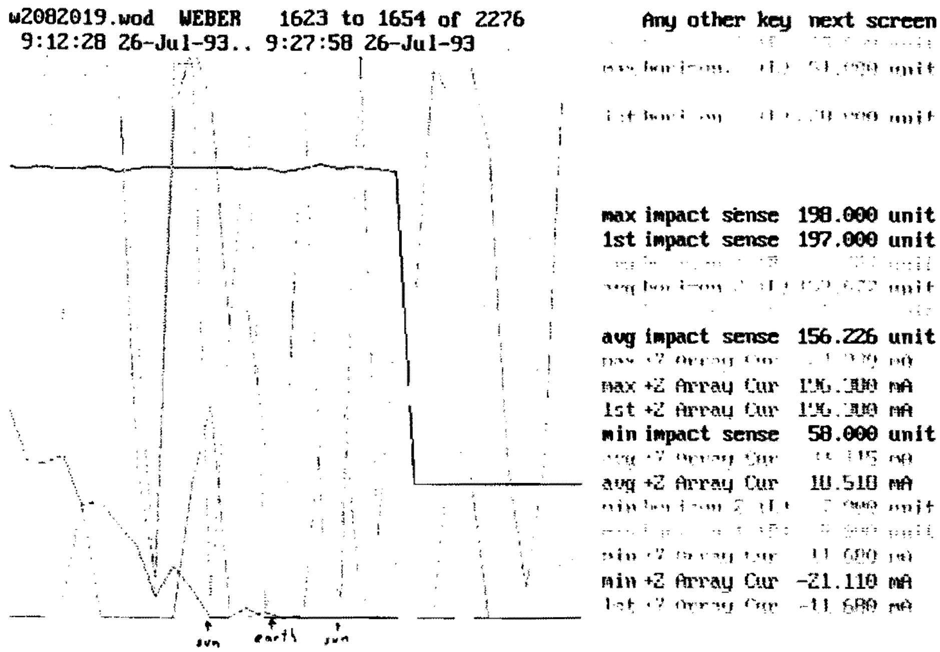


figure 9: horizon sensors versus +Y array. Note the sensors give low readings (light detected) for both the sun and earth.

tubes ridged as an optical trap, rather than straight (simply drilled). Build the circuit as conceived, but also regulate the dark-level reference voltage. Calibration would be useful. Subtracting the visible light component from the IR would yield a less-ambiguous earth sensor. Having enough sensors to detect the earth limb, and thus the geocenter, would give a second orientation vector to the sun vector and thus a less ambiguous orientation in space.

Temperature sensors

Webersat's internal temperature runs at about -2 C on average. According to the sensor readings, the internal temperature of daytime passes is about two degrees colder than for nighttime passes. Whether this is actually occurring, or is an artifact of some voltage fluctuation in the satellite, is unknown. The change in unconverted reading is about 3 units.

As with the other Microsats on the V-35 flight, the corrected identification of channels is:

dec	hex	name	coefficients			units
20	0x14	+X (RX) Temp	100.01	-0.5980	0.000	Deg.C
21	0x15	Rx Temp	100.01	-0.5980	0.000	Deg.C
52	0x34	RC PSK BP Temp	100.01	-0.5980	0.000	Deg.C
53	0x35	RC PSK HPA Temp	100.01	-0.5980	0.000	Deg.C
54	0x36	+Y Array Temp	100.01	-0.5980	0.000	Deg.C
55	0x37	PSK TX HPA Temp	100.01	-0.5980	0.000	Deg.C

We assume the attic temperature coefficients are the same as for the other thermistors.

Due to the TSFR and attic in Webersat replacing the receivers underneath the +Z array, the +Z array temperature was never connected on Webersat, despite two unused thermistor inputs available in the TSFR and attic underneath the +Z array. This has impacted our power generation.

What we'd do differently: Mount a thermistor on the wall of the attic, connect the +Z array temperature (indeed, put thermistors on all solar panels), and use much more sensitive thermistor circuitry. The 0.6 degrees between units is coarse resolution for the range of temperatures observed. Had the thermal design been less accurate, we would have needed at most a range of 0.3 degrees per unit over -25 C to +50 C. A 12-bit digitizer could give the increased resolution over the worst-case full range, and with appropriate scaling would fit in the 8-bit Microsat telemetry format.

Spectrometer

The Webersat spectrometer was designed and build by Tom Davis, now I3/EA2CLS. It consists of a linear CCD of 5000 elements arranged into two interleaved channels. Light is divided into a spectrum and each individual CCD element discharges according to the intensity of that portion of the spectrum falling upon it (and its sensitivity to those wavelengths). A pre-launch spectrum of a helium discharge tube, and detail of the two channels, is shown in figure 10.

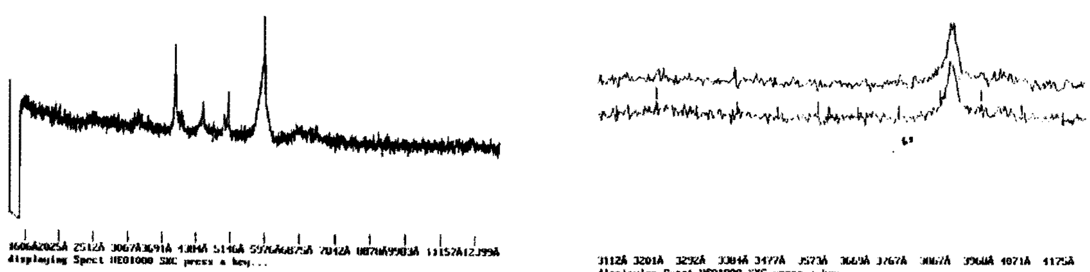


figure 10: Webersat Spectrometer helium spectra, with separated channel detail.

There is apparently some jitter in the beginning of digitization versus when the CCD begins sending the samples to the digitizer, as shown by the fact that the offset between channels must occasionally be negated for them to coincide. The sharply rising edge of the digitized data, near 160.6 nanometers (1606 Ångstrom), may be a better reference point for the calibration equations.

As with the early camera experience, proper exposure and pointing is still experimental. Some early pictures had fanciful interpretations, when they were simply glare from the sun out of view; some spectra have features at greater pixel numbers, interpreted as longer wavelengths, that cannot be real. We suspect they are from light which does not traverse the intended optical path, either from light leaking into the attic other than through the spectrometer opening, or from light coming in the opening at an angle that does not enter the optical path, possibly reflecting internally. There are also diffractions from the diffraction grating that are sidelobes of the primary refraction, at about 170 nm and 780 nm.

Other than blocking the unintended light paths (which are significant only when the spectrometer is pointing sunward), and having no jitter in the digitization, at this point we'd do the spectrometer as launched. A physically larger device may give better resolution, but unless the spectrometer is the only experiment this would remove the satellite from the microsat class.

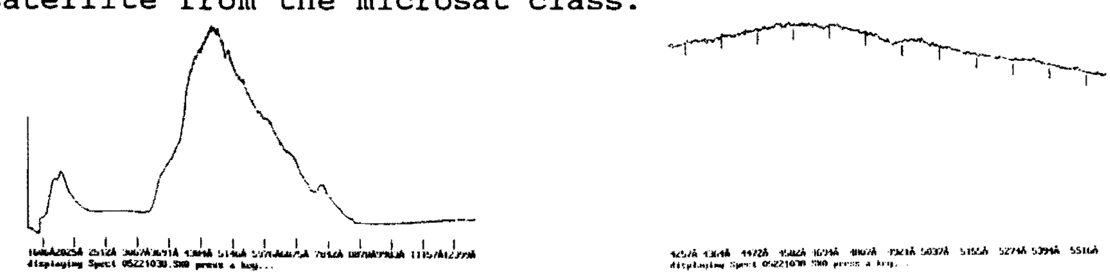


figure 11, properly exposed Webersat earth spectrum, and detail

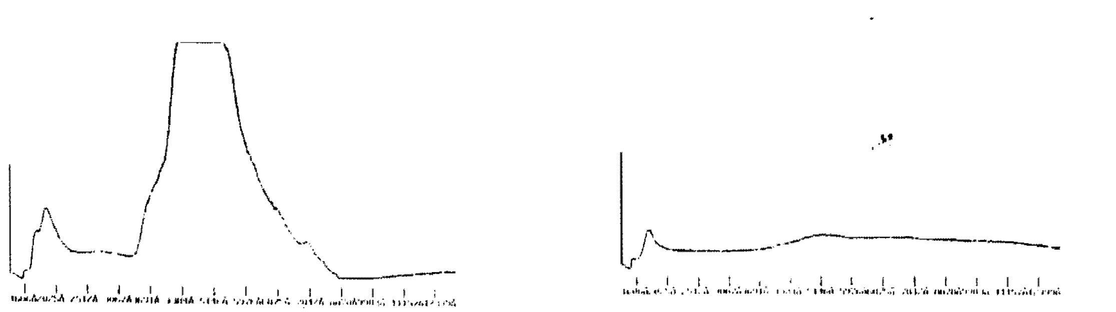


figure 12, overexposed and under exposed Webersat earth spectra

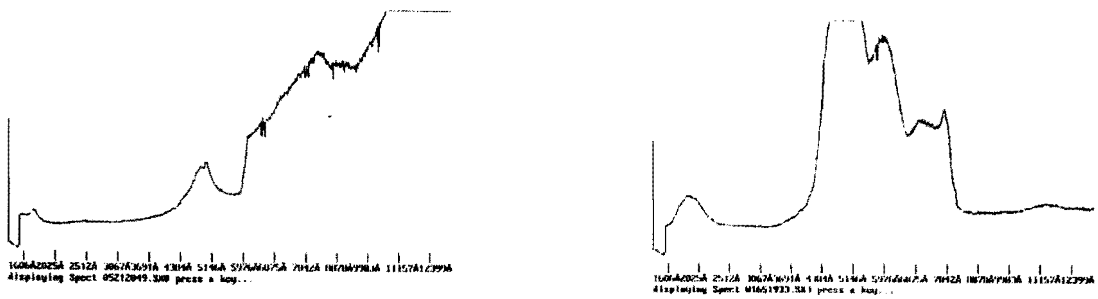


figure 13, anomalous sprectrometer exposures, pointing sunward.

Camera & Pointing

How to tell where WO-18 is pointing: As WO-18 passes through the area of the magnetic equator, it aligns itself so +Z surface -- the "top" -- points toward the south celestial pole (within 20 degrees or so, depending on the amount of wobble). The camera is mounted in the "attic" with the left side (colorburst side) of the picture towards the +Z surface. In other words, for Webersat pictures of earth, the right side of a picture is north, more or less. The camera points out the +Y surface (the Sun picture of 15-Aug-90 had the arrays mislabeled). The azimuth and elevation calculations in the header is taken from the solar panel currents and gives the sun angle from the lens axis. Azimuth is calculated from the Y versus X arrays, elevation from the Z versus combined X and Y arrays. Elevation 0 and azimuth 180 would have only the -Y illuminated, and the camera pointed directly away from the sun. Azimuth 90 would have only the +X illuminated, and the camera pointing west into deep space. Since the earth subtends an angle of about 125 degrees at Webersat's altitude, azimuth 120 would show the western horizon. The camera lens has about a 20 degree field of view.

For the angle calculation in the header, a pure cosine function is assumed for the solar panels. No correction for increased reflection at shallow angle is made, nor is any relative temperature correction for the previously exposed panel made.

Knowing where the satellite is, and roughly where satellite is pointing, one may often identify the imaged area, such as the coast of Peru (figures 14, 15):
Picture #08 taken Wed Jul 15 16:44:14 1992
horizon sensors: 16 135
iris: 28 600000
impact 204 to 204
arrays: +X:11720 +Y:19390 -X:204400 -Y:160060 +Z:-21110 -Z:13280 (uA)

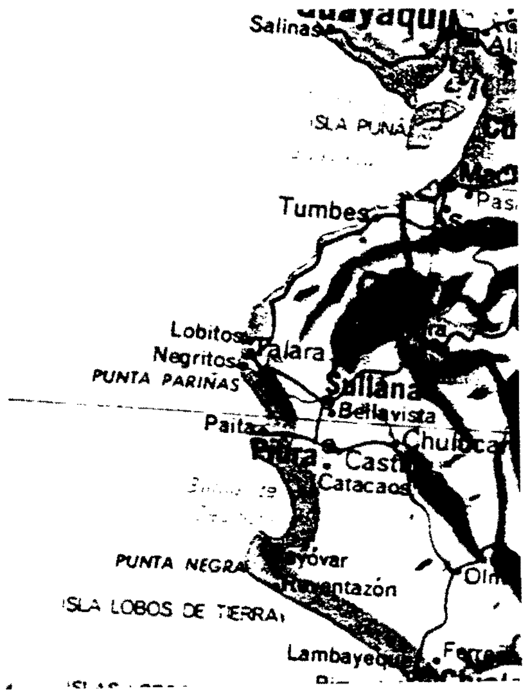


figure 14, Peru coast (WO-18) figure 15, Peru coast (atlas)

One of these days I'll write a decent print program, instead of using printscreen.

As Webersat's camera has a fairly narrow field of view, with some uncertainty of just where it is pointing, we like to shoot coastlines. Northern Niger, one of our early pictures, doesn't have any; and the atlas shows this area as almost featureless. The only identifiable feature (other than clouds) is either a shallow lake or a dry lake bed. It doesn't look like the Lake Chad shown in the atlas, but little else is in the area. Great Salt Lake here in Utah also has no outlet, and shows great fluctuations in size and shape. The possible lake is the 'y' shaped lighter area in the upper right center of figure 16.

Picture #09 (figure 16) taken Fri Jul 05 10:33:59 1991
horizon sensors: 66 12
iris: 32 20000
impact 114 to 156
arrays: +X:9460 +Y:38510 -X:55300 -Y:229500 +Z:-21110 -Z:-12790 (uA)

A coastline by itself does not always give complete identification; some coastlines, such as figure 17 of southeastern Somalia, are nearly featureless. Contrast stretching does bring out some detail.

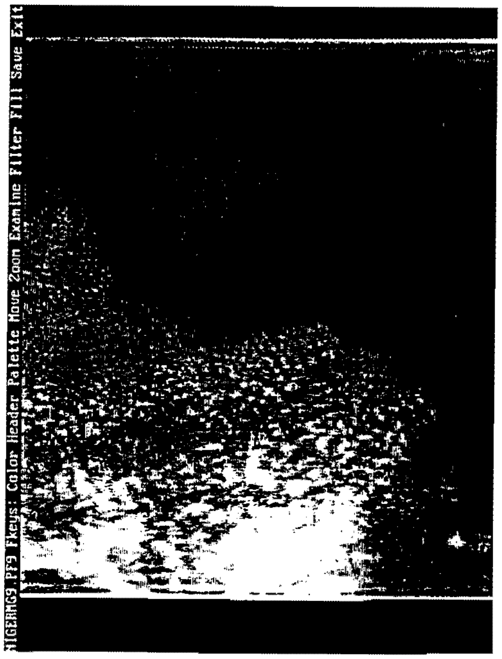


figure 16, Niger

figure 17, Somalia

Picture #02 (figure 17) taken Wed Aug 26 07:58:51 1992
horizon sensors: 109 48
iris: 28 600000
impact 123 to 136
arrays: +X:9460 +Y:2660 -X:99400 -Y:251900 +Z:-21110
-Z:-10420 (uA)

Even when you have a coastline with identifiable features, maps may disagree. The picture of the coast of northern Brazil, with clouds and haze, was enough different from the atlas in use at that time that we were unsure if the finger-like projections were real. Unfortunately they do not reproduce well; just the maps are reproduced here.

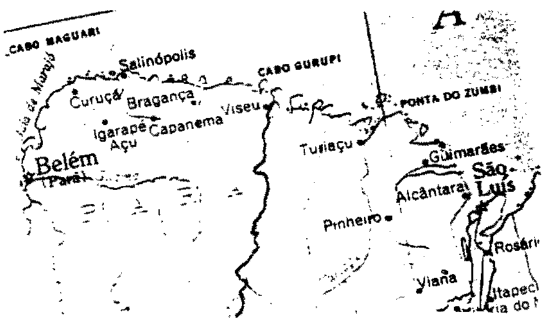


figure 18, Rand McNally

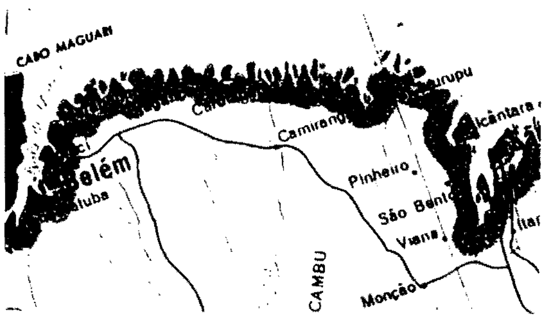


figure 19, Reader's Digest

Picture #02 (Brazil) taken Fri Nov 01 13:51:33 1991
horizon sensors: 49 16
iris: 24 300000
impact 64 to 163
arrays: +X:13980 +Y:26560 -X:700 -Y:301180 +Z:7570 -Z:-5680 (uA)

Books on photo-interpretation frequently call for the interpreter to be familiar with the area. When we took this picture of the Philippines, our protocol was to call the lighter areas land and look for an edge. In the southwest (lower right) of the picture is apparently an area of shallow water, perhaps coral reef, which is much lighter than the deeper water or the adjoining land. The inside edge of the lighter area could be matched bump for bump with the peninsula.

figure 20, Philippines

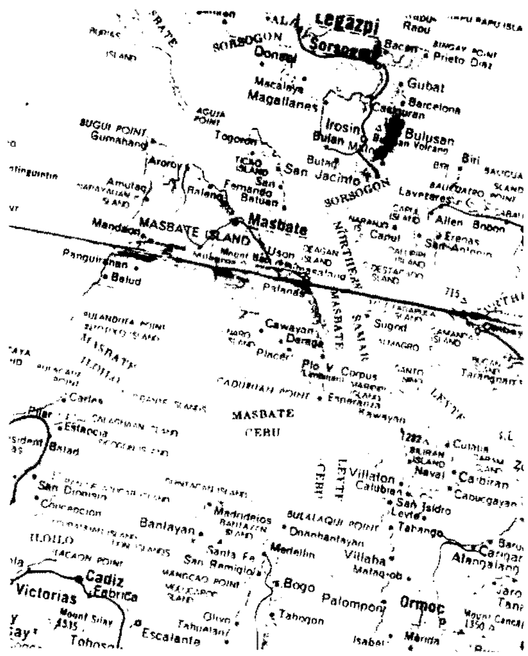


figure 21, Philippines map

Picture #00 (Philippines) taken Sun Oct 13 02:47:43 1991
horizon sensors: 68 6
iris: 24 300000
impact 154 to 184
arrays: +X:11720 +Y:12220 -X:7000 -Y:218300 +Z:69710 -Z:-12790 (uA)

What we'd do differently: Use a standard format, such as APT format, if possible. Rather than extract color in software, or require special hardware, digitize the RGB directly off the CCD. More of digitizer's dynamic range could be devoted to image. We would like to have more cameras, so at least one of them would be pointing down; and use a wide angle or normal lens (in addition to the telephoto lens) for easier identification of the area imaged. And of course, shoot anyone quoting "I've looked at clouds from both sides now" or even humming its tune.

L-band uplink (future)

The 1.265 GHz AM L-band video receiver has not produced a recognizable image since launch. A more powerful transmitter is in progress. As the estimated 2.5 kW to 30 kW EIRP needed for a quality picture will also "nuke" anything in the beam (or sidelobes), safety co-ordination will be required.

Quick Download (future) and 4800 baud (future)

One of Webersat's untested experiments is the ability to FM-modulate the 437.075 MHz transmitter. This could be used to send voice, or pictures in an analog format. This was placed at low priority because it was unknown if the SSB modulation would have to be in a special format, such as unmodulated flags, or even be turned off to copy the FM, if turning on the FM would prevent copy of the SSB (and thus possible software errors preventing command and control), and because special hardware would be required. We were not aware of the APT "weatherfax" format at the time of construction.

It is however possible to turn on both transmitters at once, so the normal downlink need not be interfered with. The 437.075 MHz transmitter may also be switched to directly retransmit one of the receiver channels. Unfortunately, no switch position exists for no SSB modulation. If this is a quiet channel, the SSB will have a regular pattern and should not interfere with the FM.

Another untried experiment is running the transmitter and receivers at 4800 baud. 4800 may be used on individual receiver channels. Or, if the receiver outputs a signal modulated at 4800 baud, this might be more easily filtered out from 2400 baud APT type FM modulation than the 1200 baud.

As 4800 baud was never tested on the ground, the digital repeating mode on the 437.075 MHz transmitter can be used to get the modems working, without loss of the 1200 baud from the CPU. When the modems on the ground are working, it will be worth implementing 4800 baud out of the

CPU. Note that this proposed digital repeating mode is not "digipeating," but will simply retransmit anything it hears. For power reasons, the 437.075 might be turned on only during daylight, and only if turning both transmitters on is safe. Just this week NASA has learned, again, that failures occur when power is cycled.

Open Access fill command (future)

Previous to the December 16 1992 software crash, the on-board software could only be commanded to begin sending a picture at a certain point, so even the Weber command team sometimes did not get all of a picture it wanted before an SEU destroyed the picture. The satellite also did not place the correct X and Y positions in the first data packet, so the first 4 lines were frequently missing. But with a complete re-write of that section of the software, and based on my decision to not have more than one line in a packet, a "FILL" command suggested itself. The present fill command software in use on the satellite leaves the area of the picture after the last packet filled coming down, the next command received terminates the present fill, and it uses the same callsign and password as other TSFR commands, so it is not suitable for immediate public availability. The next upload will remove those objections. When a fill command is received, the list of packets requested will be appended (on a space available basis) to a special list, and every second packet sent will be from that list. Open access should be implemented on or near the presentation date of this paper. The GSTATION.EXE and PICOFILL.EXE programs now being distributed with WeberWare 1.3 (or updated versions) will also be made available on AO-16 or LO-19 (whichever is not overlapping WO-18), and one or more uplink frequencies announced at that time.

Real time PHOTO / SPECT decoding (ground, future)

When one has spent several years looking at the PHOTO packet bytes as they come down, one gets the ability to classify the ASCII characters representing brightness levels into clouds-over-ocean, shoreline, horizon, and totally dark or washed-out pictures, before displaying it through the decoding software. But, to minimize the requests to fill packets already received, the GSTATION.EXE program (which presently just captures, it knows nothing about KISS mode) should be modified to examine the packets for the Y:X picture data addresses and remove those packets from the PICFILL.CMD list. And if it looks at the packets, it might as well display them.

Colorization (ground, future)

Pat Kelly and Jeff Peabody, students at Weber State University, developed a card that converts the digitized NTSC waveform as represented in a Webersat picture back into analog, so a composite monitor may display it in all its colorful glory. Rather than requiring all Webersat users to get specialized hardware, a software equivalent for equipment many users have, an EGA or VGA (or better) display, is desirable.

A program to extract the color information from Webersat pictures must solve several problems:

0. The phase and magnitude of the color carrier, and the grey level on which the carrier rides, must be taken to find the red, green and blue intensity values from the CCD.

1. Because of jitter in the color carrier frequency tripler onboard Webersat, harmonics of the 3.579545 MHz frequency exist as phase error in the downloaded data. In the present WeberWare colorization, these phase errors cause a vertical stripe appearance similar to the vertical strips caused by the color carrier in black-and-white display modes.

2. The color carrier has a quarter-phase relationship with the synchronization signals, but the digitized sample, clocked by the tripled color carrier, cannot meet that relationship. For instance, two adjacent lines in the same video field have a 180 degree phase shift of the color carrier, but only a 120 (or 240) degree phase shift is in the data. A vertical line will wander back on forth 60 degrees of phase. With 120 degrees phase per pixel this gives a half-pixel error.

3. The auto-iris will cause static images to achieve the same average grey level, but the rotating satellite may move to a different scene. If the satellite was previously looking at a cloud, and moves on to view open water and land when the digitization is taken, the scene will be underexposed; if the opposite occurs, the clouds will be over-exposed and washed out. This under- and over-exposure also occurs in commercially transmitted video, most commonly in sporting events, but the camera usually stops moving and the iris adjusts (some adjustments may be made in the control booth as well). These cameras are also much more expensive than the Canon Ci-10 color camera in use on Webersat. The levels representing black and white must be determined for each picture.

4. Image manipulation (such as the "color" and "tint" controls on a TV) should be available. This manipulation may vary in sophistication; for instance, taking the ratio of colors may be used to remove topographic effects from vegetative effects. Contrast stretching, density slicing, edge enhancement, and histographic equalization are commonly used.

5. The resultant red, green, and blue triplets at each

point should be mapped into the available colors on the video hardware without waste of palette entries. Some sort of meaningful display should be available for all graphics hardware, even monochrome graphics.

Jay Smith has written a program that solves these problems for the Macintosh IIci hardware. It makes extensive use of toolbox calls not available on PC clones. Reverse engineering of these calls is in progress.

Summary

Perhaps the greatest tribute to the design of the Microsats is that, in a package so small and inexpensive, so many powerful things can be close, but not quite right, on their first attempt.

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A SIMULATOR FOR PACSAT-1 AND UOSAT-5 DOWNLINK TRAFFIC

Robert J. Diersing, N5AHD
Department of Computer Information Systems
Texas A&I University
Campus Box 184
Kingsville, TX 78363
Internet: n5ahd@amsat.org

ABSTRACT

The current status of continuing work on the development of a PACSAT downlink traffic simulator is summarized in this paper. The first version of the computer simulation was developed two years ago and emphasized the connected mode of operation in use at that time. More recently, it has been updated to model the broadcast mode of operation for PACSAT-1 and UoSAT-5. Empirical cumulative density functions have been constructed from actual downlink data from PACSAT-1 and UoSAT-5 for important model parameters. The goal has been to develop a simulation that would help assess the effects of changing such parameters as the: downlink data rate; the arrival rate, service time, and byte count for directory and file broadcast requests; and the arrival rate, service time, and byte count for file server (connected mode) requests.

INTRODUCTION

PACSAT-1, UoSAT-5, and other digital store-and-forward satellites operating in the Amateur Satellite Service have been providing messaging services for radio amateurs in a routine and reliable manner for the past several years. These satellites can be accessed in two ways--connected mode and broadcast mode. Initially, the connected mode was used more frequently, but with the implementation of automatic hole filling and directory broadcasting, the broadcast mode has become the preferred and most frequently used access mode. Implementation of the enhanced broadcast mode features occurred around the end of 1991 for UoSAT-5 and in October 1992 for PACSAT-1.

Interest is increasing in store-and-forward satellites operating in low-earth-orbit (LEO) not only in the Amateur Radio Service but in other services as well [6] [7]. However, the successful operation of PACSAT-1, UoSAT-5, and similar satellites causes the largest experience base with this type of LEO satellite to exist within the Amateur Satellite Service. Those persons involved in the development of future digital LEO satellite missions frequently need to predict the effect of changing some system design or user parameter. Typical questions requiring study might be [4]: How many stations requiring a certain number and type of transactions per day can be accommodated under a given footprint? What is the effect of a drastic change in transaction characteristics (for example, doubling the file size) on system capacity? What is the effect of a change in uplink or downlink data rate?

One possible way to answer some of the many LEO store-and-forward satellite system design questions is through computer simulation. This author has been working on computer simulation models for LEO satellites such as PACSAT-1 and UoSAT-5 for the past several years. One previous paper [2] described the characterization of connected-mode file server transactions for PACSAT-1. More specifically, empirical distributions were found for file server: interarrival times for successful connections, transaction service times, transaction byte counts, and AX.25 link-level response times. Another paper [3] gave a brief discussion of the components of the model, its implementation details, description of the validation procedure, and the results of simulating a few previously-unused operating configurations for PACSAT-1. A similar traffic analysis was done and statistics derived for UoSAT-3 which has previously operated in the Amateur Satellite Service [1].

Besides providing a cursory review of topics in prior papers, this paper will address two aspects not previously presented. First, a description of simulator operation will be given from the user viewpoint. The description of simulator operation will show the evolution from an implementation that emphasized the connected mode of operation to one that emphasizes the broadcast mode of operation. Second, data analysis and implementation details relating to the incorporation of the PACSAT Broadcast Protocol into the simulation model will discussed. Details about the broadcast mode have not been previously published.

SYSTEM DEVELOPMENT AND IMPLEMENTATION

The packet radio satellite downlink traffic simulator program is called PACSIM. Interestingly, PACSIM is an ambiguous reference as far as packet radio satellite simulators go. The same name has been used by Gottfried and Bailey [5] for their simulation model for the Petite Amateur Navy Satellite, PANSAT. However, since this author used the name PACSIM in a copyrighted work (Library of Congress Registration No. TX 3 411 890) published in December 1991 [1], the name has been retained.

While this paper emphasizes PACSIM itself, several other programs developed along with PACSIM comprise the complete system. Before the simulation model could be developed, the characteristics of PACSAT-1 and UoSAT-5 traffic had to be determined. These characteristics were evaluated using a three-step procedure: (1) All downlink data from many passes were processed to extract statistics of interest and place these data into a database. (2) The statistics collected in step no. 1 were summarized into a form that could be imported into a spreadsheet program. (3) The analysis was completed using the data imported from step no. 2. Tables 1 and 2 and Figures 1 through 12 are typical results of the analysis of a single downlink data sample for PACSAT-1 and UoSAT-5.

Figures 1 through 6 show empirical cumulative density functions (CDFs) for a number of PACSAT-1 traffic parameters that are of interest in designing the simulation model. Figure 1, called the

Table 1
Summary of Typical PACSAT-1 and UoSAT-5
Downlink Data Samples

	PACSAT-1	UoSAT-5
Number of passes logged:	25	: 15
Number of different stations:	75	: 124
Lowest orbit number encountered:	15,886	: 7,223
Highest orbit number encountered:	16,194	: 8,831
Earliest date/time in logs:	02/07/93 @ 04:40:41	: 12/01/92 @ 04:32:22
Latest date/time in logs:	02/28/93 @ 18:57:54	: 03/23/93 @ 04:21:46
Total downlink time:	05:44:42	: 03:08:24
Total broadcast bytes:	2,510,858	: 7,494,894
Number of file requests:	691	: 1,277
Number of directory requests:	228	: 405
Total number of requests:	919	: 1,682
Total time in queue for file requests:	18:04:02	: 27:47:55
Total time in queue for DIR requests:	09:59:38	: 22:26:08
Avg wait/station for file request:	01:34	: 01:18
Avg wait/station for DIR request:	02:38	: 03:19
Average bytes per station:	33,478	: 60,443

Table 2
Typical Broadcast Queue Utilization
for PACSAT-1 and UoSAT-5

	----- PACSAT-1 -----			----- UoSAT-5 -----		
No. of Stations	No. of Times	Elapsed Time		No. of Times	Elapsed Time	
Empty	265	00:40:59	11.3%	36	00:06:07	3.2%
1	241	00:34:57	9.6%	50	00:02:00	1.0%
2	228	00:40:07	11.0%	49	00:02:11	1.1%
3	188	00:32:35	8.9%	45	00:02:31	1.3%
4	176	00:29:38	8.1%	39	00:02:37	1.3%
5	146	00:24:41	6.8%	45	00:03:37	1.9%
6	185	00:30:14	8.3%	71	00:05:49	3.0%
7	216	00:34:03	9.3%	61	00:05:57	3.1%
8	196	00:31:00	8.5%	57	00:03:49	2.0%
9	202	00:32:49	9.0%	37	00:02:59	1.5%
10				46	00:03:46	1.9%
11				29	00:02:05	1.1%
12				36	00:03:15	1.7%
13				34	00:01:30	0.7%
14				38	00:02:35	1.3%
15				43	00:02:33	1.3%
16				57	00:03:13	1.7%
17				90	00:04:17	2.2%
18				203	00:09:11	4.8%
19				801	00:40:33	21.4%
Full	157	00:31:13	8.6%	829	01:18:14	41.4%
Total		06:02:16			03:08:49	

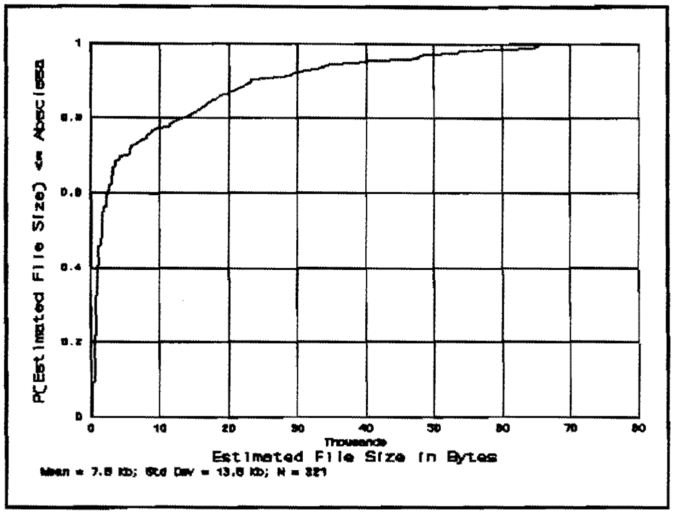

Figure 1. Empirical CDF for PACSAT-1 estimated broadcast file sizes.

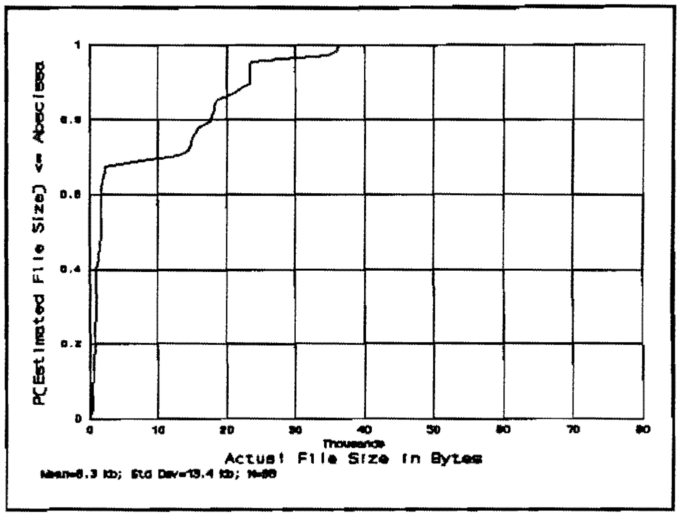

Figure 2. Empirical CDF for PACSAT-1 actual broadcast file sizes.

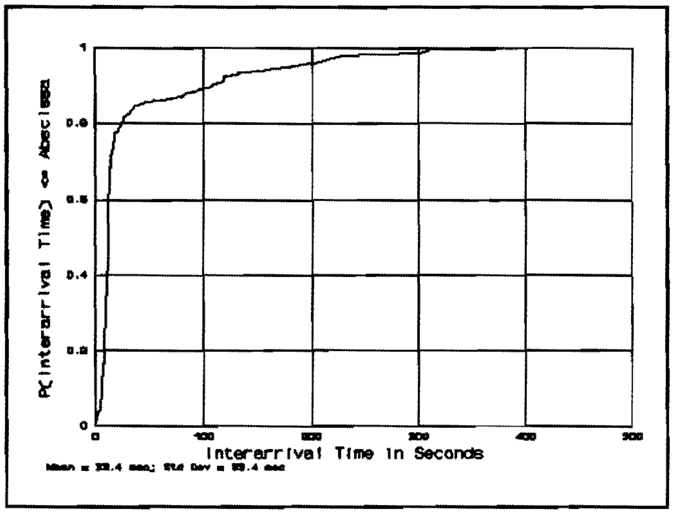

Figure 3. Empirical CDF for PACSAT-1 directory request interarrival times.

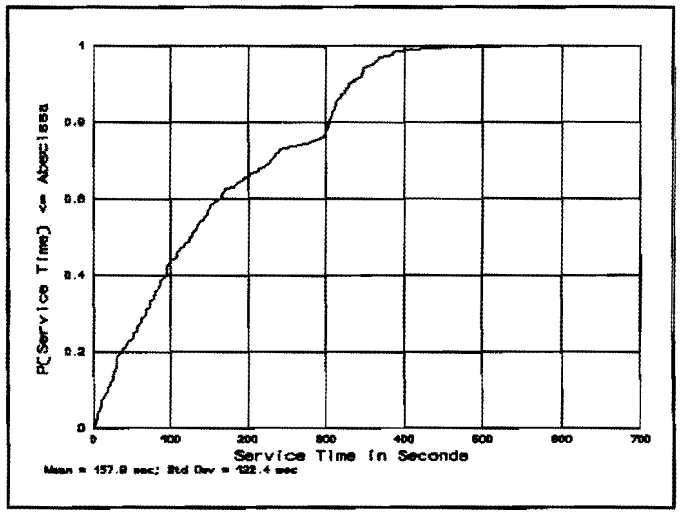

Figure 4. Empirical CDF for PACSAT-1 directory request service times.

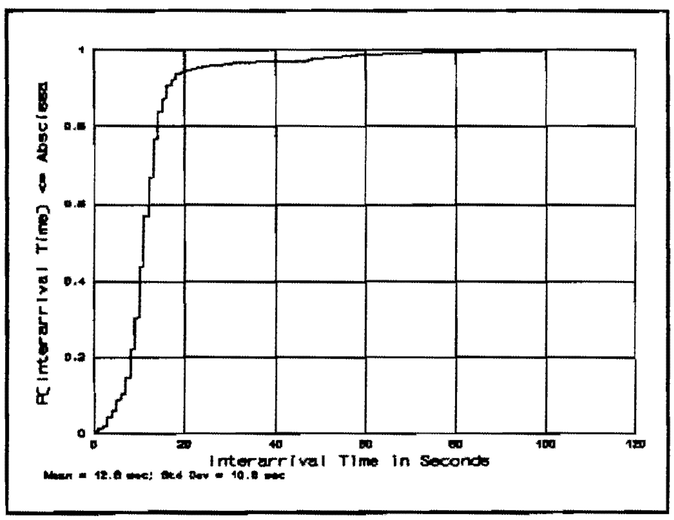

Figure 5. Empirical CDF for PACSAT-1 file/fill request interarrival times.

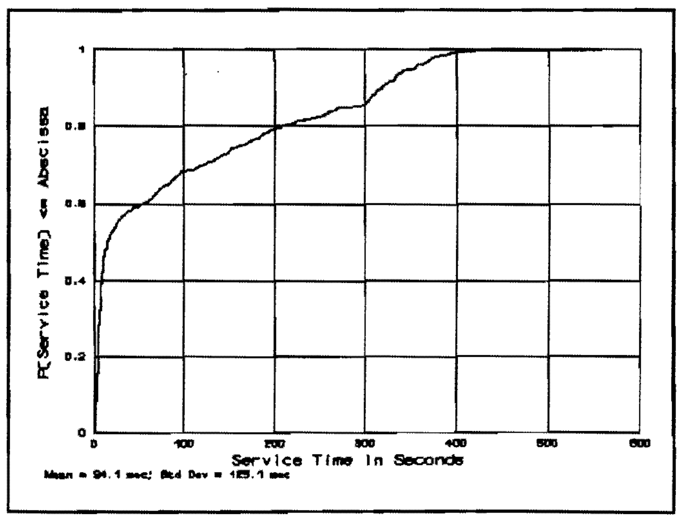

Figure 6. Empirical CDF for PACSAT-1 file/fill request service times.

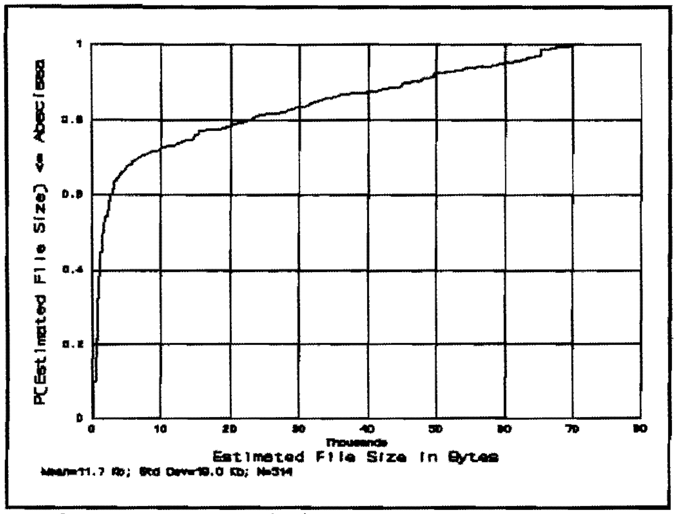

Figure 7. Empirical CDF for UoSAT-5 estimated broadcast file sizes.

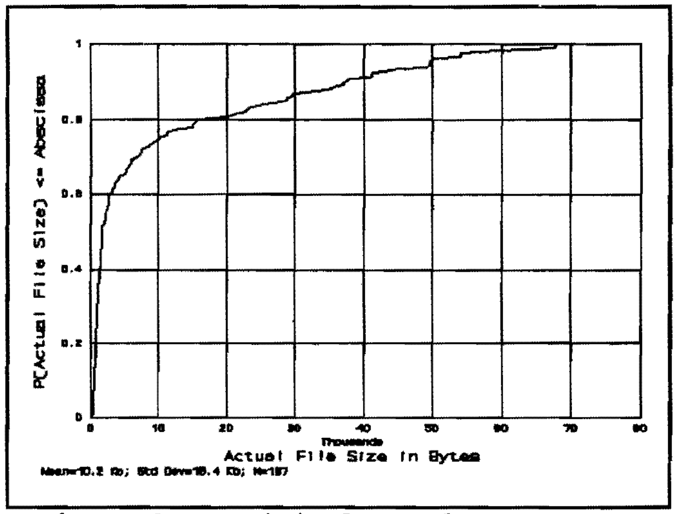

Figure 8. Empirical CDF for UoSAT-5 actual broadcast file sizes.

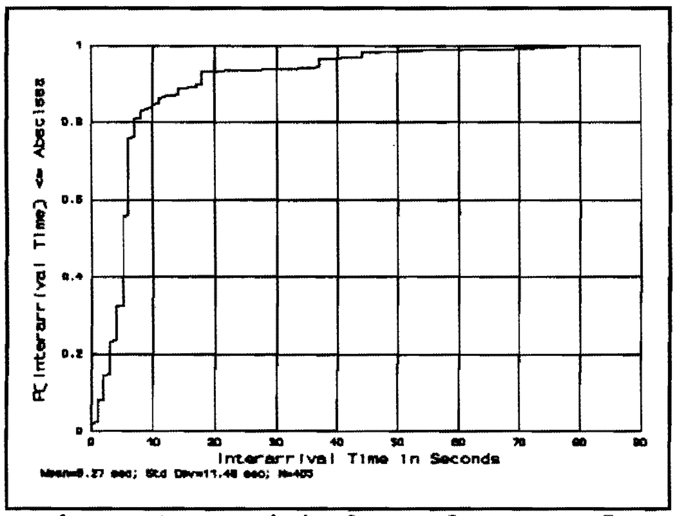

Figure 9. Empirical CDF for UoSAT-5 directory request interarrival times.

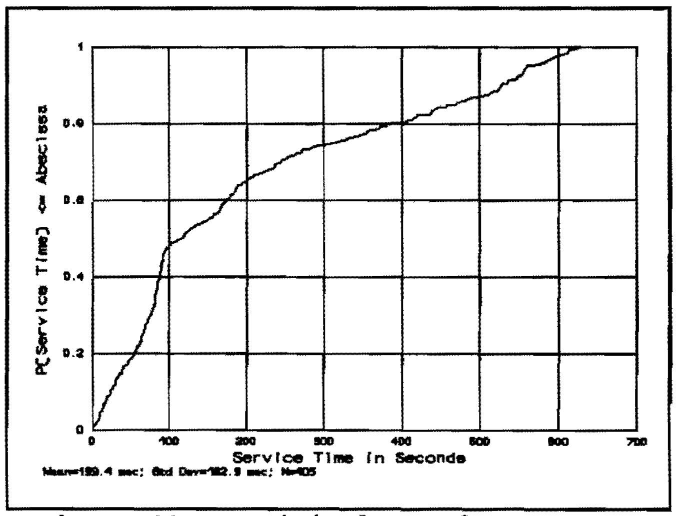

Figure 10. Empirical CDF for UoSAT-5 directory request service times.

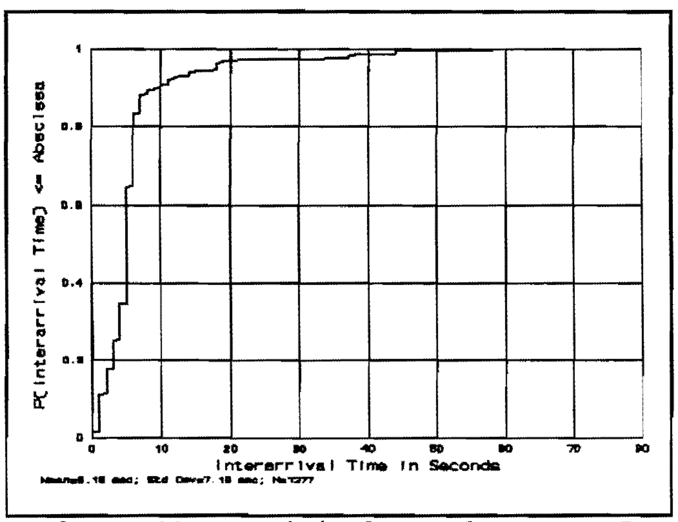

Figure 11. Empirical CDF for UoSAT-5 file/fill interarrival times.

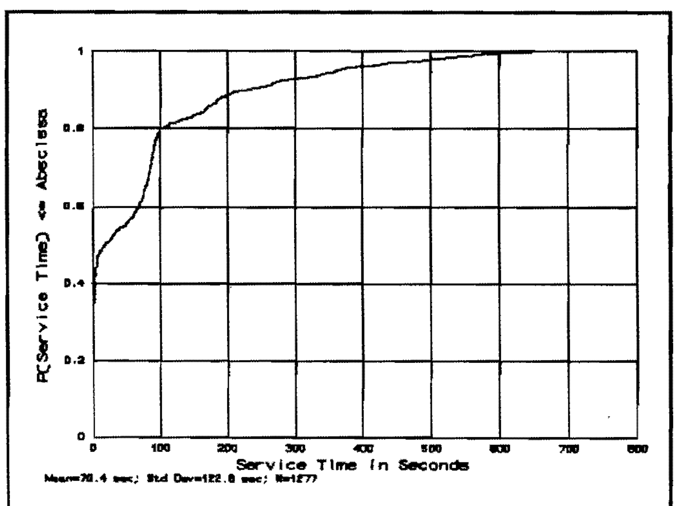

Figure 12. Empirical CDF for UoSAT-5 file/fill request service times.

Table 3
Primary Simulation Control Variables

DL_Data_Rate	The downlink data rate.
Time_Step_Sec	The size of one simulated clock tick.
QST_Info_Size	The number of bytes in a broadcast frame information field.
QST_Time_Slice	The amount of time given to the PBLIST user at the head of the queue.
QST_AR_Mean_D QST_AR_Std_Dev_D QST_AR_Type_D	Mean, standard deviation, and distribution type for directory broadcast request interarrival times.
QST_AR_Mean_F QST_AR_Std_Dev_F QST_AR_Type_F	Mean, standard deviation, and distribution type for file/fill broadcast request interarrival times.
QST_ST_Mean_D QST_ST_Std_Dev_D QST_ST_Type_D	Mean, standard deviation, and distribution type for directory broadcast request service times.
QST_ST_Mean_F QST_ST_Std_Dev_F QST_SR_Type_F	Mean, standard deviation, and distribution type for file/fill broadcast request service times.
QST_BC_Mean_D QST_BC_Std_Dev_D QST_BC_Type_D	Mean, standard deviation, and distribution type for directory broadcast request byte counts.
QST_BC_Mean_F QST_BC_Std_Dev_F QST_BC_Type_F	Mean, standard deviation, and distribution type for file/fill broadcast request byte counts.
Max_FTL0_Frame_Size	The number of bytes in a FTL0 transaction frame information field.
FTL0_SCAR_Mean	Mean interarrival time for successful file server connections.
FTL0_UCAR_Mean	Mean interarrival time for unsuccessful file server connect requests.
FTL0_ST_Mean	Mean service time for file server connections.
FTL0_BC_Mean	Mean file server transaction byte count.
FTL0_RT_Mean and FTL0_RT_Std_Dev	Mean and standard deviation for file server data link layer response time.

"estimated" broadcast file size, is based on recording the largest offset observed for a given file number. Figure 2, call the "actual" broadcast file size, is based on the known file size as determined either from the file header or a directory entry broadcast. While the plot in Figure 2 is more irregular than that in Figure 1, due to the smaller number of observations, the means and standard deviations are close to the same. Figures 7 through 12 show a parallel set of observations for UoSAT-5.

Collectively, the various graphs and associated statistics serve to characterize the downlink traffic to be modeled by PACSIM. Typically, a newly developed simulation would first be tested to see if it could produce results consistent with historical data. Next, it would be used to simulate some future event(s). Data would then be collected from the actual system and compared with the results produced by the simulator. If statistical tests performed on the two data sets produce favorable results, and if the results are repeatable, the simulator can then be used to test the effects of changing some model parameter that cannot be duplicated on a working system. The process of comparing simulator output to historical data and using the simulator to predict future data is called validation.

Validation has been done for the original PACSIM but not for the current one that includes the broadcast traffic model. The programs and program features required to accomplish the validation have been implemented, however. Specifically, PACSIM logs data describing generated traffic in its own database. Once a run is completed, the database created during the simulation can be processed just as if it contained data captured by listening to the actual satellite downlink.

Table 3 shows the most important variables that determine the characteristics of traffic being modeled by PACSIM. As will be seen in the next section, there are some additional parameters that can be controlled at program startup.

OPERATIONAL DETAILS (Initial Version)

Figure 13 shows the screen display produced by PACSIM while a simulation of PACSAT-1 is in progress. All of the fields shown are updated in step with the simulated clock time. A brief description of each field can be found in the next section.

Screen Display Field Description

The following is a brief explanation of the fields being displayed.

Epoch: The simulated time updated in real time.

AOS: The predicted AOS time from the orbital database.

LOS: The predicted LOS time from the orbital database.

Orbit: The orbit number.

Az: The ground station antenna azimuth heading in degrees.

El: The ground station antenna elevation heading in degrees.

Range: The slant range to the satellite in km.

```
Epoch: 1992 187.69418055 = 07/06/92 @ 16:39:37.30 AOS: 16:39:00 LOS: 16:52:00
Orbit: 12793 Az:  37 El:   1 Range:  3137 Doppler:   8026 Lat/Long:  46/  74

DL Path Loss:  155.0 dB                  Total DL Frames/Bytes:    28/    3,701
UL Path Loss:  145.9                          BBS Frames/Bytes:    10/    1,322
DL Sig Level:  -96.0 dBm                      QST Frames/Bytes:    12/    1,908
    DL Eb/N0:   33.0 dB                       TLM Frames/Bytes:     6/      471
   DL Margin:   23.6 dB                         DL Utilization:    62%

        From: PACSAT-11                      BBS Queue Length:     2
          To: QST                            QST Queue Length:     1
        Type: UI                             TLM Queue Length:     6
        Time:  187.69417592                   DL Queue Length:     3
       Bytes:  159                          Avg DL Queue Wait:     2.5
Tx Time Left:   0.66

                    ST     Time Off     RT     Next RT      Tot Bytes  Bytes Left
Uplink A: USER0001  50  187.69433912   3.5  187.69418286       1,256         302
Uplink B: USER0002  84  187.69497337   6.0  187.69421527       2,090       1,598
Uplink C: Inactive
Uplink D: Inactive
```

Figure 13. Screen display produced by the initial version of PACSIM. All fields shown are updated in step with the simulated clock time.

Doppler: The computed Doppler shift at the downlink frequency.

Lat/Long: The latitude and longitude of the sub-satellite point.

DL Path Loss: An estimate of the downlink path loss at 437 MHz.

UL Path Loss: An estimate of the uplink path loss at 145 MHz.

DL Sig Level: The downlink signal level at the receiver.

DL E_b/N_0: The theoretical E_b/N_0 given the downlink signal level, typical receiver characteristics, and 1200 bps BPSK modulation.

DL Margin: The theoretical link margin for a BER of 1E-5.

Total DL Frames/Bytes: The total number of frames and bytes that have been transmitted on the downlink from the beginning of the visibility period to the current simulated clock time.

BBS Frames/Bytes: The total number of frames and bytes resulting from connected-mode (FTL0) user transactions.

QST Frames/Bytes: The total number of frames and bytes resulting from broadcast mode operations.

TLM Frames/Bytes: The total number of frames and bytes resulting from telemetry transmissions.

DL Utilization: Downlink utilization based on a maximum possible of visibility_time x downlink_data_rate.

From: The originator of the frame currently being transmitted.

To: The destination of the frame currently being transmitted.

Type: The AX.25 frame type of the frame being transmitted.

Time: The time the frame was placed in the downlink queue.

Bytes: The number of bytes to be transmitted.

Tx Time Left: Transmission time left for the frame currently being transmitted, updated in real time.

BBS Queue Length: The number of frames in the downlink queue resulting from connected-mode (FTL0) transactions.

QST Queue Length: The number of frames in the downlink queue resulting from broadcast-mode operations.

TLM Queue Length: The number of frames in the downlink queue resulting from telemetry. This value will remain a constant because it is the number of frames in a telemetry set defined in a file read by the simulator at initialization.

DL Queue Length: Should be close to BBS_Queue_Length plus QST_Queue_Length.

Avg DL Queue Wait: The average waiting time of a frame in the downlink queue. A maximum value around 10 would be typical of a fully-loaded PACSAT-1 system.

Uplink: Shows whether there is simulated activity on an uplink and the generated user name if it is active.

ST: The service time in seconds generated according to some appropriate distribution.

Time Off: The scheduled termination time for this user transaction.

RT: The AX.25 FTL0 response time in seconds generated according to some appropriate distribution.

Next RT: The next time a simulated downlink frame will be generated based on the current RT and the time it was generated.

Tot Bytes: The number of downlink bytes generated for this user transaction according to some appropriate distribution.

Bytes Left: The number of bytes left to transmit before the connection is terminated.

Operator Interaction

An example of the interaction between the simulator and the operator is given in this section. The intent here is not to spell out every last detail about how the program would be run, but rather to give some feel for the simulation variables that can be specified at program startup. A typical program startup sequence follows. Items shown in square brackets [] are the defaults taken if no change is made by the operator.

```
PACSIM --- Packet Radio Satellite Downlink Traffic Simulator
Copyright (C) 1991-93 by Robert J. Diersing
All Rights Reserved

Debugging information needed [N]?

Enter one of the following Stat File choices:
    0.  DO NOT UPDATE
    1.  AO16STAT.S01
    2.  AO16STAT.S02
    3.  AO16STAT.S03

Enter Stat File choice: 0

Assume omni-directional antennas [N]?

Change number of uplinks [4] ?

Run with 100% uplink utilization [N]?

Enter Julian day for orbit to be simulated:

    Orbit       Start Time       Stop Time    Duration   Max Elev   Min Range
1. 12785    92/07/06 @ 04:18     04:32        14:00        26          1500
2. 12786    92/07/06 @ 05:58     06:12        14:00        25          1520
3. 12793    92/07/06 @ 16:39     16:52        13:00        17          1882
4. 12794    92/07/06 @ 18:18     18:32        14:30        38          1176
5. 12795    92/07/06 @ 20:02     20:04        02:30         1          3344

Choose orbit to be simulated from one of the above:
```

The stat files are used to save information while the simulation is being run. You may choose to have the simulation compute the link margin assuming an omni-directional antenna ground station receiving antenna. Otherwise the computations will assume a steerable directional antenna. Whatever is chosen here has no bearing on the simulation itself. The link margin computations are for information only.

The simulation can be run with any number of uplinks between 1 and 6. Since this version of the program was designed for PACSAT-1, the default number of uplinks is 4. Changing the number of uplinks changes the number of allowable connected-mode users. Normally, connected-mode user requests are generated according to some distribution of arrival times. It is possible to run the simulator with all of the uplinks busy all of the time. If this is done, the service times and response times are still generated according to some appropriate distribution but a new connection is generated as soon as a previous transaction is finished.

Finally, the simulator can be run for any day and visibility period in the orbital data base. A typical orbital data base record is shown.

IMPLEMENTATION DETAILS (Current Version)

Figure 14 shows a screen display from the current version of PACSIM. The principal difference between the initial version and the current version is the inclusion of a more detailed PACSAT Broadcast Protocol model. In the following section only those fields that have been added or changed since the initial version are described.

```
Epoch: 1992 292.14623737 = 10/19/92 @ 03:30:34.92 AOS: 03:30:30 LOS: 03:40:30
Orbit: 14284 Az: 104 El:   1 Range:  3300 Doppler:   6195 Lat/Long:  17/  69

DL Path Loss:  155.5 dB                   Total DL Frames/Bytes:    25/    5,039
UL Path Loss:  146.3                           BBS Frames/Bytes:     2/       80
DL Sig Level:  -96.5 dBm                    QST(D) Frames/Bytes:     0/        0
    DL Eb/N0:    23.5 dB                    QST(F) Frames/Bytes:    17/    4,488
   DL Margin:    12.0 dB                       TLM Frames/Bytes:     6/      471
        From: UOSAT5-11                     DL Utilization/Repl:    73%  1/ 6/ 1
          To: QST(USRB0001)                    BBS Queue Length:     1
        Type: UI                               QST Queue Length:     2
        Time:  292.14623529                    TLM Queue Length:     6
       Bytes:    264                            DL Queue Length:     6
Tx Time Left:    0.04                         Avg DL Queue Wait:     1.3

                     ST    Time Off     RT      Next RT   Tot Bytes  Bytes Left
Uplink A: USRC0001   12  292.14632985  2.5  292.14624304     1,095         783
Uplink B: Inactive

PB: USRB0001\F\017\006574 USRB0002\D\043\002235
```

Figure 14. Screen display produced by the current version of PACSIM. The current version includes modeling of PACSAT Broadcast Protocol traffic.

Screen Display Field Description

To: The destination address of the frame currently being transmitted. If the frame is a broadcast frame (QST), then the boradcast queue user name is also given to provide a clear association between the PBLIST user and the transmitted frame.

QST(D) Frames/Bytes: The total number of frames and bytes resulting from PBLIST user directory requests.

QST(F) Frames/Bytes: The total number of frames and bytes resulting from PBLIST user file/fill requests.

DL Utilization/Repl: Downlink utilization based on a maximum possible of visibility time times the downling data rate. Repl is of the form L/M/N where: L is the current orbit from the list selected at program startup; M is the total number of orbits selected; and N is the current replication counter.

PB: The list of broadcast users of the form User\Type\ST\BC where: User is the serially-numbered broadcast user identifier; Type identifies the request type, D for directory and F for file/fill; ST is the service time generated according to some appropriate distribution; and BC is the byte count generated according to some appropriate distribution.

Operator Interaction

An example of operator/program dialog for the current version of PACSIM follows. Aside from the informational messages about the downlink data rate, braodcast frame size, time slice value, and so forth, the only new featur is the ability to specify a run consisting of multiple replications of a combination of days and orbits. This feature was added to facilitate validation where it is desirable to run the simulation long enough to stabilize and eliminate, for example, the influence of startup effects.

```
PACSIM --- Packet Radio Satellite Downlink Traffic Simulator
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All Rights Reserved

Debugging information needed [N]?

Downlink data rate in bps: 9600
Broadcast frame information byte count:  244
Broadcast frame overhead byte count:   20
Broadcast queue time slice in sec:    5
Broadcast total bytes per time slice:  6,000
Broadcast frames per time slice:  22
Broadcast info bytes per time slice:  5,368

Enter one of the following Stat File choices.
    0.  DO NOT RECORD STATS
    1.  UO22STAT.S01
    2.  UO22STAT.S02
    3.  UO22STAT.S03
Enter Stat File choice [0]:

Assume omni-directional antennas [N]?
Change number of FTL0 slots [2] ?
Change number of PBLIST slots [10] ?
Remove PB entry when service time expires [Y] ? n
Remove PB entry when byte count transmitted [N] ? y
Run with 100% uplink utilization [N]?
Enter file name with orbits to simulate or CR for none
Enter Julian day for orbit to be simulated or 0 to end [0]: 292

   Orbit       Start Time       Stop Time   Duration  Max Elev  Min Range
1. 14284    92/10/19 @ 03:30     03:40       10:00       6         2628
2. 14285    92/10/19 @ 05:06     05:21       15:00      87          804
3. 14286    92/10/19 @ 06:49     06:59       10:00       6         2692
4. 14291    92/10/19 @ 15:51     15:57       06:00       1         3127
5. 14292    92/10/19 @ 17:27     17:42       15:00      59          899
6. 14293    92/10/19 @ 19:07     19:19       12:00      11         2230

Choose index of orbit to simulate or 0 to end [0]: 1
Choose index of orbit to simulate or 0 to end [0]: 2
Choose index of orbit to simulate or 0 to end [0]: 3
Choose index of orbit to simulate or 0 to end [0]: 4
Choose index of orbit to simulate or 0 to end [0]: 5
Choose index of orbit to simulate or 0 to end [0]: 6
Choose index of orbit to simulate or 0 to end [0]:
Enter Julian day for orbit to be simulated or 0 to end [0]:
Enter number of replications of simulation [1]: 3

Simulation for the following orbits and days
will be replicated  3 time(s):
```

```
Orbit  Day
14284  292
14285  292
14286  292
14291  292
14292  292
14293  292

Press Enter to begin simulation
```

AN EXAMPLE

Obviously, many different combinations of simulation variable values are possible. Only a few have been tested and none of the test results have been formally validated. Nevertheless, since the current version of PACSIM is a based on a previously-validated version there are probably not any gross logic errors. Consequently, an example of a possible application for PACSIM is included here.

Table 4 shows the results of two simulation runs for UoSAT-5--one for a 9600 bps downlink and the other for a 38400 bps downlink. The broadcast queue length was set to ten and the file server BBS queue length set to zero. The reader should keep in mind that in actual practice values of many of the simulation control variables would change as opposed to the case in this example where only the downlink data rate has been changed. Most likely, variables such as: the number of allowable users, the time slice value, and the average byte count per transaction, would also change.

Inspection of the values in Table 4 shows that the increase in data rate increases the byte and frame counts by less than a factor of

Table 4
Simulation Results for UoSAT-5 with 9600 and 38400 BPS Downlinks
Ten Broadcast Users and Zero BBS Users

	9600 BPS	38400 BPS
Frames Transmitted:	16,905	: 44,240
Bytes Transmitted:	4,430,882	: 11,646,735
PBP Transaction Count:	411	: 972
PBP Directory Frames:	5,782	: 14,770
PBP Directory Bytes:	1,526,536	: 3,899,280
PBP File/Fill Frames:	10,984	: 29,329
PBP File/Fill Bytes:	2,899,820	: 7,742,856
DL Queue Wait Time:	2.2	: 1.5
DL Utilization:	86%	: 56%

Note: All but the last two items are averages per day based on visibility at the author's QST as determined from the orbital prediction database.

three. Since the downlink utilization has decreased, presumably more broadcast mode users could be allowed, the arrival rate of requests increased, the transaction byte count could be increased, or the excess capacity could be used by allowing concurrent connected mode users. Probably some combination of all these factors based on the mission of the satellite would be the desired choice.

SUMMARY

The current status of the development of the PACSIM downlink traffic simulator has been presented in this paper. Tabular and graphical summaries for one of several PACSAT-1 and UoSAT-5 downlink data samples have been included. These analyses provide the basis for the simulation model. The operational details of the simulator have been described to illustrate the evolution from primary emphasis on the connected mode of operation toward emphasis of the broadcast mode. The original connected mode model has been subject to a validation procedure while the current broadcast mode model has not. An example of PACSIM use was included to compare UoSAT-5 9600 bps operation with 38400 bps operation. Hopefully, the publication of this paper will produce some suggestions as to interesting combinations of simulation control variables that could be used during future testing and experiments.

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The DSP-12 and Satellite Digital Communications - A Case History

Jan Hattingh, ZS6BMN
(AMSAT LM-1228)

Scope

The DSP modems have a reputation of being tricky little machines to tame and that they are slow uploaders on the digital communications satellites. This paper deals with an analysis of the performance of one of such little beast which has been in active daily use for some months now at ZS6BMN. While L.L. Grace DSP-12 is the subject of this analysis, there is no reason why the performance cannot be obtained with the AEA DSP-2232 or any other DSP-based modem.

Fuji and the MicroSats/UoSATs

The launch of Fuji-Oscar 12 signalled the start of the packet satellite era, but it was only after the launch of the six MicroSats and Fuji-Oscar 20 early in 1990 that most people realized that there is no way out of this one, and that something had to be done to get a station equipped for communicating with these little flying mailboxes.

James Miller, G3RUH, set the pace with his excellent FO-12 modem design which could be used with a TAPR TNC-2 or compatible terminal node controller. TAPR also brought out a PSK modem for the 1200 bps PSK downlink and the Manchester encoded uplink which is the standard operating mode of the MicroSats, ie. Fuji, Pacsat and Lusat.

Things, however, started becoming a little bit more complicated when the 9600 bps FSK mode was activated on UoSAT-14, but again a modem designed by G3RUH became the standard.

Using a TNC and the two G3RUH modems an efficient system for digital satellite communications can be constructed at a very reasonable cost. Only the DSP modems provide an alternative, but in many articles on the subject, the prospective digital satellite operator is warned against investing in a DSP modem on the grounds that they are expensive, complicated to use and still in a development phase! Hopefully this discussion will prove the opposite!

Why not go the DSP route?

Digital Signal Processing (DSP) for amateur radio applications first came to attention when a series of articles on "Digital Signal Processing Techniques for Radio Amateurs" by Matjaz Vidmar, YT3MV, was published in the German "VHF Communications" (UKWberichte) magazine way back in 1988.

In his prototype, DSP computer modems for the AO-13 400 bps PSK and the FO-20 1200 bps PSK, as well as the normal RTTY and Packet, were defined in the software. This looked like the answer and before long a DSP modem designed by Brooks van Pelt, KB2CST, of L.L. Grace Inc., appeared in advertisements in the amateur satellite publications.

After building many a modem for a variety of applications since the early seventies, the DSP-based modem seemed to provide the key to the future as any new data transmission format will only require a change of firmware! A unit was ordered for use at ZS6BMN before the DSP-12 went into full production ... and the fun really started when the unit arrived in January 1992!

The DSP-12 "Ultimate Modem"

The DSP-12 spent some time monitoring the activity on the digital satellite while gathering telemetry. It did well on ordinary packet, too and the first attempt at activating the PB broadcast mode on AO-16 was met with great success. Very soon, the need to upload messages became apparent and that is where the first problem was encountered. The very unfavorable exchange rate and my own limited budget forced me to get a "bare-bones" DSP-12 and the verdict of no 1 MB RAM == no upload capability with PG, did not hold much promise of getting anywhere without either a relatively large additional cash outlay or attempting the implementation of a modification to overcome the lack of full hardware protocol control on the RS-232C interface of a DSP-12 operating without the optional 1 MB RAM.

A lucky break - thanks to AEA!

While contemplating how to go about modifying the DSP-12 over the Christmas 1992 holiday period, I came across a technical description of the AEA DSP-2232 modem which, in the meantime joined the DSP-12, and was using the very same Motorola 56001 DSP microprocessor! The immediate question on how AEA handled their modem interface control led to a quick search on the Compuserve HAMNET Forum (CI$ is another blessing of the 20th century which only recently reached darkest Africa), where the answer was discovered in an AEA software package (DSP.ZIP) provided for use with the DSP-2232. A quick try indicated that the DSP-12 did not like all of the imbedded commands, but it did not reject the PG2232.EXE which is the AEA implementation of PG Version 920225! The TNC.CFG file was edited to get some of the vital instructions to the DSP-12 and in no time a message to Bruce, WB9ANQ, on AO-16 was the first of many to be uploaded from ZS6BMN! The need to get the 1 MB RAM option, or to implement modifications have disappeared!

Now there was a fully operational DSP-12 sat in the shack. But it was still believed the unit was slow and somewhat inferior to anything else in the performance department. (The knowledge of how to calculate the upload rates of other stations from the ALyymmdd satellite log files was still lacking at that time).

The nagging question of whether it will work at all on the 9600 bps FSK satellites was soon answered when a batch of AO-16 AL/BL log files was uploaded in one smooth action to UO-22 on the very first attempt!

A further discovery: The DSP-12/PG2232 combination is fast!

A message to Glenn, N4OUL, the resident DSP-12 mentor on the DigiSats, confirmed that the DSP-12 was giving a good account of itself even when taking the low activity level over Africa into account! At this stage, it also became clear that most of the DSP-12 units in use relý on the 1 MB RAM for establishing the required RS-232C hardware handshaking of the regular PB, and that the unit here was rare in operating without the RAM and with the AEA PG2232 software!

The DSP-12 works on AO-16, UO-22 and KO-23 with the same PG2232 program and, with the exception of satellite BBS call signs, the TNC.CFG and PG.CFG files are all identical. On LO-19 the AEA implementation of PG Version 910117, PGOLD.EXE is used with equally great success.

"Speed of TNCs" - Jeff Ward, G0SUL, Surrey

In a message by Jeff Ward, G0SUL, which was placed on UO-22, he referred to a series of messages on CI$ where he, Jim, WD0E, and Lyle, WA7GXD, have exchanged some ideas on the topic of "Speed of TNCs" and mentioned also that a DSP-box from ZS was the top performer at the time according to his analysis of the uplink performance rates of the active stations on UO-22. Tracing the messages on CI$ confirmed that the DSP-12 at ZS6BMN was the one in question and that performance was a good way ahead of the next best performer on UO-22!

The moral of the story!

What should one do with information like this! One possible use is to use it to promote the advancement of technology in amateur radio and to allay the fears of those contemplating the purchase of one of the DSP modems.

The basic no-options fitted DSP-12 is not an overly expensive little box and neither is it difficult to use. It can give excellent performance, it can be used with the readily available AEA DSP.ZIP software package and it can be used to download firmware upgrades from UO-22 and KO-23 for the burning of new EPROM sets!

It cannot work with the regular PG, nor can it run the V40 software and this necessitates the burning of a set of EPROMs to try a new L.L. Grace DSP-12 GCE version. To some the use of the AEA PG2232 and PGOLD programs with the DSP-12 may be seen as a "Mc Gyver"-solution, but nobody can deny that this is a winning combination which can provide you with a lot of fun on the digital satellites with its excellent performance!

This does not mean that the DSP-12 with the 1 MB RAM option and the regular PB cannot provide excellent performance, too, but it shows that one can save some money and in the process perhaps gain a bit of additional performance!

PS: Monitor the PB and PG performance rates of your TNC!

Jim, KH2D, very kindly released his RATE.EXE Spaceware which will do an analysis of your PB.LOG and PG.LOG files and produce a number of results files. It is interesting to see how other traffic slows things down and the results provided by such an analysis are great in determining the best satellite positions at your QTH for good upload performance. The effects of changed TNC parameters can be studied and it should be possible to fine-tune your system for optimum performance and the most efficient use of the digital amateur radio satellites. Having performance in hand may allow a link to degrade considerably before it becomes unusable. While it is true that these theories were proven under the quiet conditions over Africa and with the DSP-12, Bruce, WB9ANQ, reported having been able to improve the performance of his system by fine-tuning some of the TNC parameters following the discussions on the "Speed of TNCs".

Appendices

1. Speed of TNCs : UO-22 (G0SUL) and CI$ HAMNET Messages (G0SUL, WA7GXD and WD0E).

2. Extracts from the UO-22 PG.LOG file at ZS6BMN

3. Sample output files of the PG.LOG file analysis performed with the RATE.EXE released by Jim, KH2D.

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APPENDIXES

APPENDIX 1

UO-22 Message from G0SUL to KH2D:

Actually, upload timing should make a rather big difference in upload data rate. The best setup would be maxframes about 4, with a relatively low FRACK timer. This keeps the uplink full (maxframes) and leaves time for the acks to get generated, queued, and transmitted before FRACK runs out.

In reality, the TNC firmware places a speed limit on all data transfers. It looks like this speed limit is about 40% of link bandwidth (if the link is 9600 and async speed to your PC is 19200). I am having a discussion about this on Compuserve Hamnet's Packet Radio section in a thread called "Speed of TNCs." Lyle Johnson at TAPR is taking it up with Howie Goldstien, the TNC firmware author. We'll see what happens.

In the mean time you may find that (if you have a TNC2 clone) maxframes of 1 gives as good performance as anything.

There is an indication that other TNCs, namely the DSP boxes, give very good AX.25 link throughput. ZS6ABM (?) has the best performance at the moment, and he is using a DSP box of some kind. Of course, he doesn't have much QRM either.

JWW

Extracts From CI$ HAMNET Messages:

Subj:	Speed of TNCs		Section: Packet Radio
From:	jeff ward	100064,2616	# 187323, 2 Replies
To:	Jim White, WD0E	71477,546	Date: 27-Jun-93 18:57:02

I submit an interesting item for this thread. i have been reviewing the performance of stations on UO-22, and here are the stats for the stations with the highest uplink throughput.

	AVERAGE U/L bits/sec	MAX U/L bits/sec
ZS6BMN	3168	6287
DB2OS	1682	4268

DB2OS is closest in performance to the run-away winner, ZS6BMN. BMN uses the LL-GRACE TNC. Granted, they experience very different interference conditions, but is it just a coincidence that the best station in the network uses an alternative TNC?

JWW

```
Subj: Speed of TNCs                              Section: Packet Radio
From: Lyle Johnson, WA7GXD     76246,565         # 187341, 1 Reply
  To: jeff ward                100064,2616       Date: 27-Jun-93
                                                       22:39:04
```

Jeff,

I would expect a TNC like the DSP-12 or a Kantronics Data Engine to be able to better sustain a high throughput because they use a fast processor (V40 at 12 or 16 MHz) and have a DMA capability for the radio channels (at least the DE does: I've never seen under the hood of a DSP-12). Thus at least in "standard TNC" mode, I'd expect these devices to be able to sustain a higher throughput than a 5 MHz Z80.

Apart from the unknowns of station interference levels, uplink capture due to power levels run, pre-steering, etc., this is an interesting observation.

Question : when uploading does the ground station software put the TNC in KISS or "standard TNC" mode? Also are there "alternative" ground station software packages out there and if so, do we know which software the stations are using? (I'm just trying to eliminate unknowns in the equations...)

In any event, I've started to seriously dig into the KISS code in an effort to add CTS/RTS flow control, CHECKSUM or CRC protection of the async port link, and fast buffer management as well as tuning the "inner loop" or "task scheduler" for maximum sustainable throughput.

Cheers,
Lyle

==

```
Subj: Speed of TNCs                              Section: Packet Radio
From: Jim White, WD0E          71477,546         # 187467, *No Replies*
  To: jeff ward                100064,2616       Date: 28-Jun-93
                                                       17:47:04
```

I have no stats to back this up, but it seems to me interference just has to be the overwhelming factor influencing uplink performance. For example experience when loading software for hundreds of passes shows throughput can be essentially zero on one frequency, change to another and it jumps to 95%. Sometimes it takes much of a pass to find the one clear freq out of 5. Some days no matter what frequency performance is the pits, other days we do really well. And that is when ground stations aren't transmitting. Not station changes at all, and similar orbit geometry.

```
Subj: Speed of TNCs                              Section : Packet Radio
From: jeff ward                   100064,2616    # 187428, 1 Reply
  To: Lyle Johnson, WA7GXD        76246,565      Date: 28-Jun-93
                                                       14:23:17
```

Of course, it does seem reasonable that the more throbbing TNCs are faster.

The only message upload protocol we have now still uses AX.25 connected mode. The standard ground station software for this is PG, which uses hardware handshaking and transparent mode. This will not run on the DSP engines, since they have no hardware flow control, so someone (AEA?) has written a program called PG2232 to overcome the problem. I _assume_ that this uses AX.25 inside the DSP TNC, but I could be _wrong_ _about_ this.

There is at least one software package (PE1CHL NET) which uses the TNC in KISS mode and AX.25 in a host PC. I haven't seen any indication that it goes faster than a TNC, but it isn't widely used. Of course, there is a bit of speed-limit imposed by the protocol "bug" I mentioned, and this may be present in NET code as well as the TNC-2 code, or it may be caused by the satellite code.

APPENDIX 2

UO-22 PG.LOG File at ZS6BMN (extract, long files)

```
02/05/93 09:20:45  * UPLOAD
02/05/93 09:20:52  - Link to uosat5 established.
02/05/93 09:20:52  - Uploading file : AO-16.OUT.
02/05/93 09:20:53  - File number : 0x13a48.
02/05/93 09:22:06  - Throughput : 775 bytes/sec.
02/05/93 09:22:06  - Disconnected.

30/05/93 09:12:30  * UPLOAD
30/05/93 09:14:30  - Link to uosat5 established.
30/05/93 09:14:30  - Uploading file : A16_LOGS.OUT.
30/05/93 09:14:37  - File number : 0x15237.
30/05/93 09:16:09  - Throughput : 542 bytes/sec.
30/05/93 09:16:10  - Disconnected.

26/06/93 22:03:42  * UPLOAD
26/06/93 22:03:49  - Link to uosat5 established.
26/06/93 22:03:49  - Uploading file : 3BDR0626.OUT.
26/06/93 22:03:50  - File number : 0x16b13.
26/06/93 22:05:52  - Throughput : 833 bytes/sec.
26/06/93 22:05:53  - Disconnected.

30/06/93 21:20:01  * UPLOAD
30/06/93 21:20:09  - Link to uosat5 established.
30/06/93 21:20:09  - Uploading file : 3BDR0630.OUT.
30/06/93 21:20:10  - File number : 0x16edc.
30/06/93 21:22:37  - Throughput : 694 bytes/sec.
30/06/93 21:22:46  - Disconnected.

03/07/93 21:10:21  * UPLOAD
03/07/93 21:11:00  - Link to uosat5 established.
03/07/93 21:11:00  - Uploading file : 7ZBX0703.OUT.
03/07/93 21:11:02  - File number : 0x1716a.
03/07/93 21:11:50  - Throughput : 900 bytes/sec.
03/07/93 21:11:51  - Disconnected.
```

APPENDIX 3

KH2D RATE.EXE : PG_RATE.LOG (UO-22 at ZS6BMN)

```
03/04/93 20:43:46  - Throughput : 851
03/04/93 20:44:58  - Throughput : 701
04/04/93 20:09:46  - Throughput :  46
04/04/93 20:12:34  - Throughput :  14  Lowest rate
04/04/93 20:14:01  - Throughput :  17
05/04/93 21:13:35  - Throughput : 830
15/04/93 20:13:47  - Throughput : 218
24/04/93 07:30:50  - Throughput : 474
02/05/93 09:22:06  - Throughput : 775
02/05/93 20:05:24  - Throughput :  95
02/05/93 20:06:07  - Throughput : 440
06/05/93 20:58:36  - Throughput : 389
06/05/93 20:58:45  - Throughput : 516
06/05/93 22:40:35  - Throughput : 459
09/05/93 20:47:18  - Throughput : 607
09/05/93 20:47:23  - Throughput : 721
09/05/93 20:47:27  - Throughput : 659
09/05/93 20:47:31  - Throughput : 576
09/05/93 20:47:35  - Throughput : 566
15/05/93 09:54:37  - Throughput : 166
15/05/93 20:33:26  - Throughput : 781
16/05/93 19:59:19  - Throughput : 586
16/05/93 19:59:23  - Throughput : 509
17/05/93 20:59:32  - Throughput : 637
18/05/93 22:03:48  - Throughput : 652
30/05/93 09:16:09  - Throughput : 542
01/06/93 20:22:47  - Throughput : 304
02/06/93 19:46:43  - Throughput : 514
13/06/93 07:33:12  - Throughput : 752
13/06/93 07:33:14  - Throughput : 790
13/06/93 07:33:17  - Throughput : 321
13/06/93 07:33:19  - Throughput : 605
13/06/93 09:11:59  - Throughput : 120
13/06/93 09:13:20  - Throughput :  87
13/06/93 09:13:25  - Throughput : 263
13/06/93 09:13:40  - Throughput :  49
13/06/93 09:13:50  - Throughput : 151
13/06/93 09:14:06  - Throughput : 104
13/06/93 19:53:21  - Throughput : 497
14/06/93 22:35:27  - Throughput : 455
15/06/93 21:59:19  - Throughput : 632
15/06/93 22:00:46  - Throughput :  49
15/06/93 22:01:50  - Throughput : 882
15/06/93 22:03:44  - Throughput : 858
26/06/93 08:03:34  - Throughput : 458
26/06/93 08:03:37  - Throughput : 345
26/06/93 22:05:52  - Throughput : 833
30/06/93 21:22:37  - Throughput : 694
03/07/93 21:11:50  - Throughput : 900
10/07/93 20:18:42  - Throughput : 518
12/07/93 22:28:22  - Throughput : 117
12/07/93 22:30:28  - Throughput : 826
15/07/93 20:37:54  - Throughput : 813
17/07/93 21:11:32  - Throughput : 800
18/07/93 08:15:07  - Throughput : 669
18/07/93 08:17:35  - Throughput : 750
20/07/93 21:03:52  - Throughput : 792
23/07/93 20:52:04  - Throughput : 918  Highest rate
27/07/93 20:09:15  - Throughput :  48
28/07/93 22:50:50  - Throughput : 448
30/07/93 20:03:20  - Throughput : 752
01/08/93 20:26:51  - Throughput : 624
02/08/93 21:30:23  - Throughput : 354
03/08/93 20:56:12  - Throughput : 505
03/08/93 20:56:59  - Throughput : 167
03/08/93 22:36:46  - Throughput : 378
05/08/93 19:46:37  - Throughput :  69
05/08/93 19:47:18  - Throughput : 448
10/08/93 21:43:19  - Throughput : 340
14/08/93 08:38:09  - Throughput : 728
```

KH2D RATE.EXE PG_RATE.TXT (UO-22 at ZS6BMN)

```
On 08/14/93 UPLOAD RATES - 70 files:
High:  918   Average:  494   Low:   14
```

Microsat Ground Stations

Eric A. Cottrell WB1HBU

Background

I attended the AMSAT-UK and AMSAT-NA conferences in 1989 and left enthused about a new class of satellite called Microsat. I was active in copying Uosat-1 and Uosat-2 at that time and the new satellites expanded my horizon in Digital Communications. Since getting my amateur license in 1978, my main interest is non-human readable communications. RTTY, FAX, and Packet allowed experimentation in building equipment and writing computer software.

Growing up in the era of the space race fostered my interest in amateur satellites. The first experience was communicating through RS-5, RS-6, RS-7, and RS-8 in an automobile parked at a field day site. A satellite passed by about every half hour for six hours. What started as a Mode A station using 2 Meter multi-mode mobile and a turnstile antenna grew into a full Mode B/J station with Microsat capability. My call is regularly seen on 4 satellites on both North American and European accessible passes. This caused an Irish station to send the message, "Where are you?"

The Satellites

I will concentrate on the Microsats that I regularly use, those with BBS services. There are two types of satellites based on the speed of the downlink. The 1200 baud satellites are Lusat (LO-19) and Pacsat (AO-16). The 9600 baud satellites are Uosat-5 (UO-22) and Kitsat. Each satellite has slightly different operational characteristics. The frequencies mentioned below are the design frequencies. The measured frequencies from the satellites in orbit vary from these frequencies by a slight amount.

The satellites are used to collect telemetry, to download earth images, and as a BBS. The telemetry allows ground stations to determine the health of the satellite and read the various scientific instruments aboard some of the satellites. Several of the satellites have CCD cameras. They regularly take pictures of the earth that users can directly download. The BBS allows upload and download of Messages and Files. All messages and files are all stored as numbered files. Files include programs and pictures from the satellite's cameras and uploaded from other users.

Pacsat

A 1200 baud PSK satellite using 437.050 MHz for the Raised Cosine PSK downlink and 435.025 MHz for the Normal PSK downlink. The 4 uplink channels are (A) 145.900 MHz, (B) 145.920 MHz, (C) 145.940 MHz, and (D) 145.960 MHz. This satellite uses a later version of software which allows directories to be broadcast. The only connected mode used is for message upload. Recent engineering tests have shown the 435.025 MHz downlink to have problems. Currently only the 437.050 MHz downlink is used. The BBS callsign is PACSAT-12 and the broadcast callsign is PACSAT-11.

Lusat

A 1200 baud PSK satellite using 437.125 MHz for the Raised Cosine PSK downlink and 435.150 MHz for the Normal PSK downlink. The 4 uplink channels are (A) 145.840 MHz, (B) 145.860 MHz, (C) 145.880 MHz, and (D) 145.900 MHz. This satellite holds the record for longest continuous BBS software operation at over 400 days. Currently, connected mode is needed for both message upload and directory download. The version of satellite software with directory broadcast will be uploaded soon. This satellite uses the 437.125 MHz downlink except on experimental days when the 437.125 MHz downlink sends CW telemetry and the 435.150 MHz downlink is used for PSK. This is the backup satellite for traffic forwarding by gateway stations. The BBS callsign is LUSAT-12 and the broadcast callsign is LUSAT-11.

Uosat-5

A 9600 baud Direct FSK satellite using 435.120 MHz for the downlink. The 2 uplink channels are (a) 145.900 MHz and (b) 145.975 MHz. There is a CCD camera on board. Since the launch of Kitsat, this satellite is mostly used for messages. This may be due to the short message life as compared to Kitsat. This is the primary satellite for traffic forwarding by gateway stations. The BBS callsign is UOSAT5-12 and the broadcast callsign is UOSAT5-11.

Kitsat

A 9600 baud Direct FSK satellite using 435.175 MHz for the downlink. The 2 uplink channels are (a) 145.850 MHz and (b) 145.900 MHz. Some stations have noticed a drift in the downlink frequency. I use 435.174 MHz as the downlink frequency when setting my receiver. Wide-area and narrow-area CCD cameras are onboard. The orbit inclination of this most recently launch satellite is 66 degrees compared to the 98 degree polar orbits of the other three satellites. The inclination causes some interesting pass geometries to occur for stations in non-equatorial regions. Pass times gradually drifting through the clock compared to the sun-synchronous nature of the other three satellites. The BBS callsign is HL01-12 and the broadcast callsign is HL01-11.

Types of Stations

There are three different types of stations. They are manual, automatic, and gateway stations. Manual stations have a somewhat intelligent organic-based control system to handle antenna aiming and sometimes radio frequency control. Automatic stations use silicon-based manufactured control systems to handle the antennas and radios. Gateway stations are automatic stations that can accept messages and file requests from third-party stations. Stations that handle BBS traffic forwarding are in this category.

My station would be classed as a manual station. Being of simple tastes I enjoy having a hand in station operations. This has also allowed me to observe some situations that will be described later. I recently purchased a Trakbox so automation is around the corner.

Equipment

A wide variety of equipment can be used to receive the satellites. I will only enumerate some of the choices that I have direct experience with.

Antennas

There has been some success with omni-directional linear and circular polarized antennas. I have experimented with dipoles taped to my wall and a discone antenna through a diplexer. Discones are very marginal and anything with more gain should work better. Discones tend not to do well at low elevations. Linear polarized antennas have fading problems (which will only occur when it is your turn in the queue). Both Left-hand and Right-hand circular polarized antennas or polarization switching is needed. This is due to Lusat's orientation being inverted compared to Pacsat and a hardware design that causes one transmitter to be left-hand circular and the other transmitter to be right-hand circular on the same satellite.

My station uses KLM 40CX and 14C antennas. These type of high-gain antennas can also cause problems. When the 1200 baud satellites are not using the raised-cosine transmitters, more sidebands are generated. A high gain antenna provides enough gain that these sidebands can be heard with good strength. The modem can lock onto this sideband, but cannot decode the satellite. I found that the wrong sideband had a different tonal quality when transmitting data, so after awhile I could tune in the right sideband by listening. Another method is to calculate the approximate frequency by adding the satellite's measured frequency and the doppler, then subtract the modem's center frequency.

Recently I operated during Field Day with a 16 element circular 70 centimeter beam and a 10 element circular 2 meter beam. The results were very good even though I managed to burn out the direction indicator pot in the azimuth rotator.

Preamplifier

A preamplifier is very helpful when using omni-directional antenna. I also use it with the satellite beam antennas as it helps when the satellite is near the horizon. I use a Tokyo High Power Labs 70 centimeter preamplifier.

Radios

The 1200 baud satellites require a 2 meter FM transmitter and a 70 centimeter SSB receiver. The 9600 baud satellites require a 2 meter FM transmitter and a 70 centimeter FM receiver. The FM receiving equipment should be capable of at least 1 kHz frequency steps unless a wide IF filter is used. The convention for the 1200 baud satellites is to use upper sideband.

The easiest to get on depends on the equipment at hand. Although FM radios for 9600 baud would be easier to procure, modifications are required to directly connect the modem to the radio's FM modulator and demodulator. Not all FM radios are suitable for 9600 baud operation.

Modems/TNC

The 1200 baud satellites require a 1200 baud PSK modem. G3RUH (now discontinued) and TAPR provide separate modems that attach to packet TNC units. Newer DSP units (DSP-2232 and DSP-12) have this modem built-in.

The 9600 baud satellites require a 9600 FM modem. This modem is a Full Duplex version of the K9NG modem. Most units are based on a design by G3RUH. DSP units (DSP-2232 and DSP-12) also have this modem built-in

A 19.2k Serial Link is desirable when operating the 9600 baud satellites. This is due to the radio link being synchronous. A 9600 baud rate translates to 1200 bytes per second coming in on the radio port. Due to overhead in sending asynchronous data, a serial port to the computer with a 9600 baud rate will only send 960 bytes per second. Every second the satellite is sending at full speed results in at least 240 characters in the TNC's queue waiting to be transmitted. When using KISS, the protocol overhead will cause even more characters to be put in the queue. The result is eventually buffer overflow.

The AEA PK-232 does not work very well when dealing with 9600 baud full duplex on the radio port. One station found that sending a set of certain commands in a certain order to the unit did allow 9600 baud full duplex on the radio port to work. The serial port to the computer has a maximum baud rate of 9600. The DSP-1232 and DSP-2232 serial port to the computer will operate at 19.2k baud. TNC-2 units require a hardware modification to support a 19.2k baud rate on the serial port.

Computer

The computers currently supported are the IBM PC and Amiga ST. The PB/PG program suite is used on the IBM PC and PE1CHL's version of KA9Q's TCP/IP net program is used on both the IBM PC and the Amiga ST. The computer should have a serial port and a hard disk drive.

The current version of PB for the IBM was mistakenly compiled for a 80286 or greater processor. This leaves out IBM PCs and XT that use the 8088/8086 processors. My station's computer is a 25 MHz 386dx IBM AT Clone with 8 megabytes of memory.

The size of the hard disk drive should be big enough to hold all the programs you are using and any files you are downloading from the satellite. The 1200 baud satellites require about one Megabyte each. Uosat-5 requires several Megabytes due to the higher link speed and larger files uploaded. Kitsat requires even more space due to the number of large program and CCD Image files.

Software

One great thing about being on the satellites is many useful utility programs get uploaded. The problem is getting the initial programs to start using the satellite. The most important program is to get is the PG/PB program suite or PE1CHL's net program. Several new Microsat programs have recently appeared that I have not tried yet. The programs should be available from BBS systems, other satellite amateurs, or national AMSAT groups.

PG and PB

I recommend that you follow Jeff Ward's suggestions. I set the program to grab all broadcasted files. This allows a head start on capturing stuff you want before you even knew you needed it. Sometimes the file will be downloaded at your station before the directory entry for it is captured.

The amount of time to keep old act times depends on how long a message lasts on the satellite. I find PB deletes the act file the number of days in the PB.CFG file after it is last heard. Of course it can be heard up to the time of deletion, so the file can last longer on your computer than the satellite. I am very conservative and set Lusat and Pacsat to 14 days, Uosat-5 to 4 days and Kitsat to 8 days.

If you view the directory or use the Function keys to select files, new directory entries received after viewing the directory will not be displayed until another selection is made by pressing a Function key or use the movement keys. Going to the main menu and then returning to the directory view will not update the directory. I suggest you use the Function keys to make sure the directory is properly updated.

Currently PB is configured to block any log files. Unfortunately this includes images. This behavior can be overridden by marking image files for automatic download.

Archiving Utilities

Most programs and some messages are compressed using an archive program. There is a field in the pacsat file header that indicates the compression method used. The user file extension usually indicates the compression used. The following table shows the commonly used programs:

File Extension	Compression Program	Comments
ZIP	PKUNZIP	DOS archiver
LZH	LHA	DOS archiver
ARC	ARC or PKUNPAK	DOS archiver
ZOO	ZOO	DOS archiver. Available for other systems.
TAR	TAR	Unix Tape Archive Program. DOS version is available, but use of tar indicates programs are for Unix type systems.
Z	GZIP	Gnu zip compression Program. Z is usually the last character of the extension. DOS version is available but use of gzip indicates programs are for Unix type systems.
TAZ	GZIP and TAR	A TAR file that is compressed with GZIP.

Message Processing Utilities

I would take care of message and file processing right away. I did not when I first got on Uosat-5 and I ended up a few weeks later with hundreds of messages to go through. If hard disk space is limited it is even more important. I now use the PRC_DL program to view files and handle most of the file processing, but several methods are available. Most processing programs will automatically execute some of the previously mentioned archive utilities to decompress the user file.

If you run windows you can set up the file manger through the file associate feature to do some processing for you. If I double click on a file with a DL extension, my system will run a batch file that extracts the user file from the DL file. Double click on a file with a DLX extension and it gets the extension renamed to DL. Double click on a file with a MSG extension causes the file to be displayed using Notepad. The disadvantage is that only on one batch file or program can be associated with a extension.

I use the classic PFHADD program to add the pacsat file header on all outgoing files. PHS or PFH can be used to extract the user file from the downloaded pacsat file. PFH can also do other maintenance functions on microsat files and directories.

Image Utilities

The DISPLAY program by Colin Hurst, VK5HI, is used to display the raw CCD images from Kitsat and Uosat-5. Display4 is the version for Super VGA cards and Display5 is the version for 8514a Display adapters. The minimum resolution supported is 640 by 480. The DISP_ACT program allows display of the raw CCD image while it is still being downloaded. This is important utility as Raw CCD image files are big and some images turn out to be all white or otherwise defective. Holes in the act file will appear as "noise" in the picture when displayed.

GIF, JPEG (JPG extension), and PCX files are the most common image types for pictures uploaded by stations. Several programs can be used for displaying these pictures. I use CSHOW and SVGA for GIF files; CSHOW for JPEG files; and VIEW from PCTOOLS or Windows PAINTBRUSH for PCX files.

UO-22/Kitsat User List

Although not a program, this very useful information file is a list of Uosat-5 and Kitsat Users. This list is maintained by Sueo, JA6FTL. The UO22USR program is available to manage the list.

Helpful Hints

It is generally better to download any wanted files before doing a directory request, unless you are the only station in the satellite's footprint for the entire pass. In busy parts of the world, some other station will either have no more files to download or will do a directory request right away. It is better to wait for your directory request until later in the pass and allow other station's requests to fill your directory holes. Remember that stations around you have not seen the satellite recently and will have a similar directory request. Generally if I can receive some of a morning pass I can keep the directory up to date by receiving just one evening pass without doing a directory request.

If you want to change the file you want to download, mark the file with a priority download request and change any other requested priority download files to an automatic download request. If you disable then enable automatic operation (Control-A) one or two times, the file number marked with priority will appear on the screen. However, PB will not send any file requests while your call appears in the PB list. Do a manual fill request for the file until you receive the OK message from the satellite.

Changing from a directory request to downloading marked files is done in a similar manner as mentioned in the previous paragraph. If you disable then enable automatic operation (Control-A) one or two times, the first file number will appear on the screen. Do a manual fill request for the file until you receive the OK message from the satellite. This is handy if other stations are filling the holes in your directory and your directory requests are redundant.

If you notice other stations filling a significant amount of your file or directory request, then every few minutes manually send the file or directory request. This will help avoid redundancy and download your request faster. If other stations are filling your directory requests and no files are marked for download, it is better to disable automatic operation until later in the pass. The same problem can occur on large files.

If you are fortunate to live on a coast of an ocean and have a low radio horizon, I have found that a significant amount of requests can be filled on a 5 minute pass with a 3 degree maximum elevation. Even if there are other stations on, the satellite is not as busy as over land areas. Sometimes I have found myself the only one on the satellite, but usually stations from Western Europe join in. If I get directory and file requests mostly finished on eastern passes of the polar-orbiting microsats, it means more time for other stations to my west on later orbits. Take the most advantage of your location.

Suggested Reading/Further Information

AMSAT-UK and AMSAT-NA have publications and software for microsat operations. Check with your local AMSAT group. The AMSAT Journal (AMSAT-NA) and Oscar News (AMSAT-UK) regularly carry news and information about the microsats.

DIGITAL PROCESSING OF WEAK SIGNALS BURIED IN NOISE

by

Darrel Emerson, AA7FV

Internet: aa7fv@amsat.org
Compuserve: 74010,2230

ABSTRACT

This paper gives examples of Digital Signal Processing (DSP) applied to the reception of very weak CW signals buried in noise. Using a very modest receiving antenna, the technique gave perfect reception of experimental CW transmissions from WA5ZIB via Oscar 13 at ZRO level A, or 30 dB below the satellite beacon. Various DSP algorithms are used, and examples are shown of visualizing and searching for very weak signals buried in noise. The techniques are appropriate to low power moonbounce (EME) communication, and have been used to search for weak leakage radiation from the defective Oscar 13 Mode JL transmitter.

INTRODUCTION

A few times a year, ZRO tests[1] are conducted with AO-13, on downlink frequencies in the 70-cm (mode JL) and 2-m (mode B) bands. In these tests, CW blocks are sent with transmitted power decreasing in steps of 3 dB from a level (ZRO level 0) initially equal to the normal AO-13 beacon, down to a level 27 dB below the beacon (ZRO level 9). These tests present a challenge to improve receiving performance by trying to monitor the weakest possible signal level. Until 1992 only 2 stations, W7ID and DF7IT/DL0WH, had received the ZRO level 9 transmission perfectly at both downlink frequencies[1]. As an additional experiment, in spring 1993 an even weaker signal (ZRO level A) was transmitted[2], at a power level 30 dB below the normal AO-13 beacon.

The receiving equipment used for the ZRO tests was very modest; the antennas were circularly-polarized crossed-yagis, a 10x10 on 2 m and an 8x8 for 70 cm. The receiver was a transverter feeding an H.F. rig with a 250 Hz bandwidth crystal filter, and an optional active audio filter. On a good day, I could **sometimes** receive ZRO level 7. By ear I have never been able even to detect the presence of the level 9 signal, either on mode B or mode JL.

The home computer has a Thunder Board card from Media Vision, which is compatible with the well known Sound Blaster board. My teenage children usually used the board for game sound effects, but it can also digitize audio at 8-bit sample rates between 4 kHz and 22 kHz. I decided to use the Thunder Board digitizer to record the ZRO signal from AO-13 through the audio output of my receiver, and to apply software processing to try to pull the weaker ZRO signals out of the noise. I have not tried to make the software run in real time; this gives the great advantage that all programming can use a high level language, with emphasis on making it easy to experiment with - and often reject - new data processing algorithms. No thought was given to computing efficiency, which would have been a prime consideration for a real-time system.

The AO-13 ZRO tests are ideally suited to this DSP project. The total amount of information to be retrieved is very small - one new 5-digit number at each ZRO level. This means that many different algorithms can be tried, without becoming swamped with problems of data storage or computer processing time. There is relatively little fading or interference on the satellite link, so the noise statistics should be very predictable, allowing some straightforward statistical tests and analysis. The results were very successful; perfect copy was obtained even with the ZRO level 9 or level A signal completely undetectable by ear. The sensitivity achievable with DSP techniques is quite remarkable.

DATA ACQUISITION

The DSP has been applied very successfully to both mode JL and mode B ZRO transmissions from AO-13. The example here is from the mode B ZRO transmission by Andy MacAllister, WA5ZIB, on 24th April 1993. The separate phases of this project are in principle quite simple and straightforward, but as always there are minor complications. The data acquisition should have been easy enough; plug the receiver audio output into the Thunder Board digitizer, tune the receiver to the right frequency in USB mode, point the antennas at AO-13, and wait for the ZRO tests to begin. However, the following details were found to be important:

(1) Interference. At this level of sensitivity, interference from the computer was always a problem. I tried different computers, and in different rooms of the house. The solution was to turn all computers off during the ZRO transmissions, and to record the data on to an analog audio tape recorder. After the ZRO transmissions were over, the tape would be played back and digitized, using the standard "*.VOC" file format for the digitized data.

(2) Recorder quality. The quality of analog audio recorders varies enormously. The critical parameters are a low frequency of dropouts, good tape speed stability on record and playback, and the absence of significant harmonics of the 60 Hz power frequency. I tested several different machines before choosing the most suitable.

(3) Automatic gain control (AGC). Many analog audio recorders, and the Thunder Board digitizer, have an AGC loop to set the input level. This is very undesirable for recording the ZRO signal. I chose a recorder without AGC, and carefully set the audio input level to the digitizer to be low enough to avoid AGC action on all but the strongest signals.

(4) Receiver filter bandwidth and frequency control. In early tests I used maximum selectivity in the receiver ahead of digitization, including a 50 Hz bandwidth active audio filter. The received frequency generally varies more than 50 Hz during a ZRO test, because of changing Doppler shift and other frequency drifts. Steady drifts are easier to track in the data analysis than discrete frequency jumps. A digital analysis bandwidth of 8 Hz or less is used for the final analysis, so Doppler tracking in discrete steps as large as 5 Hz would be unacceptable. It was found to be better to use a larger receiver bandwidth - 250 Hz or more - and to rely entirely on the digital processing to narrow down the selectivity and to track the frequency drifts.

(6) Digitization rate, and disk space. The lowest sample rate available on the Thunder Board is 4 kHz, which is much faster than the minimum sample rate strictly needed for a 250 Hz bandwidth. One full ZRO test can use 6 or 7 Mbytes of disk space for the "*.VOC" file of raw data; the analysis may need much more space than this for intermediate stages of processed data. Computer disk management needs continuous attention.

DATA ANALYSIS

The various principles of digital signal processing are well known; a good summary and bibliography can be found in reference 3. The signals in this project are all weak, initially buried in noise. Processing is not attempted in real time, so programming convenience, rather than computer efficiency, is important. These factors guided the choice of algorithms. The software was written in FORTRAN specifically for this project, and consists of many stand-alone program modules that can be linked together at a higher level by procedure files. Where appropriate, existing subroutine libraries[4,5] were used.

DSP analysis tools used include:

Fast Fourier Transform (FFT)
Matched filters
Tracking Finite Impulse Response (FIR) filter
Convolution
Cross- and auto-correlation
Correlation coefficient and relative probability analysis
Polynomial curve fitting, interpolation
Data averaging to improve S/N ratio

Data display tools include:

2-D Grey-scale graphical display of time & frequency intensities
Line and X-Y plots of spectra and time sequences of data

The list of tools makes the analysis sound much more complicated than it really is. The principles are very simple. There are two distinct phases of the data analysis:
(1) finding the signal - the weaker ZRO levels cannot even be detected by ear - and
(2) retrieving the information from the modulation, once the basic signal has been identified.

The ZRO signal

In finding and decoding the ZRO data, as much use as possible is made of prior information about the signal. The stronger ZRO signals (say ZRO level 0 to level 5) are heard easily and can be studied with very simple data processing. Both the Mode B transmission from WA5ZIB and the Mode JL from N5EM clearly use machine-generated CW. The precise speed and timing of the CW transmissions were derived from the stronger ZRO levels. Much of the later data processing uses this predictability of machine-sent CW to distinguish signal from noise, in a way very similar to that described many years ago for the reception of coherent CW[6], but in this case with synchronization derived from known characteristics of the signal itself.

Although the ZRO data are sent in CW at a nominal 10 wpm, the characteristics of the CW from WA5ZIB on Mode B are very different from those of N5EM on Mode JL. The WA5ZIB CW is at a strict 10 wpm in all respects, in timing of dots, dashes, inter-character and inter-word spaces. The CW from N5EM was found to be sent in the Farnsworth manner; the individual characters were sent at 13 wpm, with longer inter-character spaces to keep the average CW speed at 10 wpm. This is critical to the data analysis. There is an interesting implication for the relative limits of sensitivity; because the individual CW characters from N5EM are somewhat faster, the matched filter used to recover N5EM's signal needs to be wider, letting in more noise, with shorter averaging times possible for the post-detection signal. This gives about 1 dB S/N penalty to the ultimate sensitivity achievable on the N5EM signal, compared with the true 10 wpm data sent by WA5ZIB.

For each ZRO level, there is typically a short transmission of unmodulated carrier as WA5ZIB or N5EM adjust the transmitter power level, followed by three 5-figure groups identifying the ZRO level, then the three 5-digit groups to be copied. For example, a level 9 transmission might consist of:

99999 99999 99999 12345 12345 12345

where "12345" represents the unknown 5-digit number group to be copied to prove reception at this level. If the "99999 99999 99999" sequence - or "AAAAA AAAAA AAAAA" for the level A test - can somehow be detected in the noise, then the known timing of the machine-sent CW can be used to predict precisely when the first dot or dash of each "12345" or unknown sequence begins.

Identifying the Signal

Perhaps fortunately, it is much easier to detect the presence of a weak signal than to decode its modulation. Figure 1 shows an example test spectrum generated by digitizing the 983 Hz keyed audio tone output from an electronic keyer, sending a repeating sequence of "1234567890" in CW at 10 wpm. The raw test data were sub-divided into overlapping 2-second blocks, each containing 8192 data samples. A Fourier Transform (FFT) was then made of each block, converting the raw numbers sampling the signal in time, into a sequence of numbers describing the frequency spectrum of that block. Power spectra derived from many such 2-second blocks were averaged together to produce the average power spectrum, with a frequency resolution of about 0.5 Hz, shown in Figure 1. It shows that most of the energy in this CW sequence is contained within less than 1 Hz of the central "carrier." The sideband peaks at $\pm$ 4.2 Hz and $\pm$ 12.5 Hz result from regular sequences of dots - e.g. a "5" in CW at 10 wpm resembles 5 cycles of square-wave signal at 4.17 Hz. These sidebands repeat at intervals of 8.33 Hz, gradually diminishing in amplitude away from the central "carrier." The recognition of CW characters is only possible from the CW sidebands. However, for the first stage of analysis only the detection of a signal, not yet interpretation of the modulation, is needed. The focus initially is on searching for the central spike of energy, allowing the use of a very narrow filter to improve the detection sensitivity.

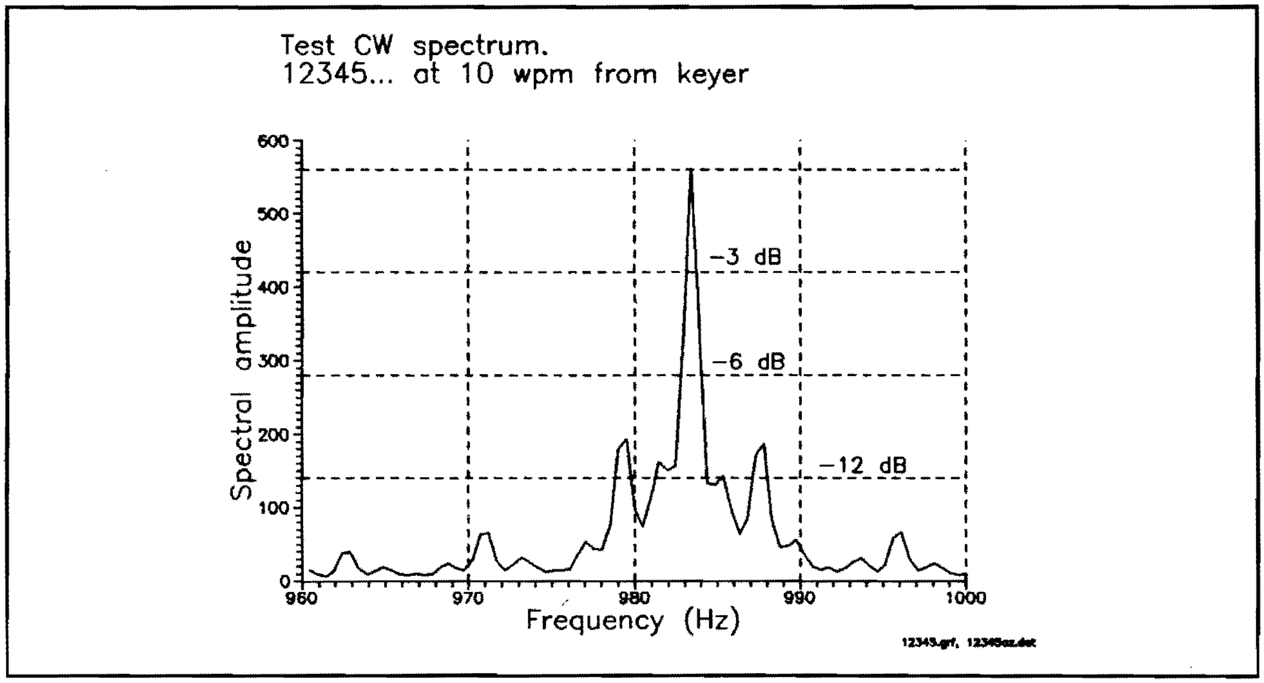

Figure 1 *Average spectrum of keyed 983 Hz tone from an electronic keyer sending "1234567890." This shows that most of the energy is within < 1 Hz of the central "carrier" frequency.*

Figure 2 shows a grey-scale representation of the changing frequency spectrum received from AO-13 during part of the ZRO level 9, and the entire ZRO level A tests transmitted by WA5ZIB on 24 April 1993. Each horizontal row of the plot represents a separate power spectrum; the spectral intensity is represented by varying shades of grey, with white indicating higher power. Each row is derived from a Fourier Transform of 0.5 seconds of data, which yields a frequency resolution of 2 Hz. There are ~200 rows in this plot, covering 100 seconds of digitized data; time increases from bottom to top. A total range of 390 Hz is represented, with frequency increasing from left to right. Each pixel of the plot represents the average intensity in a 2-Hz band, averaged over 0.5 seconds of time. The purpose of the display is to show the presence of any weak signal, without attempting to decode the modulation.

The broad background of speckled dots in Figure 2, covering most of the plot, is due to receiver noise; the edge of receiver's i.f. filter causes the gradual roll-off in noise intensity in the right of the plot. At the start of the data, at the bottom of the plot, the ZRO level 9 transmission is in progress, and shows as the vertical white line. After about 20 seconds of data, the ZRO level 9 gives way to the level A signal, which shows as a much fainter white line continuing upwards beyond the level 9 signal. This signal slopes slightly to the right, corresponding to a changing Doppler shift of the signal received from the satellite, combined with any other receiver or transmitter drifts. About 12 seconds before the end of the data represented here, near the top of the plot, the signal returns to higher power. After 2 or 3 seconds WA5ZIB adjusted his transmitter to full power, and began the "End of test" CW message; simultaneously, the frequency dropped lower by a few Hz. The CW modulation sidebands show for the final few seconds of data, at the very top of Figure 2.

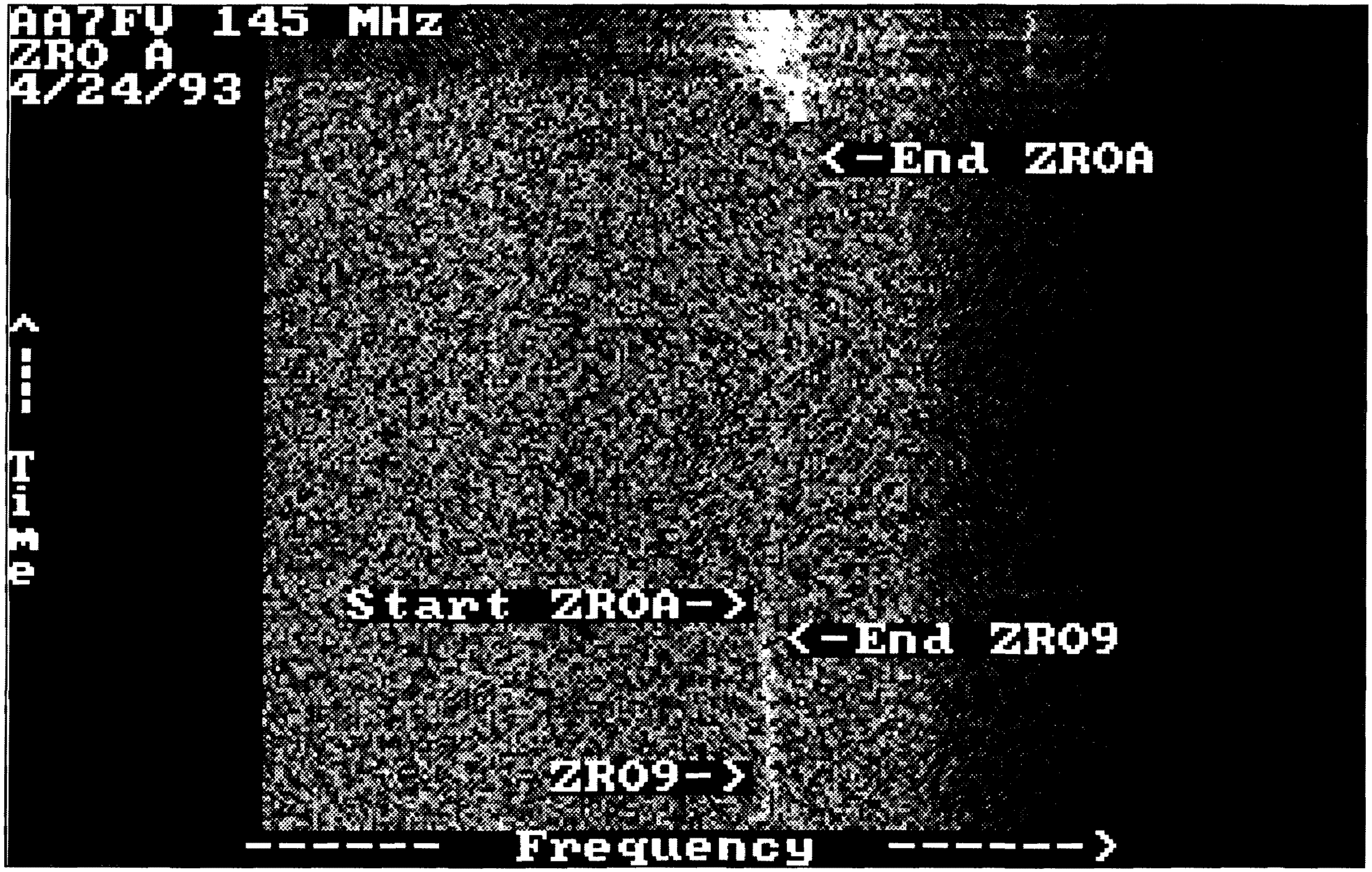

Figure 2. A 2-D greyscale representation of power spectra against time. The horizontal axis is frequency and covers 390 Hz; the vertical axis is time, increasing from bottom to top, and covers 100 seconds of data. Each pixel corresponds to the intensity in 2 Hz of bandwidth averaged over 0.5 seconds of time, with higher intensities shown white. The end of the ZRO level 9 signal shows as the faint white vertical line in the lower part of the plot. The ZRO level A signal is just visible as an extremely faint near-vertical line extending between the "Start ZROA" and "End ZROA" labels.

This type of representation of weak narrow-band signals buried in noise is very powerful. By ear, no trace whatever of the ZRO level 9 signal could be detected, yet it appears very clearly in the lower part of the grey-scale plot, with a clear detection of the even weaker level A signal. This type of display has been used by astronomers engaged in the Search for Extra-terrestrial Intelligence (SETI). The human eye is particularly good at discerning weak coherent patterns, such as faint lines, otherwise hidden in noise.

Apart from just detecting the weak ZRO level A signal, Figure 2 also allows a determination of the rate of frequency drift of the received signal. The gradual shift to the right of the line showing the ZRO signal in Figure 2 suggests a frequency drift of about 15 Hz during the level A transmission. Since the decoding of the CW modulation will use a matched filter of nominal bandwidth 8 Hz, a correction has to be made for this drift. The frequency drift results from a combination of changing Doppler shift and any instabilities in the transmitter, satellite transponder, and receiver; a combined oscillator drift of less than one part in a hundred million is enough to be very noticeable, but is probably inevitable. Peaks of signal along the weak ZRO level A transmission shown in Figure 2 were picked out, and a simple 2nd or 3rd order polynomial was fitted to the points to give an empirical analytic expression for the instantaneous frequency at any moment during the ZRO level A transmission. Later stages of signal analysis use this.

One last piece of information from Figure 2 concerns the short-term stability of the signal. The ZRO level 9 signal shows that there may be a frequency jitter of about 2 Hz in the received signal, with a timescale of one or two seconds; similar plots of the stronger ZRO level signals show the effect much more clearly. This fact alone shows that there would be little gain in going to even higher resolution, say to better than 2 Hz. Plots similar to Figure 2 but with 0.5 Hz frequency resolution were made, and confirmed that there was no improvement in detection sensitivity. Any of the local oscillators in the earth-satellite-earth link could be responsible. The frequency jitter is also a phase jitter; an attempt to apply a phase-coherent detection algorithm was unsuccessful. If the r.f. phase of a given dot or dash element could be predicted from the average phase of the signal before and after that dot, taking into account the known slow but steady drift in frequency, then coherent demodulation could be used. In principle this could gain 3 dB in S/N ratio. It was found that the phase jumped randomly on a time comparable to the duration a CW dot or dash, so that the r.f. phase of any given CW dot could not be predicted from the average phase of the neighboring signal. Nothing would be gained over normal incoherent (square-law) detection of the filtered signal.

Decoding the Signal

So far, the ZRO level A signal has been identified, but no modulation information has been retrieved. To decode the CW modulation, a matched filter is required that allows the CW sidebands to pass, without admitting unnecessary noise. Figure 1 showed the typical spectrum to be expected from the CW signal. A digital matched filter was made based on the spectrum of a single dot element, widened a little to allow for the small but unpredictable frequency jitter found in the signal, and tapered a little to allow for the anticipated waveform shaping at the transmitter and to reduce the far-out frequency response. Figure 3 shows response of the central 40 Hz of this filter to a steady 980 Hz tone. The first and successive sidebands of this matched filter coincide exactly with the narrower sidebands observed in the CW spectrum of Figure 1. In both signal (e.g. Figure 1) and filter (Figure 3), there are minima in the response at $\pm$ 8.33, 16.67, 25.0 ... Hz. The filter (voltage) passband shape is a slightly modified sin(x)/x function; the width between 3 dB points is 7.4 Hz, but the filter sidebands extend much further than that. The filter admits the same noise power as a perfectly rectangular filter of width 8.33 Hz. Elsewhere in this paper it is simply referred to as an 8-Hz filter.

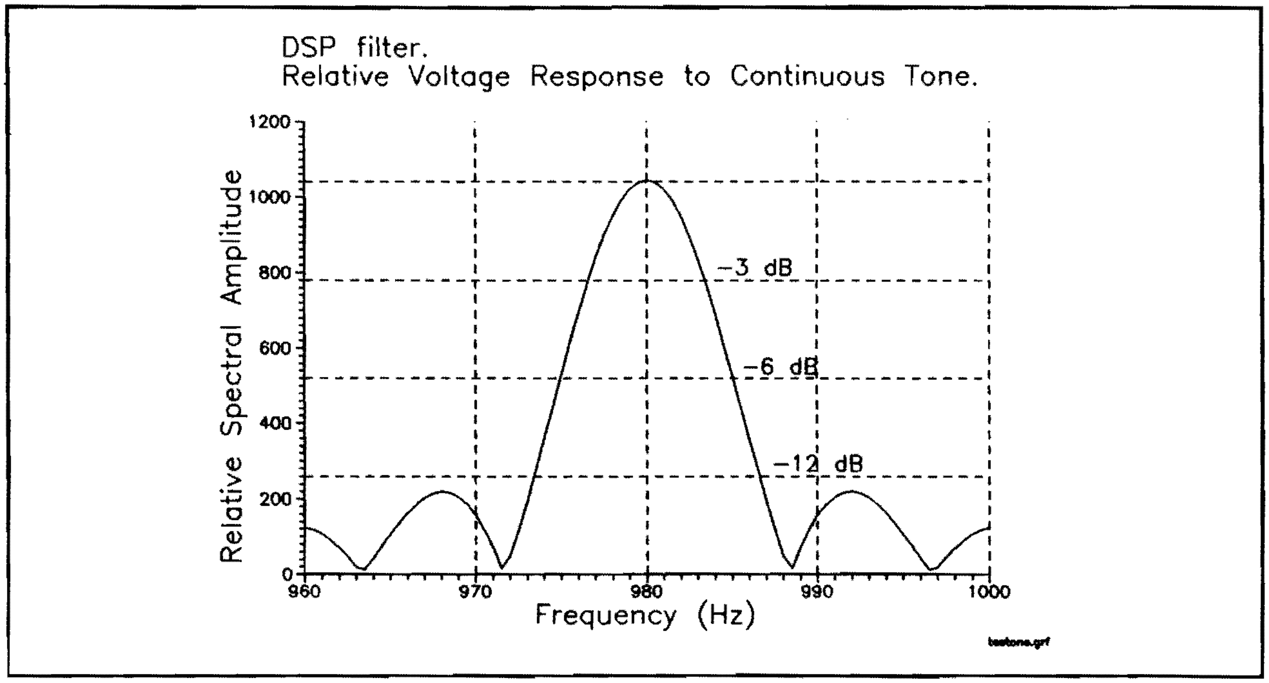

Figure 3 *Response of the DSP filter used to recover the CW modulation from the ZRO transmission. This filter was made to track the changing signal frequency.*

This matched filter was implemented as a FIR filter, but tracking the signal in frequency. It was used to extract the ZRO level A signal visible as the faint near-vertical track in Figure 2. The filter effectively averages the signal over the duration of one dot period (120 ms), but with some oversampling it was made to give a measure of the ZRO signal every 40 ms. The output, after demodulation with a perfect square-law detector, is plotted in Figure 4. This shows the end of the period of ZRO level 9 signal, followed by the first few seconds of the ZRO level A signal. The filter has tracked the slowly changing frequency of the signal seen in Figure 2, using a passband (Figure 3) that includes the important CW sidebands. Figure 4 shows the expected drop in average intensity from the level 9 down to the level A signal, but the noise is still too high to permit discrimination of single dots or dashes, or even the gaps between individual CW characters.

To obtain an estimate of the real S/N ratio of the ZRO level A signal, and to give confidence that the signal really is there, I made an average power spectrum. To do this, the same FIR 8-Hz filter was used to generate a complete power spectrum of the signal every 40 milliseconds, tracking the frequency drift. (The filter could equally, and more efficiently, have been implemented using multiple FFTs.) These 1000 or more spectra were averaged, to give the mean power spectrum of the ZRO level A signal shown in Figure 5. This very clearly shows the weak ZRO signal at 835 Hz, sitting on a general plateau of receiver background noise. A total frequency span of nearly 200 Hz is shown, but above about 890 Hz the response rolls off due to the passband of the receiver i.f. filter. In the 8-Hz passband, the mean power of the ZRO level A

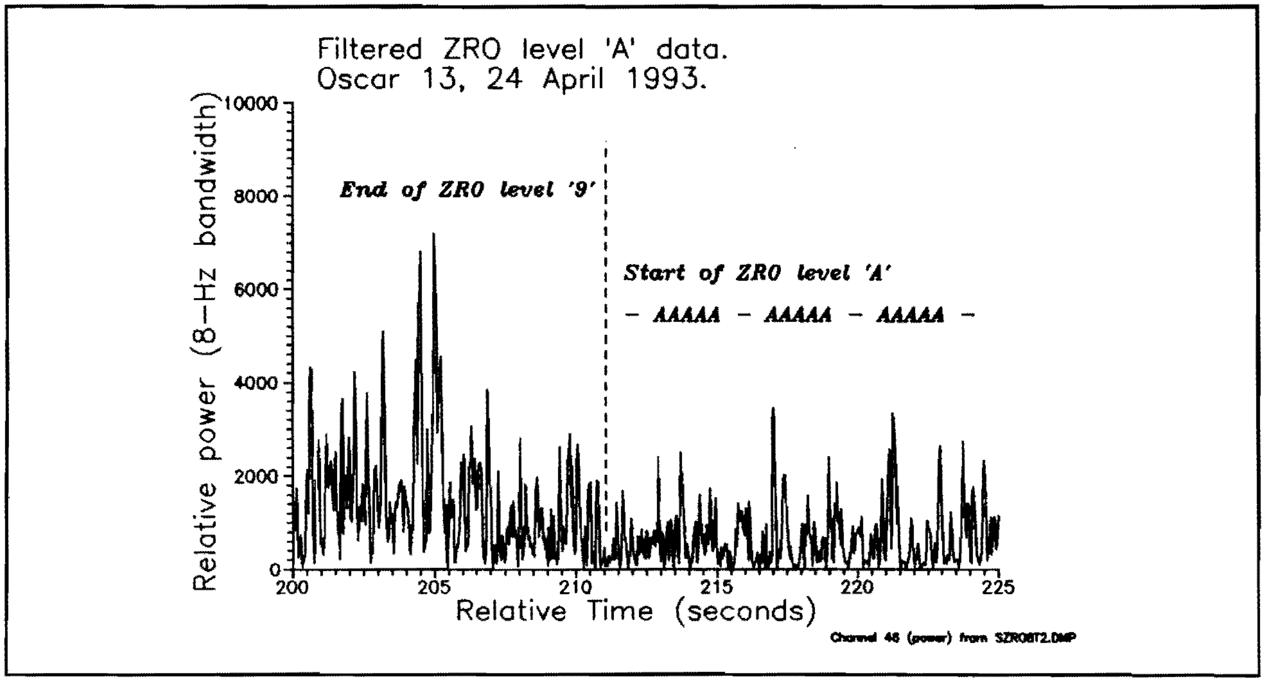

Figure 4 *The detected output power, using the 8-Hz bandwidth matched filter, of the end of ZRO level 9, followed by the start of ZRO level A. The signal is too noisy to be able to discern individual dots and dashes.*

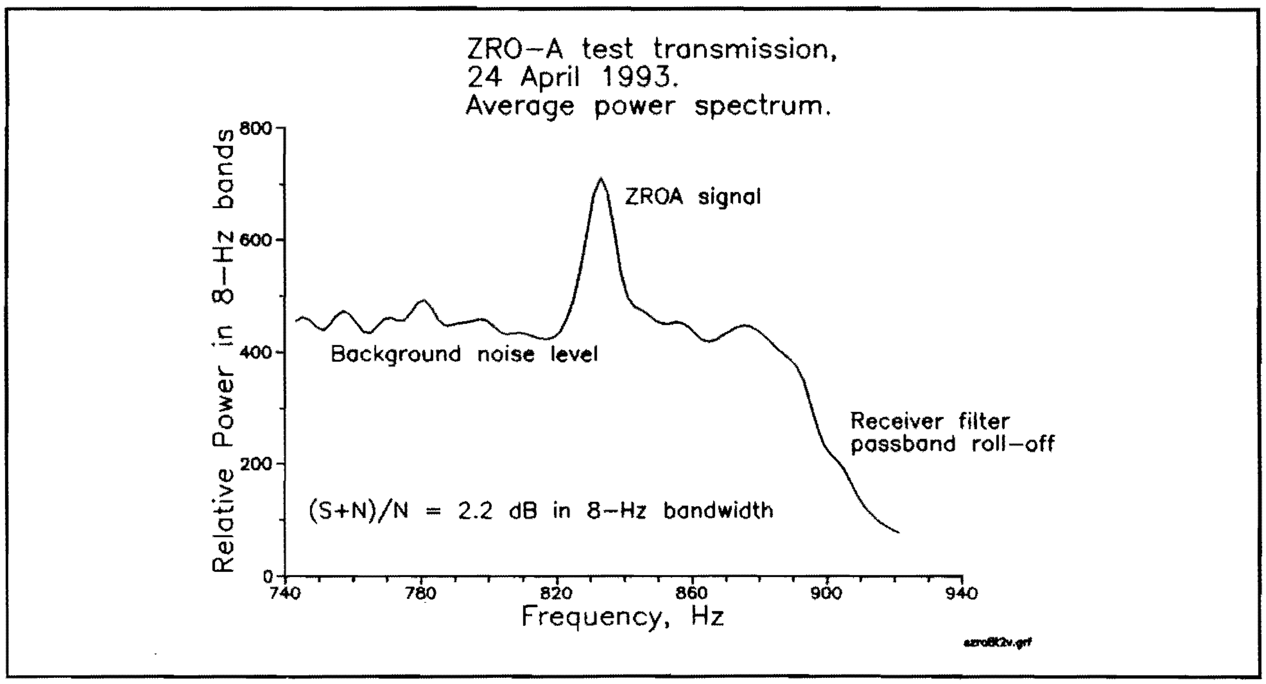

Figure 5 *An average power spectrum covering the period of the ZRO level A transmission, made using a tracking FIR filter to allow for the drift in frequency.*

signal is only 2.2 dB above the background noise floor.

Some much more sophisticated technique than trying to identify individual dots and dashes

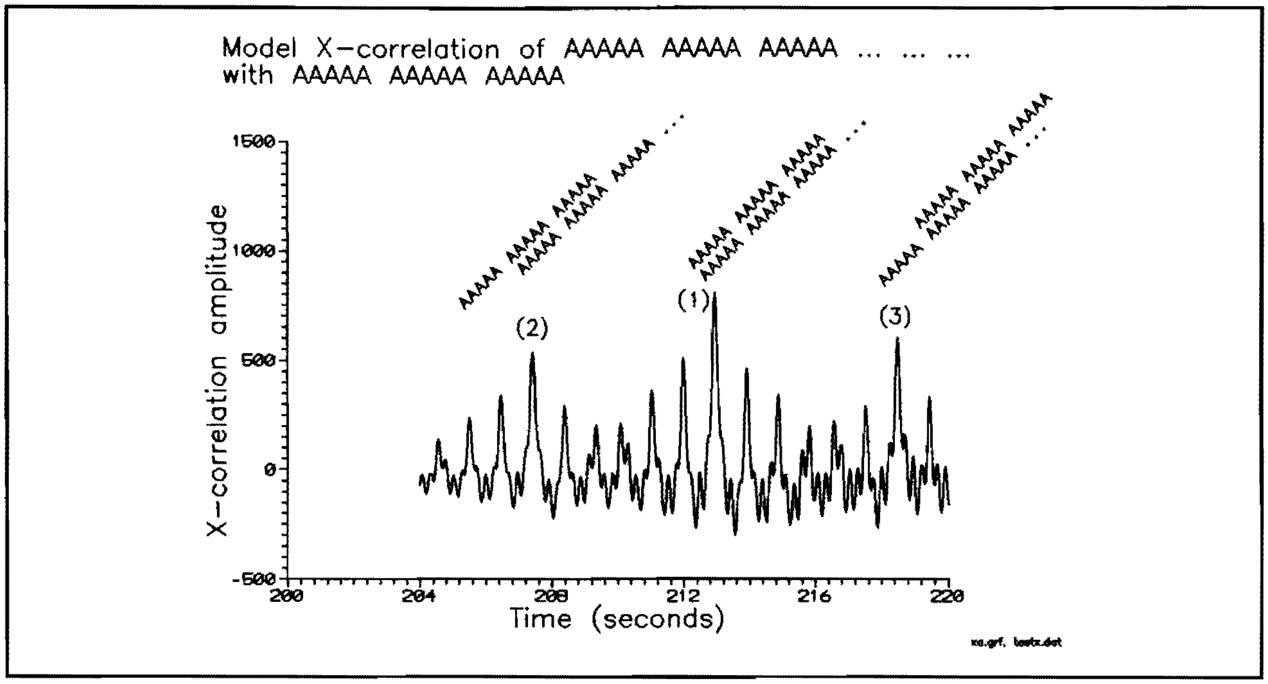

Figure 6 *A convolution of the CW pattern for "AAAAA AAAAA AAAAA" with an identical, model pattern without noise. The highest peak (1) shows the perfect match.*

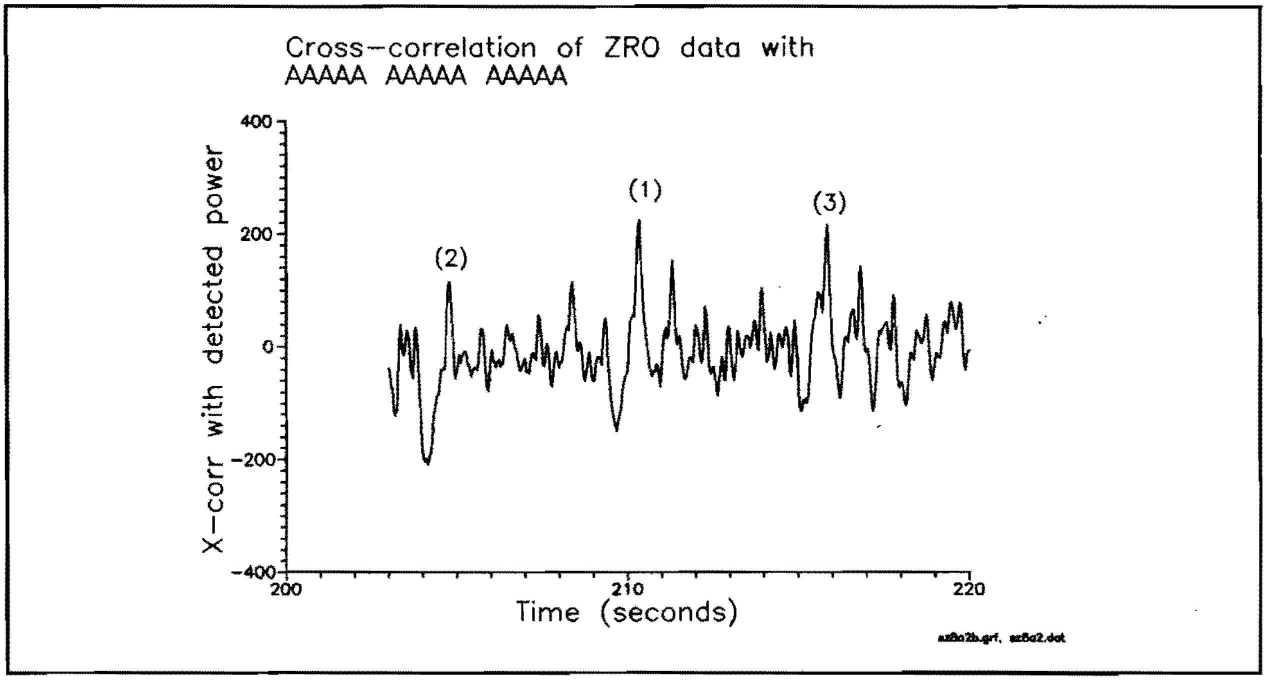

Figure 7 *A convolution of ZRO level A data with the CW pattern for " AAAAA AAAAA AAAAA ." The peaks marked (1), (2) and (3) correspond to the similarly labelled peaks of the model data shown in Figure 6.*

is needed to decode data such as that shown in Figure 4. One possible algorithm uses cross-correlations of the noisy data with known patterns; the more complex and the longer the known pattern, the more likely it is to find a good match to an identical pattern buried in noise within the data. As an example, Figure 6 shows a convolution of the CW pattern for " AAAAA AAAAA AAAAA " with an identical, model pattern without noise. There are 3 strong peaks, corresponding to where the patterns match, or correlate, best. The main peak, labelled (1), corresponds to perfect alignment of the two patterns. The subsidiary peaks, marked (2) and (3) show somewhat weaker correlation; they correspond to where one pattern is shifted in time by exactly one whole 5-letter group. Two of the three 5-letter groups still match perfectly.

Figure 7 shows a convolution of the same CW pattern for " AAAAA AAAAA AAAAA " with the ZRO level A data of Figure 4. The result (a cross-correlation function) shows 3 main peaks of correlation, labelled (1), (2) and (3), corresponding - albeit with added noise - exactly to the labelled peaks of the model data shown in Figure 6. The final confirmation comes from measuring the separation in time of these peaks; this agrees, to within a few milliseconds, with that predicted from the known timing of WA5ZIB's CW, derived earlier from the stronger ZRO levels. The position of the expected " AAAAA AAAAA AAAAA " sequence in the ZRO level A data has been found without having to identify individual dots and dashes at all. This time information is critical; we can now calculate the exact start of the first dot or dash of the unknown ZRO level A data, using the identification of the expected " AAAAA ..." sequence as a synchronization pulse.

Initially, using this precise timing information, an attempt was made to decode the ZRO A data, letter by letter, as would have been done with true coherent CW. Although this worked well for ZRO level 9, the weaker level A data needs a more powerful algorithm. A brute force approach was adopted, making trial cross-correlations of the data with all possible combinations of a 5-digit sequence. There are only 100,000 possible combinations! Starting with the CW pattern for " 00000 00000 00000 ", then " 00001 00001 00001 " and working through to the final " 99999 99999 99999 " all possible combinations were tried, to see which gave the best match, or relative degree of correlation, at the required instant. This requires very precise knowledge of and stability in the sending CW timing. When several possible, or "most likely" answers had been identified from this correlation technique, a convolution of the best candidate answer with the raw data was made, to produce another plot with peaks equivalent to (1), (2) and (3) shown earlier in Figures 6 and 7. In this case, it was found that the separations of these peaks were not quite identical, but implied a drift in apparent CW sending speed from 10.00 wpm in the first 5-digit group down to 9.95 wpm during the 3rd and last group. This may not seem much, but it is enough to cause loss of synchronization with the timing of dots and dashes near the end of the data.

Finally, more trial cross-correlations were made taking this drifting CW speed into account. Correlations for each trial 5-digit number were calculated with additional time offsets in steps of 40 ms, over a 1-second interval. The revised candidate answers were then listed in order of relative correlation magnitude. Figure 8 summarizes the results; the maximum correlation amplitude found for a given 5-digit number is plotted against the time at which that maximum correlation occurs. The best ~100 of the 100,000 trials are shown. It is encouraging to see that the strongest correlation occurs within a few milliseconds of the predicted start of the data. The most probable answers are also clustered at start times separated by intervals of 0.24 seconds, which is the duration of a CW dot-space combination. The 5-digit number showing the highest correlation amplitude was submitted to WA5ZIB as the ZRO level A report. There was a small celebration at AA7FV when Andy MacAllister confirmed that this was the correct number!

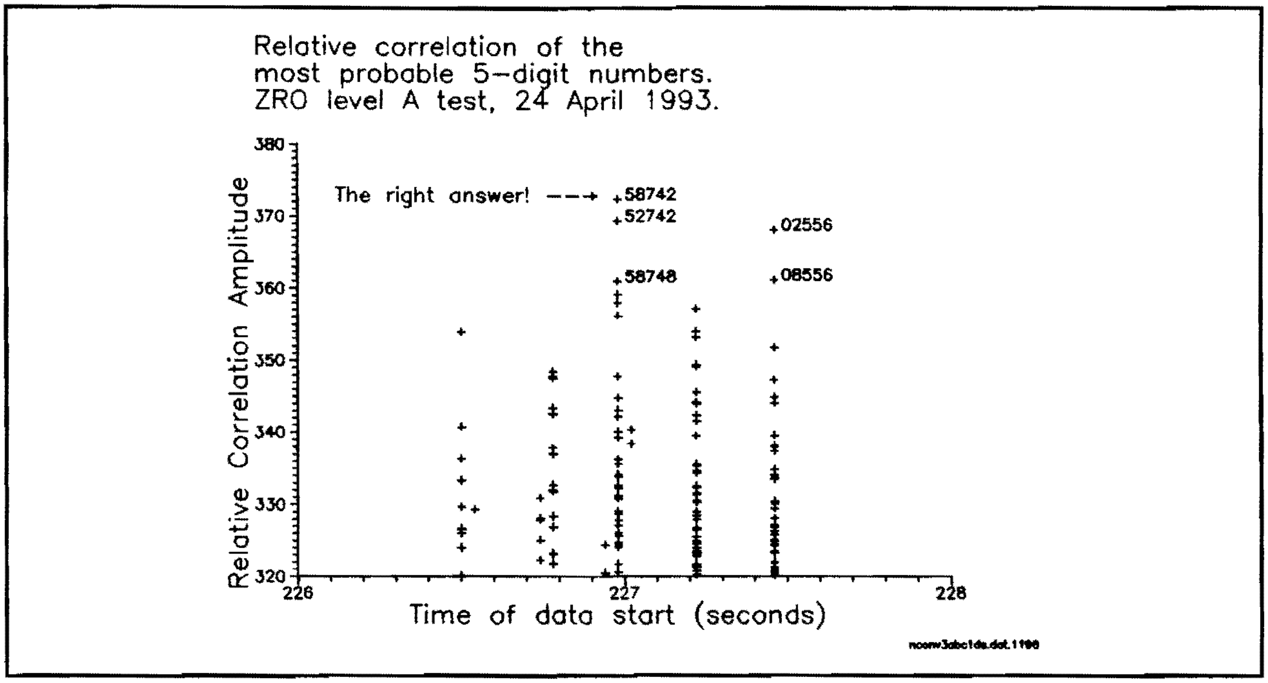

Figure 8 *Relative correlation of the most likely matches of different 5-digit numbers to the ZRO level A data. The predicted start time is 227.0 s; correlations were computed every 0.04 s from 226.5 to 227.5 s.*

OTHER APPLICATIONS

Moonbounce

One obvious application of these techniques is to low power moonbounce (EME) communication. For this to be successful, conventions need to be agreed on the detailed format of transmissions: the precise speed, timing, and the "synchronization" sequence (e.g., CQ CQ CQ ..., or repeated callsigns). It is essential to use machine-sent CW, or other modulation. Although the processing described here has been for CW, similar techniques can be applied to most forms of modulation. An additional 3 dB gain in S/N with CW could be realized by using frequency-shift keying (FSK) instead of on-off keying. With signals buried so far in the noise, active error correction modes such as AMTOR bring little gain in sensitivity on their own, but could be combined with these DSP algorithms. The gain in sensitivity achievable with the processing presented here depends on the exact circumstances (CW speed etc.), but is at least 10 dB when compared to the human ear alone.

Oscar 13 Leakage Radiation

DSP algorithms were used in August 1993 to search for possible leakage radiation from the 436 MHz exciter of Oscar 13. The mode JL downlink transmitter of AO-13 failed[7,8] in May 1993. The cause of failure is not yet known, but if any weak signal from the mode JL exciter could be detected, for example via leakage though the defective power amplifier, this might help the understanding of the problem. During August 1993, the S-band beacon and the L-band beacon (i.e. the L-band exciter) were both switched on simultaneously[7] for part of AO-13's orbit. An

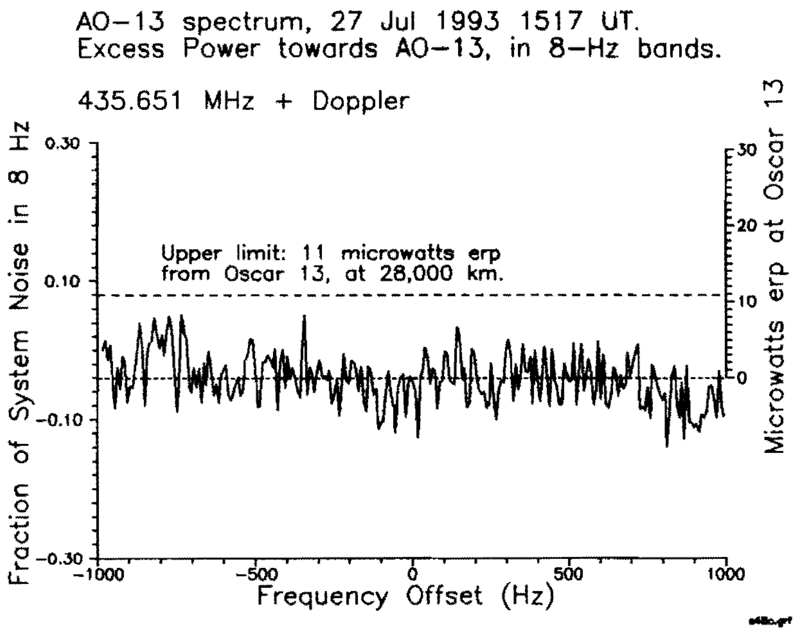

Figure 9 *A spectrum of the radiation at 436 MHz from AO-13, when the mode JL exciter was turned on and should have been sending RTTY. Maximum leakage radiation from AO-13 is less than 11 microwatts erp in any 8 Hz band.*

unsuccessful attempt was made to detect low level leakage from the mode JL exciter during these periods.

Data were recorded with the antenna pointed towards AO-13, and the Doppler-corrected 70-cm beacon frequency centered within the 2 kHz receiver passband. More than 800 power spectra, with 8 Hz frequency sampling and covering ~100 seconds of raw data, were generated using the FFT algorithm. Each spectrum was individually shifted in frequency to allow for the Doppler drift of ~0.3 Hz/second. These Doppler-corrected spectra were then averaged together, giving a combined spectrum which showed the receiver noise passband, with any possible additional energy from AO-13 superposed. A similar spectrum, generated from data taken with the antenna looking at blank sky, was then subtracted. The difference spectrum was then normalized, to give uniform sensitivity across the 2 kHz passband, calibrated as a fraction of receiver system noise. This analysis removes frequency-dependent offsets and gain variations in the spectrum, which result mainly from ripples and slopes in the receiver i.f. passband. The final result is shown in Figure 9. There is a small residual DC offset of about -4% of the average system noise, which is consistent with a gain change of ~0.2 dB between the observations on AO-13 and on blank sky. The intention is to search for narrowband emission from AO-13, so this offset is unimportant. The raw data had been recorded while AO-13 should have been sending RTTY, so leakage radiation would appear as a pair of spikes in the spectrum, separated by the FSK shift of 170 Hz. No such signals are seen, with an upper limit (3 times the rms noise along the spectrum) equal to 12% of the system noise within any 8-Hz band. For this experiment the total system noise temperature was believed to be 140 K, and the antenna gain 14.5 dBd; these values were confirmed by careful observations of solar noise. The upper limit can then be calibrated in terms of erp from the satellite, which was at a range of 28,000 km. The corresponding limit for leakage radiation from

AO-13 is **less than 11 microwatts erp in any 8-Hz band**. For an RTTY transmission, power is on average split equally between the two FSK tones, and the modulation sidebands. Allowing for this, the maximum **total erp** from AO-13 is **less than 44 microwatts**. Several additional spectra similar to Figure 9 were produced, covering a total frequency span of $\pm$ 2 kHz from the expected beacon frequency, allowing for Doppler shift. No significant emission from AO-13 was found in any of these spectra, to the same upper limit of 11 microwatts erp in any 8-Hz band. There are always uncertainties and errors in measurements like this, but it is reasonably certain that the total 70-cm leakage radiation from AO-13 must be well below 100 microwatts erp.

The sensitivity to narrow-band radiation could be improved with longer averaging times, or if the receiver had been sufficiently stable by higher selectivity than the 8 Hz used here. The overall frequency stability of receivers and transmitters may limit the ultimate sensitivity attainable.

SUMMARY

This paper has shown the application of some DSP techniques to the recovery of very weak CW from Oscar 13, giving 100% copy of the ZRO level A test at 30 dB below the AO-13 beacon. The procedure can allow reception of signals very much weaker than the background noise level, and gives 10 dB or more advantage over the human ear. Although the example given is for CW, similar techniques are applicable to other modes of modulation. Finally, by averaging power spectra together, DSP algorithms have been used to set a limit of less than 44 microwatts erp for leakage radiation through the defective 436 MHz power amplifier from Oscar 13, at a range of 28,000 km. Longer averaging times, and if the receiver and transmitter are sufficiently stable, higher frequency resolution, could improve the sensitivity to narrow band signals even further.

All the analysis so far has been carried out off-line. A future project is to adapt the algorithms and software to real-time processing and display.

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DSP-93: The Joint DSP Program (TAPR/AMSAT)

Bob Stricklin, N5BRG

Greg Jones, WD5IVD

Have you ever given a child a Big Chief pad and a #2 pencil and watched while their creative juices flowed? With both time and patience, the child learns and develops new skills until he/she can draw objects and write prose on the pad. The pad and the pencil become tools which may be used for expression. There is about to be a new tool available which will allow you new avenues of creativity and expression. The new tool is called DSP-93. In most cases your knowledge will be limited, but with undoubting diligence you can learn to apply the tool and produce desirable results. DSP-93 is designed to provide radio amateurs most of the wonderful capabilities of Digital Signal Processing.

History

The history of DSP-93 can be traced back to 1990 when development began on the KISS DSP. The KISS DSP was a single board DSP engine designed around the Texas Instruments TMS320C25. The KISS DSP board, as described in an earlier AMSAT publication (1), included the DSP, memory, serial I/O, and a limited audio interface. The KISS DSP was designed as a stand alone box to interface between the computer and radio. In some cases a TNC was needed to process the HDLC digital data. To simplify the computer interface, a monitor routine (DSP BIOS) was developed which included functions to download DSP programs from a computer, view and change both program memory, data memory, and DSP registers. To make software development possible, work was undertaken with Thomas Anderson of Speech Technology in Issaquah, Washington to produce a TMS320C25 assembly table for his assembler. The result was an inexpensive assembler for the a TMS320C25 based DSP.

Several amateurs obtained and built the KISS DSP board and placed them in operation. Frank Perkins, WB5IPM, has developed DSP code for the following applications; 1200 Baud FSK, 1200 Baud PSK, SSTV, WEFAX, and APT. Frank has been using the KISS DSP board for satellite activity and development for over a year. The KISS DSP served as an excellent initial platform to develop and understand the realities of developing DSP software and hardware for amateur applications. We learned many things about applying DSP to amateur radio applications during the KISS DSP project. Areas which needed work were the radio interface circuitry and understanding how to match the hardware with the particular application at hand. A single do all DSP box is not a practical solution to all amateur DSP applications. It is not Only Software. It is a combination of selecting the best hardware for the particular application and developing the software around the selected hardware. Since most amateurs are looking for a cost effective solution, you can sacrifice some of the capability and provide them as separate additions.

DSP-93

Based on these lessons, DSP-93 has been designed in a modular fashion with multiple four-layer boards which include an interconnecting bus structure. The boards include a DSP engine board, a radio and computer interface board, a second high speed radio interface board, and a high speed network interface board. Any of these boards can be replaced with a future board designed for any number of unique applications. It's sort of like adding a new application card to a PC without redesigning the complete PC. The first board (DSP Engine) contains the TMS320C25 DSP, 64K by 16 bits of program and data memory, the clock circuitry and some programmable array logic (PALS) for system I/O. Refer to Figure 1 for the block diagram of this board. All the DSP IO lines are connected to the backplane bus. This was intended to make it easier to add additional features on additional DSP-93 boards. The floating input lines have 100K pull up resistors. The clock circuit for driving the DSP is also included on the DSP Engine board. Since slower EPROMs are used to boot the system, the clock is designed to shift between half the maximum clock rate and full speed. Clock shifts are software controlled and will be transparent to the application. The target clock speed is 40 MHz; however, we have demonstrated that 26 MHz is adequate for most amateur applications. Additional testing of the Beta boards will be required to establish the final clock rate.

Board two (Radio Interface Board) is illustrated in Figure 2 and Figure 3. This board contains two eight pin mini-DIN connectors for the radio interface. Incoming radio signals pass through a voltage divider to establish the initial levels, then through an eight channel multiplex chip. The multiplex chip will feed the single A/D input with either of the radio inputs or one of the six auxiliary inputs. Before reaching the A/D, the signal is conditioned by an OP-AMP whose gain is software selectable. Gain options include; 1X, 2X, 5X, 10X, 20X, 100X, 1000X and a comparator mode with ground being the reference voltage. Once again this is all software controlled and it should make for some nice adaptive signal conditioning algorithms.

The Texas Instruments TLC32047 Analog IO (AIO) chip is included on board two. This chip samples and updates at a rate of 25K operations per second and it includes aliasing filters. The chip communicates with the DSP using a 5 MHz serial interface. The 5 MHz interface is routed through a selection PAL to allow the user to disable this serial device in favor of another. It is anticipated that this AIO chip will be fast enough for most of the current amateur modes.

The D/A output of the AIO chip is routed through a buffer OPAMP and then a pot for selecting drive level. This output is fed to both radio connectors. A second audio amp and speaker connection is also supplied for speech and radio filter applications.

Board three (High Speed Radio Interface) is a second radio interface board with higher speed analog IO chips. This board is blocked out in Figure 4. In general, its functionality is just like board two, except board three contains the Burr Brown DSP101 Analog to Digital converter (used for input data) and the Burr Brown DSP201 Digital to Analog converter (used for output). The A/D chip is capable of 200K samples per second with eighteen bits of resolution and the D/A chip can attain 300K updates per second with eighteen bits accuracy. Neither of the Burr Brown chips includes a filter, so two EXAR XR1015 filters were included which are capable of operation at 200KHz. The clocking signals for all these chips are individually controlled and selectable through software. The clocking rates are used to establish the filter characteristics, the sampling rate for the A/D, and the update rate of the D/A. Clocking rates are established by loading an 8 bit divisor to apply to a 20MHz reference clock. Additional division can also be attained in PAL chips used for interface.

Board four (Network Interface) is intended to support higher speed modes like HRPT which require moving large amounts of data to the computer faster than a serial port can handle. Figure 5 is a block diagram of the network interface board. A National Semiconductor ST-NIC chip was selected for the task. The ST-NIC will be working in the eight bit mode. An 8K SRAM buffer is included for network packets. The DSP will be able to read and write to all the registers of the ST-NIC. This high speed data interface will be an advantage when dealing with video applications. The ability to utilize the card in a network environment will be limited. It is intended to work only at a netbios level with a very simple structured DSP protocol. A netbios interface will require dedicated software in the computer for communications. The success of the network board will depend on the available DSP cycles left over between A/D samples after all DSP tasks are completed. This will also be influenced by the final DSP clock speed. The answers to these questions will have to wait until more software and hardware development work is completed. It may be ultimately possible to use some of the networking capabilities of the ST-NIC to create a driver for a DSP modem. You may be able to extend your current PC network to the radio world. We may also use the packetizing capability of the ST-NIC. We probably have enough possibilities here to keep a lot of folks busy for a long time.

Current Development

At this point, 10 alpha boards were produced utilizing funding provided by The Joint DSP Program, co-funded by TAPR and AMSAT. Volunteers, most of which worked with the KISS DSP, have been identified to build the ten alpha boards and debug the design. When the time is right (Fall 93), beta kits will be produced and made available to testers. After these are assembled and the feedback is collected and evaluated, a larger production run will be made. If you would like to take part in the beta build, applications are being accepted. You may contact TAPR at 602-749-9479 to obtain one of the applications. A selection process will be used to insure we can get the best possible feedback and a fast turnaround on the beta build.

DSP-93 will eventually be supplied as a kit (date to be determined). The initial offering will only include boards one (DSP Engine) and two (Radio Interface). A low cost assembler will be made available for code development. To develop code for this board you must have good reference material. You can find numerous books on DSP algorithms and developing DSP code. A few of the books used for this project are listed in the references. The manufacturers data sheets and books for the complex chips will be good reference material. The hardware, software, and firmware details needed to write DSP code for the DSP-93 will be supplied with the kits.

For those not wanting to build a kit, there are several preassembled DSP units on the market today. Ads for these units can be found in various AMSAT publications. It is our hope that this project will expand the use of DSP in the amateur community and become a tool for education. We believe this project will cause the market for the existing commercial vendors to grow, with the final result being more hardware with more features available for amateurs.

Unlike the child mentioned at the beginning, you have the knowledge to begin with and you can direct your energy into a particular area. To make this project a bigger success, more people are needed who want to learn about developing DSP applications, networking, and converting from the real linear world to the digital world. Ideally, everyone taking the challenge will select a particular idea and become so focused in the application that they become the expert. Some of the areas for development might include: new modulation techniques, speech synthesis, filters, spectrum analyzers, and many more applications you will think of. If you choose to work on the hardware aspects of this project, the modular approach should allow you to convert to other DSP chips or Analog I/O chips or to add additional capability.

References:

1. Stricklin, R.,"KISS DSP", Proceedings of The AMSAT-NA eighth Space Symposium and Annual Meeting, Houston, Texas
2. Texas Instruments, TMS320C2X User's Guide, TI Book #SPRU014B, Customer responce 800-336-5236
3. Texas Instruments, Digital Signal Processing Applications with the TMS320 Family, TI Book #SPRA012A
4. Texas Instruments, Linear Circuits Data Conversion, DSP Analog Interface, and Video Interface, #SLYD004A
5. Hutchins B. and Parks T., A Digital Signal Processing Laboratory Using The TMS320C25, Prentice Hall ISBN 0-13-211723-1, Apx $22.00 - Includes Software
6. TAPR, Inc. PO Box 22888, Tuscon, Az., USA
7. AMSAT, Inc., 850 Sligo Ave., Suite 601, Silver Spring, Md. 20044, USA.

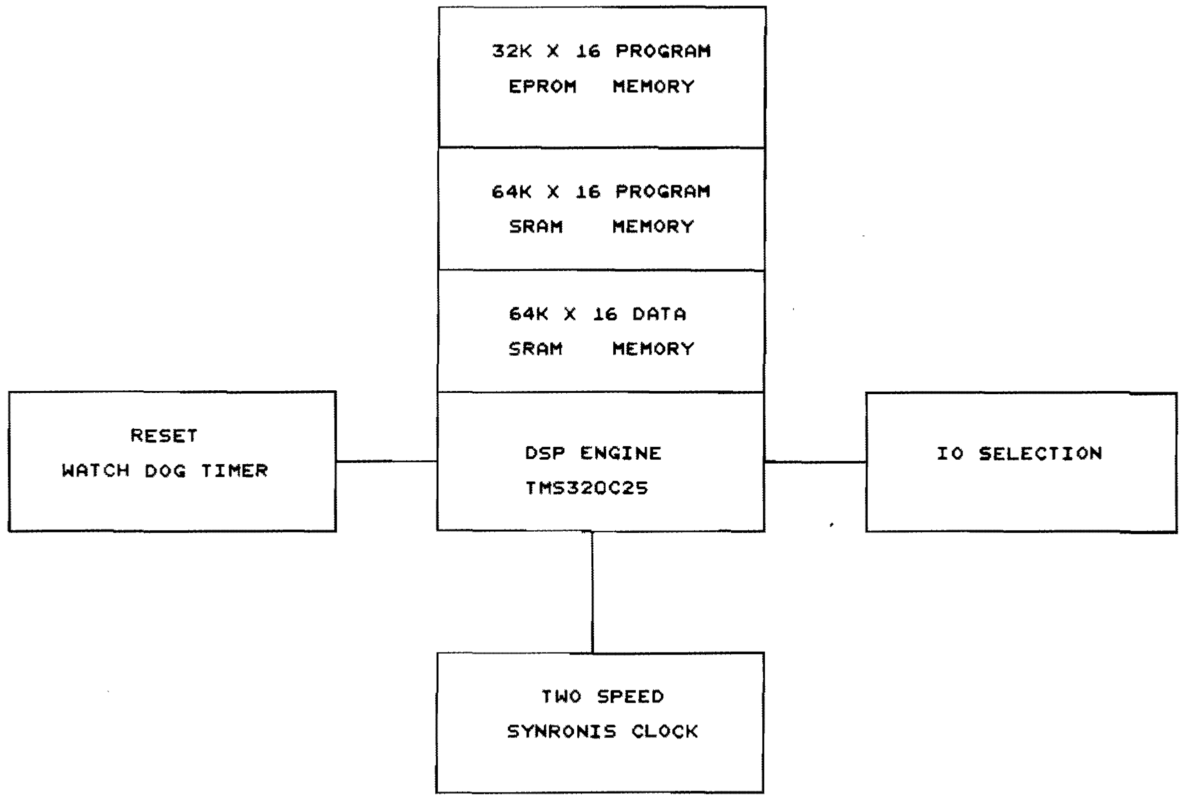

32K X 16 PROGRAM
EPROM MEMORY
64K X 16 PROGRAM
SRAM MEMORY
64K X 16 DATA
SRAM MEMORY
RESET
WATCH DOG TIMER
DSP ENGINE
TMS320C25
IO SELECTION
TWO SPEED
SYNRONIS CLOCK

FIGURE 1

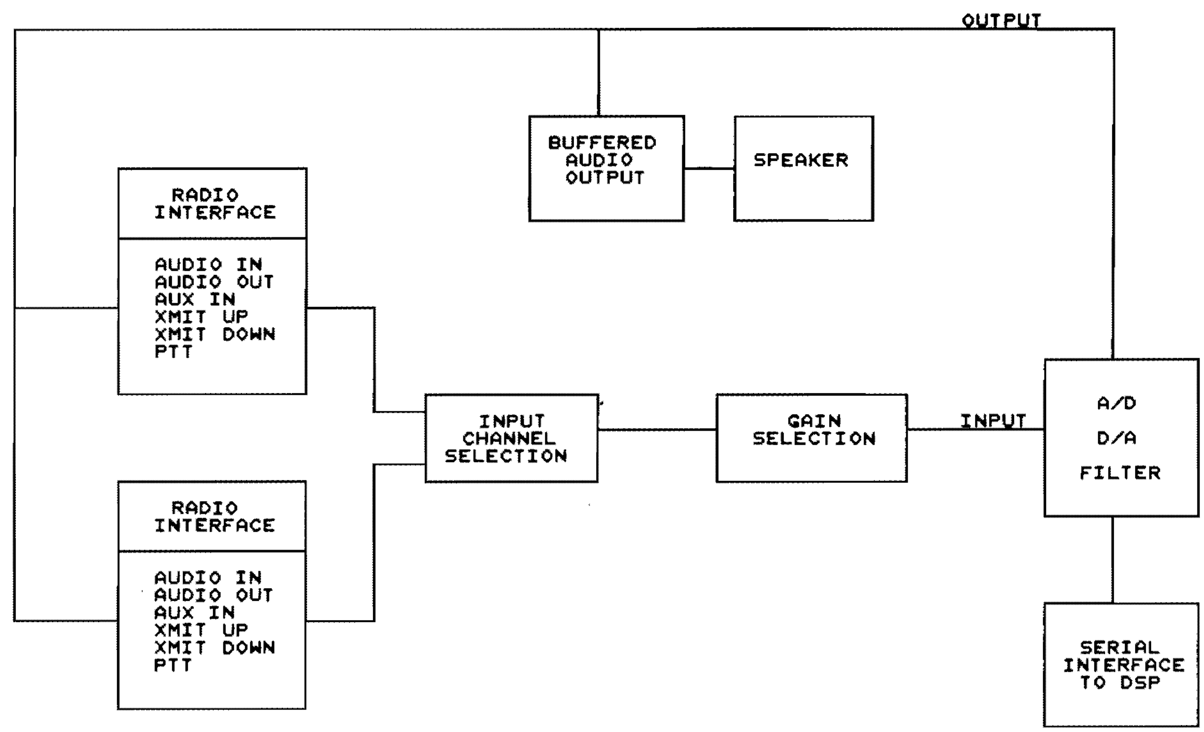

OUTPUT
BUFFERED AUDIO OUTPUT
SPEAKER
RADIO INTERFACE
AUDIO IN
AUDIO OUT
AUX IN
XMIT UP
XMIT DOWN
PTT
INPUT CHANNEL SELECTION
GAIN SELECTION
INPUT
A/D
D/A
FILTER
RADIO INTERFACE
AUDIO IN
AUDIO OUT
AUX IN
XMIT UP
XMIT DOWN
PTT
SERIAL INTERFACE TO DSP

FIGURE 2

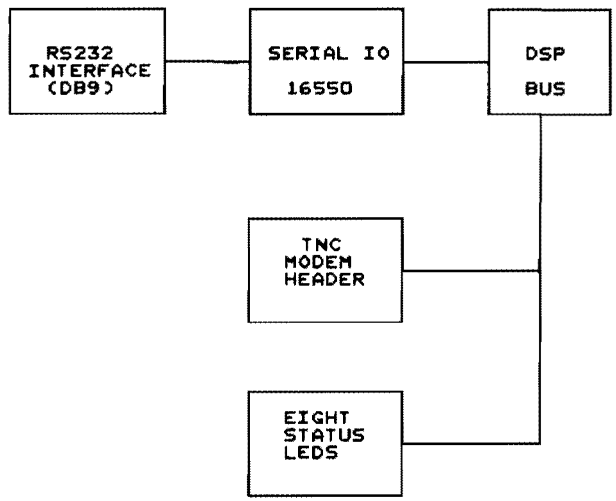

RS232
INTERFACE
(DB9)
SERIAL IO
16550
DSP
BUS
TNC
MODEM
HEADER
EIGHT
STATUS
LEDS

FIGURE 3

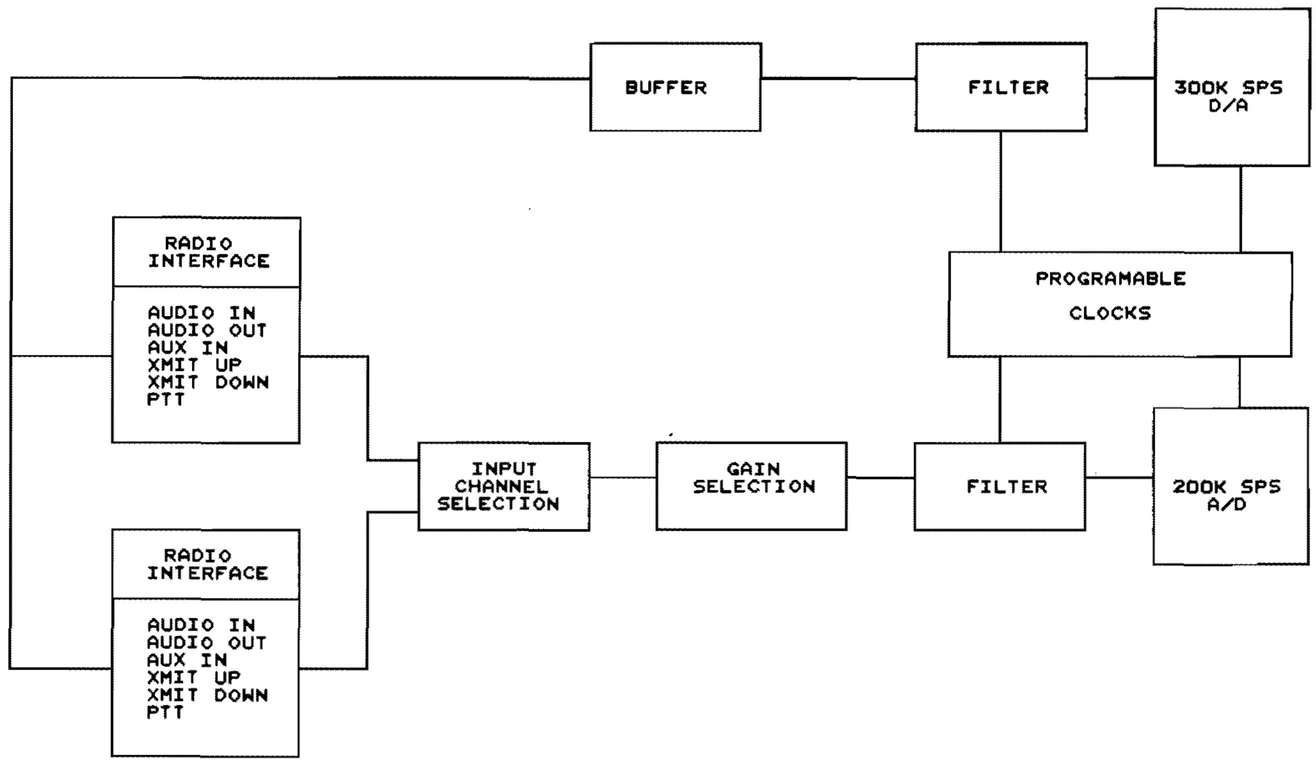

BUFFER
FILTER
300K SPS D/A
RADIO INTERFACE
AUDIO IN
AUDIO OUT
AUX IN
XMIT UP
XMIT DOWN
PTT
PROGRAMABLE CLOCKS
INPUT CHANNEL SELECTION
GAIN SELECTION
FILTER
200K SPS A/D
RADIO INTERFACE
AUDIO IN
AUDIO OUT
AUX IN
XMIT UP
XMIT DOWN
PTT

FIGURE 4

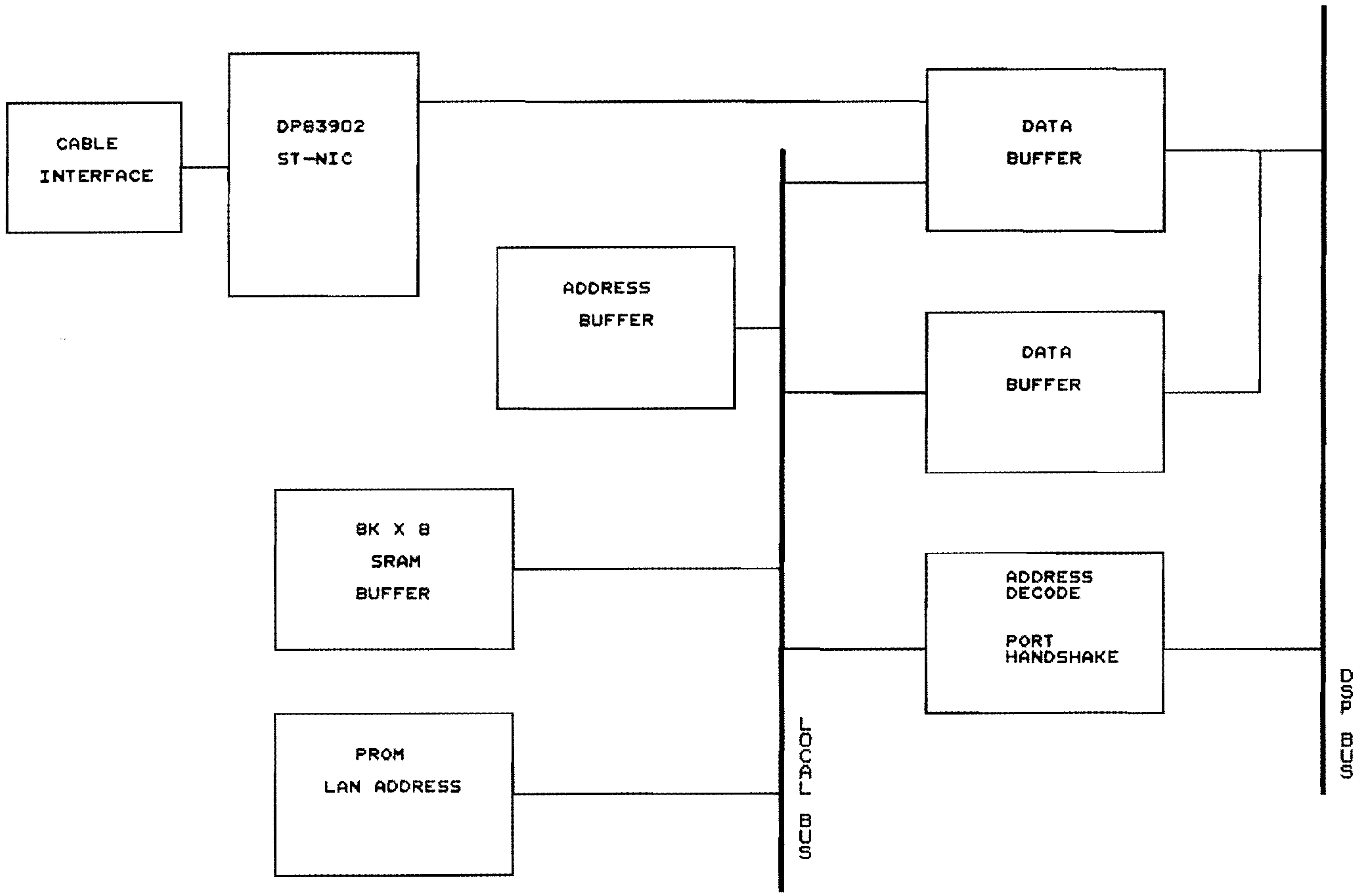

CABLE
INTERFACE
DP83902
ST-NIC
DATA
BUFFER
ADDRESS
BUFFER
DATA
BUFFER
8K X 8
SRAM
BUFFER
ADDRESS
DECODE
PORT
HANDSHAKE
PROM
LAN ADDRESS
LOCAL BUS
DSP BUS

FIGURE 5

Non-Messaging Uses of the Store-and-Forward Satellites
The Integrated Power Corporation Nusa Penida Project

Eric Rosenberg, WD3Q
Satellite Communications Specialist
Volunteers In Technical Assistance (VITA)
August 1993

To the amateur radio community, satellites are used for two purposes: communicating directly with other similarly equipped stations and to send messages and files from one point to another.

Through its involvement in the UoSat-3 satellite, VITA -- Volunteers In Technical Assistance -- has expanded the use of low-earth orbiting satellites to include services that do not require or otherwise involve human intervention. One of the more popular areas of use is the transmission of telemetry data from remotely located monitoring systems.

This paper describes the design and development of a ground station system to monitor and control the performance of small power generation systems in remote locations in eastern Indonesia.

Since the inception of the Digital Communications Experiment on the UoSAT-2 satellite, the discussion of store-and-forward communications using satellites has been based on the notion of users -- individually or in groups --- sending messages to each other.

With UoSAT-2, the intent was that gateway stations strategically located around the world would, using manually operated equipment, service messages between distant locations using amateur radio frequencies. This project, begun in 1984 and continuing up through the commissioning of Uosat-3 in early 1990, proved that passing groups of messages via satellite was more than a passing or theoretical notion. Messages were passed between gateway stations in the UK, South Africa, Oceania (Australia and New Zealand), and to a lesser degree, the United States. Additionally, groups as diverse as Greenpeace (at their Antarctic outpost) and VITA (in suburban Washington, DC) used the system as a test-bed for the further development of a non-commercial means of communication for non-government and private voluntary organizations worldwide.

The subsequent launches and operation of UoSAT-3, -5, Kitsat-A, and the AMSAT-Microsats have further refined the use of store-and-forward satellites for passing traffic between individual ground stations and/or gateway stations worldwide.

VITA'S INVOLVEMENT

VITA's interest, since the beginning of it's involvement in packet radio and the Digital Communications Experiment in 1984, has been to enhance the communications capabilities of non-government development organizations and agencies worldwide. VITA's initial interest was to facilitate our own communications between the home office in Arlington, Virginia (suburban Washington, DC) and our field projects in Africa and Central America.

Since the initial success of the DCE (the results of which we see today in the development of and difficulties with gateway stations), we have seen a dramatic increase in both the need and growth of the messaging service provided by store-and-forward satellites among development agencies.

In early 1992, we were approached by Integrated Power Corporation, a subsidiary of Westinghouse Corporation, who was looking for an affordable means to both collect telemetry and remotely command two power generation stations in eastern Indonesia.

From the outset, the design criteria were quite simple and straightforward:

> the communications equipment must be capable of operating without any human intervention, and
>
> the communications equipment would be responsible for controlling the interaction with the power generator's controller to receive its telemetry and to send commands generated by the engineering stations in Jakarta and in Rockville, Maryland (outside Washington, DC).

As the power generator project was a cooperative venture between IPC and the Indonesian government (the partners being BPPT, the Indonesian Directorate for Technology Development who would be evaluating the system, and PLN, the Indonesian power company, who would be operating the power generator systems), IPC attempted to secure the service from an Indonesian provider. IPC was able to identify only one Indonesian provider, IndoSAT, operators of the Palapa satellite, and the Indonesian signatory to the Intelsat agreement, who offered real-time, 2-way communications capabilities using the Palapa satellite for approximately US$5000 per month.

It was at that point that IPC chose to explore other options. The communications project would be funded by the United States Agency for International Development (USAID) through the Export Council for Renewal Energy (ECRE).

In agreeing to take on this project, VITA would have the opportunity to provide a service that we had not previously considered viable for low-earth-orbiting satellites.

Additionally, it would force us to take a new look the design of our ground station from top to bottom, computer and RF equipment, with an eye to both future installations and in particular, this installation, where reliability in a high temperature, high humidity environment would be crucial. Some of the elements could and eventually would be changed, while others would remain the same.

DESIGNING A NEW TYPE OF GROUND STATION

Our first task was an evaluation of our existing ground station equipment in terms of this project. After meeting with IPC's programmer and Manager of Research and Development, we (myself and Mark Oppenheim, VITA's packet radio specialist), determined that the existing VITASAT ground station, using a desktop computer with software specific to that platform, would not be appropriate for this project. The existing VITA software, initially developed at the Virginia Polytechnic Institute and subsequently by David Carre, required a high degree of operator intervention, and considering that the power generator stations did not offer much physical space for the equipment and would be unmanned, it became obvious to us that a different approach would be necessary.

To that end, we drew a schematic diagram of what we considered to be the minimum requirements for an unattended VITASAT station. The intent was that this station platform could be transferrable between VITA's satellite installations and future packet radio stations that would (or would not) include terrestrial packet radio services. Regardless of the applications, the ground station would perform all of the mundane housekeeping functions automatically, leaving the operator with only the necessity to compose messages for sending or read messages received. The approach they chose was to use an embedded processor -- a computer on a card -- as the engine for the ground station.

Because of the time problems we encountered with this project, few hardware changes were made. At all three sites, we used the same Kenwood TS-790A transceivers and PacComm TNC's that VITA had been using for all it's other stations. At the field sites we had M2 Enterprises design and fabricate small yagis for the uplink and downlink that would use a common boom while providing an adequate amount of gain for accessing the satellite. The antenna gain figures were determined by factoring the amount of telemetry data that would be sent from each FSC, received by each FSC from the engineering station in Jakarta with the number of passes each day and the length of each pass window. The antennas provide approximately 6 db gain with a 70° beamwidth at the unmanned sites, where presumably terrestrial RF interference would not be a problem for either the downlink or uplink signals. It was our feeling that with the limited number of passes available at the sites each day, the FSC could successfully send upwards to 20 kilobytes of data in addition to receiving 1 kilobyte of commands. At the engineering site in Jakarta, where terrestrial interference posed significant problems, we used steerable yagis (also manufactured by M2 Enterprises) in addition to dual bandpass cavities on the downlink and a high-power amplifier for the uplink. To control the positioning of the antennas we chose the SM0TER/JAMSAT Trakbox, which was supplied by Bruce Lockhart, SM0TER. While the Trakbox is capable of controlling the radio, compatibility with all the sites was considered extremely important, so we chose to have the embedded controller perform that task. Figures 1 and 2 describe the different ground stations.

As per the space requirements dictated by IPC, we mounted all the equipment in standard 48" equipment racks. IPC undertook the task of mounting, packaging and shipping all the equipment.

Once our requirements for the controller were determined, we contracted with Harold Price of BekTek to determine the appropriate device and configuration for the "VITASAT Controller". Harold's research came up with a single-board computer designed and manufactured by Kila Systems of Boulder, Colorado. The Kila processor is a 3/4-size card running an NEC V53 CPU at 12 or 16 MHz. The standard card draws approximately 600 ma at 5 volts DC, and comes with four serial ports and a video port. It runs as a PC, so the PC/MS-DOS environment and all the software written for that environment (including VITA's own VGS ground station software) could be ported with little difficulty. This board was exactly what we needed both for this project and for future projects, where we could mount it on a passive backplane with related peripherals (e.g., Kansas City Tracker card, Clover or TNC cards, hardcards, etc.).

Once configured, the controller would, at local midnight, poll the power generator's controller (or two controllers, as in the case of the Tanglad site) and dump the data collected for the previous 24 hour period. After receiving that data, it would compress it and add the appropriate Pacsat file header. The controller would then scan the upper and lower edges of the satellite's bandpass, listening for the beacon. Upon hearing the beacon and time signal (which, we were assured by the SSTL ground control staff could be kept accurate to within 5 seconds), the controller would then run a tracking program and reset the radio to the correct frequency. It would also listen for the keplerian elements sent by the satellite, and insert them into the program. At that point the controller would listen for the OPEN flag and begin transacting with the satellite.

After successfully transacting with the satellite, the process would be reversed -- the controller would strip the Pacsat file header off the file, uncompress it and send the data (commands) back to the power generator controller.

At the Engineering station in Jakarta, a similar process would be followed, except that there would be steerable antennas and a Trakbox. In this instance, the Trakbox would be fed the time and keplerians from the satellite, and park the antennas in the proper direction in anticipation of the next pass. The host computer, running IPC's telemetry program R-Access, would poll the VITASAT controller and import the received data to allow the operators to view and interpret it. If necessary, they could generate and send back commands to the field sites.

Because Indonesia is near the equator and sees UoSAT-3 only four times each day, the pass number and window size limitations would add another requirement to this project. Instead of using the Pacsat Broadcast Protocol to receive messages, we would be required to use the FTL0 (connected mode) protocol at both the FSC and ESC stations. This would be done to maximize the amount of time available to the ground stations for passing date. The data and commands uploaded by the FSC's and ESC respectively, would have unique file types assigned to them, which would be used in the creating the select equation.

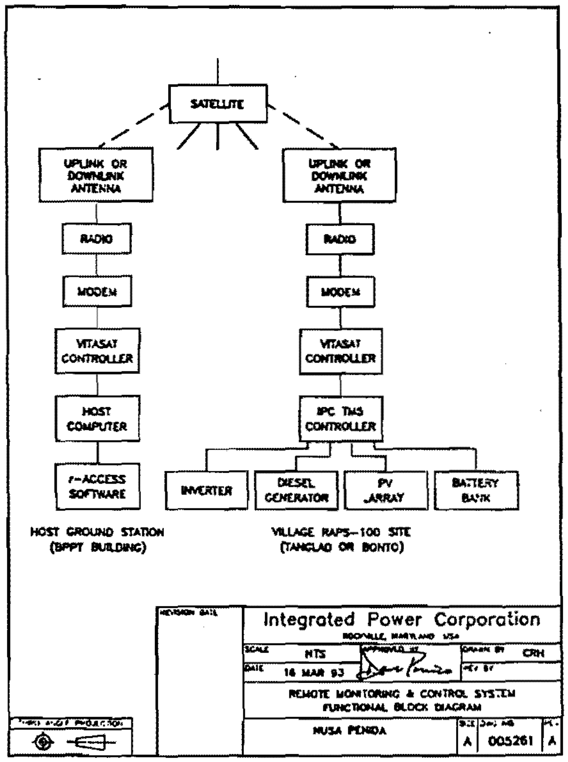
The commissioning dates began to slip from mid to late 1992 to the early 1993. Once the date had been determined by IPC, it was agreed that VITA would install the equipment while IPC personnel were at the sites finishing up their work. After 9 months of talking about this project, we now had ten weeks to turn it into reality.

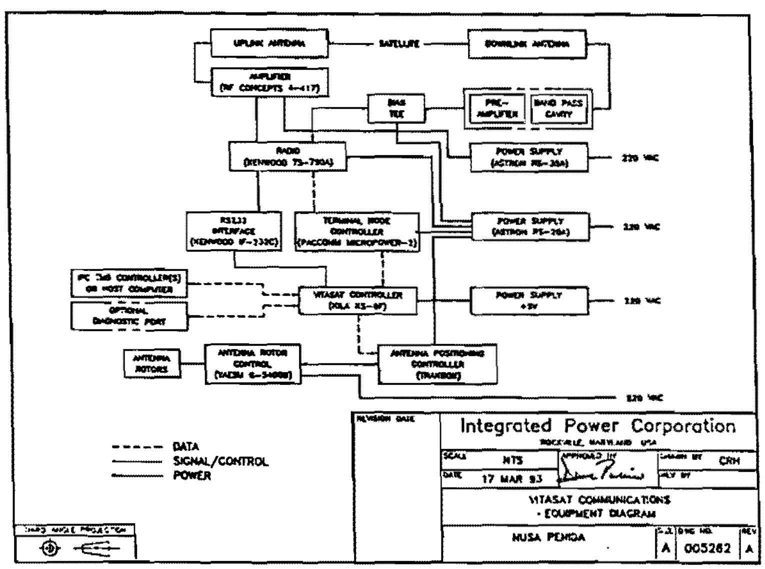
The first hurdle was to get an operating license for Bektek from the Federal Communications Commission. The process of getting an experimental license (as UoSAT-3 operates on experimental frequencies, all users in the USA -- VITA, SatelLife, Interferometrics and the Woods Hole Oceanographic Institution -- must apply for fixed term experimental licenses) is long and drawn out, usually taking many months. Thanks to the able work of our lawyers, the process took only two weeks. Next was to get the controller, hardware, and VITA software to Harold to begin work. It was our hope that Harold would be able to port part or all of the VITA-developed VGS software to the embedded controller. As it turned out, it was more cost and time effective not to use the VITA software. While Harold was working on the software, I was working at IPC fabricating the three units.

Working long hours and on short deadlines, all of the software, controller configuration, documentation, debugging and testing was completed on schedule and on budget. The fabrication work and hardware integration was completed and shipped by IPC in early March.

For all the work that was completed on short deadlines, my arrival in Indonesia was fraught with problems which precluded my installing the equipment. A second trip took place in June 1993. During this trip all of the equipment was extricated from customs, trucked to the three locations, and successfully installed. The installation of the equipment in the field was not without its difficulties. At both sites, none of the power drops were grounded, which caused difficulties with the AC operated equipment (burned up surge suppressors and power supplies). A not-insignificant time was spent overcoming these equipment problems. As a test, we erased the keplerian elements and incorrectly set the clock in embedded controller. As we watched, the radio acquired the satellite signal, reset its clock and captured the keplerian elements. The controller then ran the tracking software and connected to the satellite. Everything worked as designed.

A third trip to Indonesia is being planned for mid-October to complete both the power generator system and communications portions of the project.





MODE A SATELLITES IN IONOSPHERIC PROPAGATION RESEARCH

HANS VAN DE GROENENDAAL, ZS6AKV
PRESIDENT - SA AMSAT

SYNOPSIS

Propagation is an interesting field of study which has been sadly neglected by Radio Amateurs and Short-wave Listeners. With the advent of satellites, answers to many new questions have to be found! What happens to signals that hit the ionosphere from above? This paper looks at some of the work done and proposes an all out effort for Radio Amateurs to carry out some serious research.

INTRODUCTION

With the development of an Educational Broadcast Transponder for Phase 3D, the question of the influence of the ionosphere on 29 MHz downlink signals became an area of concern, and is now an interesting new field of study.

A search of the literature produced very little in the form of research findings. One of the pioneers in this field is Pat Gowan, G3IOR, who published results of some of his work in the this field.

The effects of the ionosphere on 29 MHz signals transmitted from below are well documented. The first references about propagation anomalies on 29 MHz signals transmitted by satellite from above the ionosphere came from an article published by the late Barry Guthrie who made a study of the mode A downlink of OSCAR 8. He reported receiving signals before the satellite crossed the horizon and after predicted LOS. It is a pity that his research was not recorded in more detail as it would have made useful reference material.

HF SATELLITE RECEPTION

At HF frequencies, the ionosphere is only marginally transparent. At night the signals will normally penetrate through the ionosphere with out much difficulty, particularly when a satellite is nearly overhead and the signals penetrate the ionosphere at a steep angle. Signals entering the ionosphere at a low angle may be refracted back into space.

During 3 to 4 hours around sunrise and sunset, more difficulties may be experienced. The satellite sees a ground station first through a thin, night time ionosphere and then, as the pass progresses, through a dense daytime ionosphere. During the period that the signals travel through the thin ionosphere, good signals are received. As the satellite passes overhead and the ionosphere changes to a dense day time layer, the signal are refracted and disappear into space. The lower the frequency, the more severe the problems. This phenomenon was first noted on signals from Sputnik 1 on 15 MHz.

SOLAR CYCLE VARIATIONS

There are also effects from the variations during sunspot minimum and sunspot maximum. In March 1987 when the flux was measured at 71 and the critical frequency was 5.7 MHz and the MUF approximately 17.1 MHz, horizon-to-horizon reception of RS-5 signals on 29.450 MHz was recorded. With the flux measured at 241 (March 82) and the critical frequency 14 MHz, the 29 MHz satellite signal hardly penetrated the ionosphere. No wonder as the MUF was in the region of 42 MHz.

MULTI-PATH FADING

Two other problems which can plague the HF satellite user are Multi-path fading and Faraday rotation of polarization. These will not be discussed in this paper.

WHY RESEARCH?

Amateur radio is a hobby for self-education. What better way of finding out first hand and sharing the findings with others, which may encourage more original research work being carried out.

RS-10 THE IDEAL RESEARCH TOOL

The beacon signal from RS-10 provides the ideal research tool. The satellite beacon operates on 29.357 MHz. RS-10 will soon be joined by another RS satellite also operating on mode A. This ensures continuity.

To do basic propagation research, only simple 29 MHz receiving equipment and antenna is needed, but lots of listening and accurate recording. A satellite tracking program is needed to accurately record the pass times. InstantTrack is today, by far, the most popular software package (1). As RS-10 is a low earth satellite, it will be necessary to frequently update the keplerian elements on InstantTrack. These elements are available on Beltel (2) or on packet radio bulletin boards.

BASIC OPERATION OF THE RESEARCH PROJECT

On a weekly basis, update the satellite tracking program and compute the passes of RS-10 for the week. Start monitoring the beacon frequency up to 5 minutes ahead of the predicted AOS (Acquisition of Signal) and record the time at which the first signal is heard. Allow for doppler shift. InstantTrack will calculate the doppler shift so that you can calculate frequency on which the beacon signal should first appear. Read the S-meter every 2 minutes and record in a data book. Also record any other anomalies. Observe at various times and pay particular attention to morning passes over the weekends.

Record the flux number available from WWV or the SARL Sunday bulletin in your data book. Continue to monitor and record until LOS (Loss of signal). During the entire operation, adjust the frequency. This is best done by keeping the CW signal at a constant pitch.

TIME COORDINATION

Set your clock weekly to WWV or any other accurate time signal. If your clock drifts more than 10 seconds a week, reset it more frequently.

REVIEW AND REPORT

Review and note any unusual variations. Get your friends involved in the project and start comparing notes. This is a long term project that should stretch over several years, ideally over an eleven year cycle. A real challenge!

SA AMSAT

SA AMSAT would welcome copies of regular observations and encourages you to register as a contributor to the research project. Reports will be combined and results published in Satellite Update. Copies of the report will also be supplied to the contributor.

(1) Instant Track is available from SA AMSAT if you life on the African continents, in all other areas contact AMSAT-NA.

(2) Beltel page 3315 (In South Africa only).

CONCLUSION

This is an ideal project for a local club or group. The more participants, the lower the load and the higher the number of observations. The project is long term and should ideally carry on till the next solar maxima. The author welcomes comments and suggestions and would like to hear from any person interested in the project.

<u>REFERENCES</u>:

Space Radio Handbook, John Branegan GM4IHJ published by RSGB

Personal communications with the Late Barry Guthrie (1978-1981)

Personal notes from Pat Gowan G3IOR

Experimental Determination of Properties of the RS-10 Mode A Transponder

Walter K. Daniel KE3HP
PO Box 1686
Bowie, MD 20717
Internet: ke3hp@amsat.org

Users of the RS-10 Mode A transponder have found that uplink frequencies during contacts were about 5 kHz higher than expected. Experiments demonstrated that the translation constant of the transponder was -116.5048 MHz, 4.8 kHz different from published values. An uplink frequency lookup table using this empirically-derived constant as well as typical Doppler shift values was developed and tested for use as an operating aid. Other experiments determined that the lower limit of the passband extended more than 15 kHz below the published value of 29.360 MHz.

INTRODUCTION

While Mode A may not be on the cutting edge of amateur satellite technology, RS-10 still provides valuable transponder service worldwide. The ground station equipment needed is modest and indoor antennas can be used (Reference 1).

Numerous users of RS-10 have noticed that uplink frequencies were approximately 5 kHz higher than calculations based on widely-distributed data had indicated. This discrepancy prompted the investigations described in this paper to determine properties of the Mode A transponder.

TRANSLATION CONSTANT EXPERIMENTS

The frequency plan for RS-10 Mode A operations is listed in Table 1 (Reference 2). The table indicates that for a downlink frequency is 29.380 MHz, the uplink frequency when the Doppler shift is zero should be 145.880 MHz and so on. Standard practice is for the user to hold the 10-meter downlink frequency constant and compensate for Doppler shift using 2-meter uplink frequency. This procedure minimizes the magnitude of the Doppler shift at the transponder.

Table 1. RS-10 Mode A Frequency Plan

	29.357	Beacon
145.860	29.360	Passband lower limit
	* CW *	
145.880	29.380	Passband center
	* USB*	
145.900	29.400	Passband upper limit
	29.403	Beacon

The RS-10 Mode A transponder is non-inverting, so the equation for determining uplink frequency is

uplink = - translation constant + downlink - Doppler

using the convention that Doppler shift is positive during approach and negative during departure. The translation constant for this transponder is -116.500 MHz (Reference 3). Doppler shift values can be calculated using satellite tracking programs such as OrbiTrack. A series of experiments was conducted to determine the translation constant empirically. The downlink frequency was kept fixed, the uplink frequency was adjusted throughout a satellite pass, and this frequency was recorded at 30 second intervals.

Table 2 lists the results of one experiment with 29.3980 Mhz as the downlink frequency. This RS-10 pass over North America took place on 15 August 1993 at approximately 1900 UTC. The elevation and Doppler shift columns in the table were calculated using OrbiTrack while the uplink frequency column contains recorded data. The translation constant column was calculated using a spreadsheet program. The average value of the constant for this pass was -116.50497 MHz. Similar experiments conducted from March 1993 through August 1993 have shown that the translation constant is approximately -116.5048 MHz. It is not apparent whether the quoted value of -116.500 MHz represents a number rounded to the nearest 0.1 MHz or if transponder circuit components have changed since launch.

Table 2. Translation Constant Data for 29.3980 MHz Downlink

15 August 1993, approximately 1900 UTC

ELEV deg	UPLINK MHz	DOPPLER MHz	TRANSL CONST MHz
27.0	145.89990	0.0032	-116.50510
31.6	145.90000	0.0031	-116.50510
37.1	145.90015	0.0028	-116.50495
43.5	145.90045	0.0025	-116.50495
50.8	145.90080	0.0021	-116.50490
59.0	145.90135	0.0016	-116.50495
67.3	145.90200	0.0010	-116.50500
72.8	145.90270	0.0002	-116.50490
71.3	145.90350	-0.0005	-116.50500
64.2	145.90420	-0.0013	-116.50490
55.8	145.90480	-0.0018	-116.50500
47.8	145.90520	-0.0023	-116.50490
40.9	145.90555	-0.0027	-116.50485
34.9	145.90595	-0.0029	-116.50505
29.8	145.90610	-0.0031	-116.50500
25.4	145.90625	-0.0033	-116.50495

UPLINK FREQUENCY OPERATING AID

The amount of Doppler shift for which RS-10 Mode A users must compensate is an operational challenge. For illustration, examine tracking information for a typical RS-10 pass (see Table 3). One of the parameters in the computer program used to create Table 3 was that the transponder is not considered usable until the satellite is 10 degrees above the horizon in order to account for trees, buildings, and other antenna obstructions. At the beginning of the pass, the Doppler shift is 3.3 kHz, greater than the bandwidth of a single-sideband signal.

Table 3. Satellite Tracking Information for Typical Pass

RS-10/11

DOW	Time EDT MM/DD/YY	HH:MM:SS	Az Deg	El Deg	Range km	Doppler Hz	
Fri	08/20/93	04:12:19	337.3	11.1	2665	3345	Rise
Fri	08/20/93	04:17:55	270.2	40.6	1400	-27	Max
Fri	08/20/93	04:23:31	204.0	10.7	2680	-3341	Set

The uplink frequency equation with Doppler shift is too complicated for real-time calculations. An alternative is to construct a lookup table (see Table 4). The conditions chosen for this table include a ground station horizon of 10 degrees and a peak satellite elevation of 40 degrees; the Doppler shift at the beginning of the pass is approximately 3.3 kHz or 0.0033 MHz. The experimentally-determined translation constant of -116.5048 MHz was used to generate table entries. Uplink frequencies were calculated at AOS (Acquisition of Signal) when Doppler shift is +3.3 kHz and at TCA (Time of Closest Approach) when Doppler shift is zero.

To use Table 4, select an RS-10 Mode A downlink frequency. As the satellite rises above the horizon, the uplink frequency for the chosen downlink will be within 1 kHz of the corresponding value in the AOS column. During the maximum elevation of the pass, the uplink frequency will be close to the value shown in the TCA column. For example, assume that a user wishes to have a voice QSO with a downlink frequency of 29.390 MHz. The uplink frequency at the beginning of the pass would be near 145.8915 MHz. After a QSO, the user wishes to move to a downlink frequency of 29.398 MHz. The satellite is at peak elevation, so the uplink frequency will be near 145.9028 MHz. In testing, several users have found this lookup table approach to be fast and accurate.

Table 4. RS-10 Uplink Frequency Operating Aid

RS-10 Uplink Frequency Table

DWNLNK	------UPLINK------		
	AOS	TCA	
29.362	145.8635	145.8668	CW
29.364	145.8655	145.8688	
29.366	145.8675	145.8708	
29.368	145.8695	145.8728	
29.370	145.8715	145.8748	
29.372	145.8735	145.8768	
29.374	145.8755	145.8788	
29.376	145.8775	145.8808	
29.378	145.8795	145.8828	CW
29.380	145.8815	145.8848	-----
29.382	145.8835	145.8868	USB
29.384	145.8855	145.8888	
29.386	145.8875	145.8908	
29.388	145.8895	145.8928	
29.390	145.8915	145.8948	
29.392	145.8935	145.8968	
29.394	145.8955	145.8988	
29.396	145.8975	145.9008	
29.398	145.8995	145.9028	USB

SPECIAL CHANNEL

In AMSAT News Service Bulletin 135.05 dated 15 May 1993, RK3KPK, "...the ground controller for all of the RS satellites," is quoted as having invited "...all to use RS-10's special channel with its uplink frequency of 145.850 MHz and a downlink frequency of 29.350 MHz." Previously, various sources listed the lower end of the passband as 29.360 MHz, 10 kHz above the frequency given in the bulletin.

Experiments in May and August 1993 showed that the RS-10 Mode A transponder did function below the 29.357 MHz beacon. While 29.355-29.359 MHz downlinks are not usable on USB due to the strong CW beacon, the transponder relays signals down to 29.345 MHz. Signals drop in strength below 29.345 MHz. A test similar to the one detailed in Table 1 proved that the Doppler shift corresponded to RS-10 and the translation constant was approximately -116.505 MHz. Tests of the transponder at frequencies above the upper limit of the passband revealed that signal strength fell so rapidly with increasing frequency that 29.400 MHz is the practical upper limit of the transponder.

In practice, the "special channel" downlink frequency of 29.350 MHz corresponds to an uplink frequency of 145.8548 MHz with no Doppler shift (i.e., TCA). The AOS uplink frequency using the same typical pass parameters incorporated into Table 4 would be 145.8515 MHz. While few users know of this portion of the transponder, some contacts do take place at these frequencies. During one of the tests of the 29.350 MHz downlink, XE1KK from Mexico initiated a QSO with KE3HP in Maryland.

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AMSAT-NA OPERATIONS REPORT
1993

by

Keith D. Pugh, W5IU
Vice President of Operations, AMSAT-NA

Another successful year "on the Birds" has come and gone. For the most part, operations have been routine; however, we have one new "Bird" to account for and one major operational change on our "DX Bird," AO-13. This report will document these changes as well as report on the normal operations throughout the year and the people who are responsible for the continued success of our satellites, nets, and other operations.

SATELLITE OPERATIONS

With the addition of ARSENE, the Amateur Radio Satellite count is up to fifteen this year. By the time this paper is presented, the count should be up to nineteen with the launch of KITSAT-B, PoSAT, EYESAT, and ITAMSAT. I will attempt to summarize the activity on each category of satellites. Where applicable, I will describe our control activity or our input to that activity.

High Altitude - AO-13, AO-10, & ARSENE

AO-13 continues to be our premier DX "Bird." The list of operators achieving DXCC through AO-13 is growing by leaps and bounds. More DX-Peditions are discovering it all the time. In spite of this being a bad year for the Sun on AO-13, our command team - G3RUH, VK5AGR, & DB2OS - have done an outstanding job of keeping our "DX Bird" operational. Operation during Field Day was good, but for a very short period this year due to the poor Sun Angles.

Regrettably, at approximately mid-year, we lost the 70 cm transmitter on the "Bird" making modes J and L useless. Fortunately, prior to this setback, G3RUH, KA9LNV, and others started blowing away the Myths about how difficult it would be to operate on mode S. Several articles were published by these folks "priming the pump" for increased mode S operation by the time the 70 cm downlink failed. By the time this paper was written, W4FJ's mode S list had grown from a few lines to several pages. Many thanks to K0RZ, N6CA, and others for having the foresight and persistence to develop the S-band downlink and get it included on AO-13 despite many obstacles. Through the efforts of all of these folks, we are being treated to a preview of the "mode of the future."

Our old standby, AO-10, has been with us an even decade now and is still operational, but under-utilized. Although "brain dead" for approximately five years, the power generation and RF systems continue to work fine as long as the "Bird" gets plenty of Sun. Occasionally, it requires a Reset to get it's attention, but so far the command team is still able to exercise at least that much control. Who knows, AO-10 may still be around to greet Phase 3D.

The latest addition to the high altitude "Stable" is ARSENE. This long awaited French "Bird" was launched in mid-year. It's primary two meter down link failed very shortly after separation from the booster and it was "touch and go" for the first days of it's life. Through the efforts of a dedicated French command team led by F6BVP, the S band downlink was commanded on, orientation was confirmed, and a successful "kick motor" firing was accomplished to bring perigee up to the design altitude from the dangerously low perigee it was left in by the booster. Since achieving it's final orbit, investigations have been performed in an attempt to determine the nature of the two meter downlink failure. So far these investigations have borne no fruit. The S band downlink continues to be successful; although, much weaker than AO-13's. As time goes on, more stations are trying ARSENE mode S and learning of the optimum times to use it. Who knows, someone may still discover the secret of it's two meter downlink.

Low Altitude Digital - AO-16, DO-17, WO-18, LO-19, UO-22, KO-23, and UO-11

Operation of all of these "Digital Birds" continues to be very successful with the exception of Dove, DO-17. Dove has remained on S band downlink all year with the exception of a brief test conducted by WD0E, K0RZ, and N5AHD. This brief test proved that the "Bird" is still basically healthy and awaiting attention. WD0E and N5AHD have been putting forth much effort toward fulfilling Dove's mission whenever it can be reloaded and restored to two meter operation. There appears to be a "light at the end of the tunnel," but we need to get a bit closer to confirm it. Read WD0E's paper on the Dove story!

After a long study period, the PACSAT Command Team - WB9ANQ, WD0E, KB5MU, and NK6K - succeeded in making several modifications to the PACSAT control software which led to an optimization of the PACSAT power budget and other parameters. After this down period, the latest Broadcast Protocol (PB & PG versions) were uploaded and operation has again proceeded uninterrupted for a long period following this change. LO-19 was left using the old PB and PG versions during this down period on PACSAT. The Argentine Command Team for LO-19 is in the process of making these changes to LO-19. When completed, all of the PACSAT based "Birds" will be again using the same protocol.

WEBERSAT, WO-18, was down for a period during the past year also. Following it's downtime, it has been modernized with new software and new experimentation. It's popular picture taking activity continues and a new version of WEBERWARE permits re-construction of better-than-ever pictures. With the addition of more software and control activity, an experiment routine has been established allowing data collection from several of the other experiments that were originally placed on board WEBERSAT. Interest in these other experiments is growing.

The 9600 baud FSK "Birds," UO-22 and KO-23, are still the fastest growing "Digital Birds." Last year's Gateway controversy has subsided to some degree with the addition of KO-23 and additional operation maturity. Picture taking continues and it is easy to fill up your hard drive if you have an automated station for these "Birds." As hardware and software matures, many more stations are becoming fully automated for use of these "Birds." Look for more high speed activity as the next generation of "Digital Birds" is launched in September 1993.

The original "Digital Bird," UO-11, celebrated it's ninth birthday this year and continues to operate flawlessly. It's Digital Communications Experiment, DCE, pioneered the store-and-forward concept that is so popular today on other "Digital Birds." It has suffered somewhat from inattention in the past year, but that situation is improving now that the University of Surrey has a full time command team.

Low Altitude Analog - RS-10/11 and RS-12/13

Popularity of these two entry level "Easy Birds" continues to be high. Mode A has been active on RS-10 throughout the year while mode K has been in operation on RS-12. With the decline in the Sunspot Cycle, the 10 meter downlinks for these "Birds" are improving.

RS-10 has been used on several occasions this year in conjunction with AO-21 for satellite Dual-Hop experiments. Around Christmas time, a new feature was added to RS-10 - text messages. The first such message was Christmas Greetings to the World from the RS Command Team. A nice gesture from our AMSAT-U brothers.

More Amateurs are discovering satellites every day through the totally HF mode K on RS-12. Several of my personal friends have taken the "Satellite Plunge" this year through the mode K transponder. More Over-the-Horizon Satellite Contacts are being made every day; particularly, when the "Bird" is in the vicinity of UA0 and KL7. Low Doppler on this mode makes modern HF rigs, which will work a band split, popular on this mode.

Low Altitude Mixed - FO-20 and AO-21 (RS-14)

Fuji, FO-20, has performed well throughout the year. It is listed here as a mixed mode satellite since it contains both analog and digital transponders; however, it usually spends six days a week in digital mode and Wednesdays in analog mode. Around Field Day this year, it spent several days in analog mode. This was a great help on Field Day due to the limited availability of AO-13 for analog contacts. It's conventional Packet BBS is very popular and is an easy way to transition from the Terrestrial Packet world to the Digital Satellites.

The RUDAK Transponder on AO-21 has become very popular this year because of it's FM Voice experiment. Interesting variations in the voice messages have shown up during the year with speakers in English, Russian, German, French, Slovenian, and other languages. Content has ranged from best wishes for an AMSAT member recovering from an accident to a World Peace message from PY2BJO. Many of Junior's DOVE goals have now been realized through AO-21. Conventional AFSK packet telemetry has been added, permitting the casual satellite user to see packet operation from a satellite. The very popular FM Voice transponder is suffering quite a bit from "Hogs" and "Alligators." Please use discretion in the use of this single channel resource. Several operators insist on using a lot of ERP and monopolizing the "Bird." There are even operators that are trying to work WAS and other awards through this "Bird" at the expense of many other operators that would like to use it but "can't get a word in edgewise." This year on Field Day, AO-21 was almost useless due to the "Hogs" and "Alligators." If this continues, it might be better to follow FO-20's example on Field Day and turn one of the analog transponders on instead of RUDAK for the contest. One of the linear transponders has been used several times this year in conjunction with RS-10 for Satellite Dual-Hop Experiments.

AMSAT NEWS SERVICE (ANS)

Dave Cowdin, WD0HHU, has gathered up and published the news weekly for several years now. He does this almost single handed and should again be commended on a job well done. "Hitches" develop from time to time and occasionally Dave needs time off. For these reasons, the AMSAT News Service could use some additional volunteer help. This is an excellent opportunity to exercise your writing and editorial skills to help provide information read around the world on a weekly basis. Through a combination of INTERNET, Packet Radio, AMSAT Voice Nets, and Bulletins on the "Birds" this service gets distributed as wide and as fast as CNN, but with amateur means.

AMSAT NET OPERATIONS

Overall, AMSAT Net Operations were good this year; however, we still are in danger of "burn-out" on some of our Net Control Stations if we don't provide some relief. Several times throughout the year, our primary twenty meter net control operators have had to be absent for personal reasons. This is understandable, but we should have enough depth to absorb these problems with no interruption to the net service. For a while, we were able to maintain two net control operators on the twenty meter net to help with the load, but this is no longer the case. If you have a decent HF station or can operate from a good club station on a regular basis, please consider joining the ranks of the AMSAT Net Control Stations. Another thought, why not make it a club project for your local club?

Overall coordinator of the HF Nets is Wray, W8GQW; however, he gets assistance from all of the other stations. A list of active AMSAT HF Net Control Stations follows:

75 meters, 3840 kHz, Tuesday evenings

East Coast Net -	2100 Eastern -	W8GUS, WJ9F, K8RSP
Mid America Net -	2100 Central -	W0CY, W5IU, W5GEL
West Coast Net -	2000 Pacific -	K6OYY, WB6LLO, KI6QE

20 meters, 14.282 MHz, Sunday afternoons

Pre Net Warm-up -	1800 UTC -	WD0HHU, W5IU, W8GQW
Formal Net -	1900 UTC -	WD0HHU, W5IU

15 meters, 21.280 MHz, Sunday afternoons

Formal Net -	1900 UTC -	W8GQW, KB7UZ

NOTE

Simulcast on AO-13 at 145.955 MHz when in view.

17 meters, 18.155 MHz, Sunday evenings

Formal Net -	2300 UTC -	N4QQ

It should be noted that Bob, W5GEL, with his outstanding HF signal on all bands, has done fill in duty on virtually all of the AMSAT NETS. Keep up the good work, Bob.

In addition to these HF nets, a number of VHF nets exist throughout the country. Martha, at AMSAT Headquarters, has compiled a complete list of all nets and will be glad to supply a copy of this list upon request. This list is published occasionally in The AMSAT Journal and other publications.

AMSAT OPERATIONS NETS are held regularly on AO-13 for the purposes of exchanging information of a more technical nature and to introduce operators to the unique opportunities that exist for net operations when the entire AO-13 footprint is in view at one time. Downlinks are 145.950 MHz (primary) and 145.955 MHz (back-up). Currently, this net is only available on mode B. Dave, WB6LLO, schedules these nets and keeps a list of volunteer net controls current. These nets cannot always be held at the same time due to satellite visibility and other factors, so the schedule is published weekly in ANS. Dave also schedules and coordinates Slow Scan Television activity on AO-13.

COMMAND STATION DEVELOPMENT TEAM

The concept of a Command Station Development Team was proposed by Courtney, N5BF, several years ago and is currently in a state of "limbo." The concept was to develop a team of individuals capable of commanding satellites by putting these individuals through a progressive program of demonstrated capabilities and skills necessary for satellite command stations. Upon satisfactory completion of all demonstrations, each individual will be certified as a potential command station. The goals of this program were good, but the volunteer administrators of the program became too busy with other priorities and the project became disorganized. Other problems with the program were the limited number of satellites to control and the geographic distribution of stations required for efficient control. Discussions with current command stations about the Command Station Development Team have failed to yield any positive results to date.

It is felt that some sort of incentive plan is still needed to develop potential talent to draw from for our command station duties. The number of small satellites world wide keeps growing and we certainly have a challenge with Phase 3D. Many skills are required of a good command station operator. The obvious one of being able to communicate with the satellite is a trivial case. A good command station operator must demonstrate an excellent understanding of all spacecraft systems, telemetry, orbital mechanics, environmental constraints, and other subtle subjects. Suggestions for reorganization of the Command Station Development Team concept will be considered. As usual, dedicated volunteers to administer this program would be most helpful. One last note - dedication is a prime characteristic for a potential Command Station Operator to possess.

SUMMARY

The above discussions illustrate the scope of the problems/ opportunities within the Amateur Radio Satellite program. I hope the discussions have been informative and that any criticisms are received as constructive. In closing, I would like to reemphasize the following points:

1. The Amateur Radio Satellites are placed in orbit by Amateurs for the use of Amateurs. Let us respect the rights of others to use these resources and, above all, never loose sight of the fact that they are shared resources.

2. Don't be afraid to volunteer for any of the many duties required to keep AMSAT alive, but remember; if you volunteer, be a dedicated volunteer.

3. With our ever increasing number of satellites and the magnitude of the Phase 3D development effort that will be required over the next four years, we need to actively recruit some new blood into the organization from other parts of the Amateur Radio Community. We should also set our sights on bringing new people into Amateur Radio that can help our cause.

4. Keep an open mind about new ideas and techniques. The Phase 3D Mode B controversy this past year was a classic example of closed minds. The current mode S explosion on AO-13 is an example of people finally accepting new ideas and techniques - even if it took the failure of a downlink transmitter to prod them along.

Remember - building, controlling, and using Amateur Radio Satellites is fun! When some of the fun disappears, burn-out is just around the corner. Help recruit new, dedicated, volunteers to prevent burn-out.

Keith D. Pugh, W5IU

Spreading the Word About the Birds -- on Video

by Richard S. Moseson, NW2L
CQ Video Productions

ABSTRACT

A new educational tool makes it easier than ever for hams, clubs and organizations such as AMSAT to introduce and promote the use of amateur satellites. ***Getting Started in Amateur Satellites*** *is a video operating guide from CQ., available through AMSAT as well as other sources. This paper describes, from the producer's perspective, the learning process that went into creating the program, as well as ways that it can be used in the field.*

THE CHALLENGE

How do you explain, in fairly simple terms, an aspect of amateur radio that most hams consider exotic, expensive and so complex that you literally need to be a rocket scientist to understand it? How do you demonstrate that it's interesting, exciting and, most of all, within reach of the average ham?

That was the challenge I faced when setting out to produce a video introduction to amateur satellites, a challenge I suspect that most readers of this paper have faced at least once themselves, and have met with varying degrees of success or failure. Part of my goal in meeting this challenge was to create a tool which would make it easier for others to meet it in the future. The result was the *CQ* video, *Getting Started in Amateur Satellites.*

GETTING STARTED

I started out with a problem that was actually an advantage: Although I've been a ham for more than 20 years, I knew virtually nothing about amateur satellites. In other words, I was not only the producer. I was also the audience. (So if I understand it, chances are that other viewers will, too.)

My first task was to educate myself. I began with great encouragement and assistance from AMSAT President Bill Tynan, W3XO, and Executive Vice President Ray Soifer, W2RS, who served as Technical Advisor for the project. And while the printed materials they provided (satellite guides, etc.) gave me a good start, my real education came from the satellite operators I met and interviewed as the program progressed.

Getting Started in Amateur Satellites was one of four programs in simultaneous production. And videotaping locations were chosen based on my ability to cover all four topics in a single visit. After traveling to several cities, looking for articulate hams with a combination of "big-gun" and basic stations in each of the topic areas, I settled on Akron and Columbus, Ohio; Raleigh, North Carolina, and the New York City metropolitan area. And while AMSAT's field organization wasn't quite up to the task of helping me find the hams I needed (most area coordinators either couldn't be reached or were too new in their positions to know who was whom), local radio clubs came through with flying colors -- particularly the Cuyahoga Falls Amateur Radio Club in Akron, the Columbus Amateur Radio Assn. and the Raleigh Amateur Radio Society.

In Akron, we found Rich Burgan, WC8J, who pioneered transmission of digitized images over amateur satellites, and Bill Ramsey, KA8WTK, whose enthusiasm and ability to explain complex terminology in simple terms became a centerpiece of the program. Bill's enthusiasm was exceeded only by that of Ron Vanke, K8YAH, in Columbus. If Ron can't get you excited about satellites, then no one can.

In Raleigh, Carl Ebhardt, W4HJZ, and Rob Oates, KM4OH, added more explanations and demonstrations, plus one important element we didn't get very much of in Ohio -- actual contacts on OSCAR-13! (The satellite was in the midst of a magnetourqing maneuver when we were taping in Ohio, and thus was unavailable for much of the time we were there.) Finally, in New Jersey, Dave Marthouse, N2AAM, added more OSCAR-13 QSOs as well as a demonstration of OSCAR-21's FM repeater. Plus, we joined Dave and others on Field Day, at an all-satellite station headed up by Al Tencza, NX2Q. And W2RS helped prevent a minor crisis by providing an audio tape of RS-12 contacts, which we hadn't been able to capture on video. John Hansen, WA0PTV's, excellent video on his automated digital satellite gateway rounded things out, along with historic footage from ARRL & AMSAT, provided by Bill Pasternak, WA6ITF.

By the time we finished taping, I had gotten a solid introduction to most of the ham satellites currently operating, with the benefit of having all of the explanations and demonstrations recorded on videotape. Now my job was to organize that information in a clearly understandable way so that I could share my new knowledge with the eventual viewers of the program.

PUTTING IT ALL TOGETHER

While in Raleigh, I had taped 8-year-old Laura Sobon, KD4OZC, "wishing on a star." We blended her audio and video with tape of the OSCAR-10 launch and animation of OSCAR-13 in orbit. That became the opening for the program, followed by most of the hams we interviewed for the show, explaining why satellites were exciting to <u>them</u>. To people like Ron Vanke and Bill Ramsey, it was just a natural extension of living in the space age -- and their opportunity to become personally involved. For others, such as Rob Oates, Carl Ebhardt and Dave Marthouse, the main drawing card was satellite technology and the chance "to be a part of extending that technology". And for Rich Burgan, it was the allure of doing something different. As he put it: "How many people do you know with their own satellite station in their home?"

Next came a brief introduction of the amateur satellites and what they do, followed by a "satellite dictionary," in which our participants explained many of the terms that a satellite operator needs to know.

The program then moved into descriptions and demonstrations of how to operate specific satellites, starting with the analog family and moving through the analog/digital hybrids to the pacsats. Finally, we demonstrated satellite image transmission and introduced the "manned satellites," Russia's MIR space station and the US space shuttles. We looked ahead to Phase 3-D and closed with sources of additional information. At the very end (for those who stay through the credits), 8-year-old Laura, KD4OZC, made a return appearance.

Overall, *Getting Started in Amateur Satellites* runs about 49 minutes and provides the newcomer with not only basic information about satellite operating, but also a taste of what it's really like to make satellite contacts. You can't get that in a book.

HOW YOU CAN USE THIS TRAINING TOOL

Getting Started in Amateur Satellites is an ideal guide for anyone considering becoming active on ham satellites, or for anyone who just wants to know more about them. It's also an excellent tool for clubs, AMSAT area coordinators and any satellite operator who is often asked "What's this all about?"

Under an hour in length, it's an ideal length for a club meeting program. One way to build a program around *Getting Started in Amateur Satellites* is to have the presentation hosted by a local satellite operator or AMSAT area coordinator, who introduces the program, then answers questions at the end. If time and resources permit, a live demonstration of an OSCAR contact may also be helpful. The program can be especially useful if your club is planning a satellite station at Field Day, and most members are not familiar with how satellites work. After viewing this video, they should be familiar with transponders, dual-band operation, inverted frequencies and Doppler shift, among other satellite basics.

While *Getting Started in Amateur Satellites* is a great introductory tool for a large audience of hams, it's also excellent as a reference source for an individual who's "getting started." However, a one-time viewing at a club meeting might not be enough to absorb all the specific information, so a personal copy would probably be a better bet. That way, it can be referred back to at any time -- even at 3 a.m. -- without waking anyone . And with its emphasis on operating, it's a great companion to more technically-oriented books, such as *The Satellite Experimenter's Handbook.*

CONCLUSION

Getting Started in Amateur Satellites, along with its companion programs in the CQ Video Library, is a valuable tool for promoting amateur satellite activity and for providing new and prospective satellite operators with a well-rounded introduction to the entire family of OSCARs. With its focus on operating, it complements technical material currently in print. And it adds the dimensions of sight and sound that only video can provide.

Additional programs in the CQ Video Library which feature segments on amateur satellite communication include: *Ham Radio Horizons*, a basic introduction to the hobby; *Getting Started in Packet Radio,* which includes a segment on packet satellites and digital image transmission, and *Getting Started in DXing,* which includes satellites as a means for Technicians to work DX. Other programs in the CQ Video Library include *Getting Started in Ham Radio,* which advises new hams on setting up their first stations; and *Getting Started in Contesting,* which is due for release in the fall of 1993.

The CQ Video Library is a service of CQ Video Productions, a division of CQ Communications, Inc., publishers of *CQ*, *Communications Quarterly, Popular Communications* and other books and magazines. Each tape retails for $19.95 (+ shipping &/or tax, as appropriate).

AMSAT is an official dealer for *Getting Started in Amateur Satellites* and *Getting Started in Packet Radio.* AMSAT volunteers selling materials at hamfests should be sure to request copies to sell. The programs are available through AMSAT, from many ham dealers or directly from CQ Communications (76 N. Broadway, Hicksville, NY 11801 / Phone: 1-516-681-2922 / Fax: 1-516-681-2926).

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"FREQUENCY PLANNING FOR AMATEUR SATELLITES" AFTER TWENTY YEARS

by Ray Soifer, W2RS

Twenty years ago, I wrote a paper entitled "Frequency Planning for Amateur Satellites" for the first-ever amateur radio satellite conference, the ARRL Technical Symposium on Space Communications held in Reston, Virginia in September of 1973. Because of other commitments I never actually got to present it in person (which was probably a good thing because the text took up 40 pages in the published Proceedings) but I find that my 1973 paper is still cited every so often by authors covering similar ground.

A Look Back

In that original paper, I surveyed in detail all amateur bands in which satellite uplinks or downlinks might be situated. For each band, I considered propagation factors, noise levels, operational constraints and the state of the art of amateur satellites and earth stations. This survey also included regulatory considerations (remember, this was 1973 and the status of most of our present Amateur-satellite service bands was not at all clear). My 1973 paper also had a second purpose: to document the reasoning behind the choices of a 145 MHz uplink and 29 MHz downlink (Mode A) for the only amateur radio satellite then in orbit, AMSAT-OSCAR 6, and of a 432 MHz uplink and 145 MHz downlink (the present satellite sub-band at 435-438 MHz had not yet been allocated), to be called Mode B, for

AMSAT-OSCAR 7, then in the advanced construction stages for launch in 1974.

With circular, polar orbits of 1,460 km in altitude, AO-6 and AO-7 would today be considered low earth orbit (LEO) linear transponder satellites, albeit in somewhat higher orbits and with longer communication ranges than today's Microsats and UoSATs whose orbital altitude is approximately 800 km. My original paper did not address satellites in elliptical orbits, such as AO-10 and AO-13, which were just a dream in 1973. In fact, another paper at the same Symposium by one Karl Meinzer, DJ4ZC, recommended the use of Molniya-type orbits for long-haul amateur radio satellites as opposed to geosynchronous orbits and, insofar as their operating frequencies were concerned, suggested that Mode B -- once it could be proven operationally through its use in the forthcoming AO-7 -- would be far superior to Mode A for high-altitude spacecraft.

Fast-Forward to 1993

Twenty years is a long time, in which the available technology has improved as much as the uses of amateur radio satellites have expanded. It is time to revisit the assumptions and conclusions of my earlier work, to develop up-to-date considerations for the frequency planning of amateur satellites in the 1990s and beyond. You will, no doubt, be relieved to know that I do not expect to return to this subject again until 2013! Unlike the earlier paper, however, I wish to stress that the views expressed here are entirely my own personal ones and do not necessarily reflect those of AMSAT NA, AMSAT UK or any other organization with which I might be affiliated.

The Present Analysis

The main body of the present paper is presented in Tables 1-4, which are actually a series of Lotus 1-2-3 (R) spreadsheets, a very useful tool for this sort of work which was, regrettably, unavailable in 1973. For each of four cases and for every band above 21 MHz in which the Amateur-satellite service has a worldwide ITU allocation, these tables present the applicable path losses, noise sources and noise levels, from which they go on to calculate uplink power requirements and downlink signal-to-noise ratios. In all cases, I have tried to be careful to document all of the assumptions employed so that the reader may vary them to suit the specifics of the situation he wishes to analyze. You are very much encouraged to think of these tables as building blocks with which to construct your own analysis, rather than accepting my (hopefully reasonable) assumptions as givens.

Tables 1 and 2: LEO Satellites

Tables 1 and 2 assume a satellite in low Earth orbit (LEO); for analytical purposes, I have assumed that its slant range from the Earth station is 2500 km and its elevation angle is 10 degrees above the horizon. Table 1 assumes that the Earth station is using omnidirectional antennas, while in Table 2, satellite-tracking (az-el) Earth station antennas are assumed with forward gain as shown for each frequency, which gain figures I consider reasonably illustrative of current practice. Again, if you don't like these assumptions, you are welcome to substitute your own!

Table 1: Omnidirectional Antennas

Table 1, assuming a LEO satellite and an Earth station without satellite-tracking antennas, is actually an updated version of the case which I analyzed in 1973. I still consider this case to be one of vital importance for the future of the Amateur-satellite service. Surveys show that fewer than 1% of radio amateurs in the U.S. and Europe are presently equipped with satellite-tracking antennas, but many more than this are at least potentially interested in participating in this aspect of amateur radio. These amateurs, not presently satellite-equipped but interested nonetheless, are perhaps the primary source of new members for our AMSAT organizations as well as a fertile recruiting ground for the "serious" satellite operators of the future; we continue to need satellites which are capable of attracting and holding their interest.

Looking at Table 1 in more detail, for the case presented the one-way free-space path loss at 21 MHz is 127 dB, while a typical value (also at 21 MHz) for ionospheric absorption in daytime at 10 degrees elevation is 17 dB. Putting these figures together, Table 1 calculates that to produce a signal of -100 dBm at the satellite, the Earth station needs to have uplink power output of -3 dBW (500 mW) at night and 14 dBW (25 W) in the presence of typical daytime absorption.

Moving on to consideration of the downlink and staying with 21 MHz for illustrative purposes, Table 1 shows what amount to best-case and worst-case examples. Under the best case, a "quiet" location and cold sky, the 21 MHz noise level would consist primarily of atmospheric noise of 100,000 K and cosmic noise of 27,000 K, for a combined noise level of approximately -148 dBm/Hz. Less fortunate circumstances, namely a rather noisy "residential" location with 1,200,000 K of man-made noise and "average" cosmic noise of 48,000 K, result in a noise level of -138 dBm/Hz. At UHF and higher frequencies, Earth noise and receiver noise dominate as one might expect.

Table 1 calculates six different measures of downlink performance. It shows the signal-to-noise ratios for best-case and worst-case noise levels, under both day and night conditions, assuming 1 W output at the satellite, in a 2.4 kHz bandwidth typical of SSB communications. For frequencies above 144 MHz, it also calculates the carrier-to-noise ratios for best-case and worst-case noise levels (in daytime) in a 15 kHz bandwidth as might be employed for FM and packet radio transmission. The last row in Table 1 shows the maximum one-way Doppler shift at each frequency.

Table 2: Satellite-Tracking Antennas at the Earth Station

Table 2 is the same as Table 1, except that antenna gain at the Earth station is assumed as shown. Earth noise of 290 K is still present in the analysis, in view of the assumed elevation angle of 10 degrees.

Tables 3 and 4: Phase 3 Spacecraft

Table 3 assumes a Phase 3 satellite rather than one in low Earth orbit. The slant range is assumed to be 40,000 km (ie, near apogee) with an elevation angle of 45 degrees; the higher elevation angle results in a lower level of ionospheric absorption than in the LEO case as well as in the absence of Earth noise from the downlink. As in the earlier cases, receiver noise of 80 K (system noise figure of 1.05 dB) is assumed throughout.

In Table 3, we have assumed antenna gain at the satellite comparable to that currently being planned for Phase 3D and a downlink power level of 5 W per signal rather than 1 W as in Tables 1 and 2. Again, all of these assumptions may be changed to suit the reader.

Table 4 is similar to Table 3, but assumes an omnidirectional antenna at the Earth station; once again, Earth noise of 290 K returns to the analysis since the omnidirectional receiving antenna will not discriminate against it.

Tables 5 and 6: Combining Uplinks with Downlinks

The reader will probably want to compare various combinations of uplink and downlink parameters to arrive at the optimal transponder modes under various sets of assumptions. One way of doing this, though certainly not the only way, is illustrated in Tables 5 and 6. These tables make use of a simple (some might say simplistic) relative figure of merit, computed by subtracting the required uplink power (expressed in dBW) from the downlink S/N ratio. The resulting figure, expressed in dB, is meaningful only when comparing one uplink/downlink pair with another under a given set of assumptions. It is entirely relative, with no significance whatever attaching to whether the sign is positive or negative.

Under the assumptions embodied in Tables 1-4, what do Tables 5 and 6 tell us?

For LEO satellites, the merits of HF uplinks are clearly demonstrated, especially at night when ionospheric absorption is low. This should come as no surprise to anyone who has tried Modes K and T on the RS satellites under such conditions. For digital LEO spacecraft, where HF uplinks and downlinks are not practical due to bandwidth constraints and the very large Doppler shift argues strongly against the use of 2.4 GHz, the comparison comes down to Mode B vs. Mode J. (The Doppler figures in Tables 5 and 6 are based on those in Tables 1 and 2, assuming the use of frequency inversion.) Under the assumptions embodied in these tables, Modes B and J come out about even under best-case conditions, ie, in the absence of man-made noise, but Mode J is shown to be superior when a high noise level is present.

The relative merits of various uplink and downlink pairs for Phase 3 satellites have been the subject of much recent debate. Under the assumptions of Table 3, Tables 5 and 6 show the following results for selected frequency combinations:

	Best Case (Quiet)	Worst Case (Noisy)
Mode UV (Mode B)	18 dB	3 dB
Mode VU (Mode J)	23	15
Mode LU (Mode L)	20	13
Mode US (Mode S)	18	18

Additional Factors to Consider

The analysis in this paper considers only the factors listed in Tables 1-4, and does not take into account other relevant issues which must be considered. Among the latter are the existing use of frequencies by amateur radio satellites, the sharing of some HF uplink and downlink channels with terrestrial stations, the presence of interfering signals in the 145.8-146.0 and 435-438 MHz bands in many parts of the world, and the difficulty experienced by many users (especially the new users whom we wish to attract) in attenuating the third harmonic of their 145 MHz uplink signals when listening on the Mode VU (Mode J) downlink.

The cost and complexity of Earth station equipment must also be considered; in general, this argues for placing the uplink at the lower of the two frequencies employed by the satellite, to reduce the cost of generating the required uplink power. However, there is a countervailing argument in favor of Mode UV (Mode B) rather than Mode VU (Mode J): Suitable uplink equipment for 70cm is already widely available, and the provision of a downlink in the 2m band -- by far the most popular and most widely listened to of any amateur band in the world -- is undoubtedly helpful in attracting new users.

Be that as it may, the 2m band is also by far the most crowded with satellites of any of our current bands. Table 7 lists all of the uplink and downlink channels in use as of this writing (June 1993) in the international satellite sub-band of 145.8-146.0 MHz. Clearly, future assignments in this portion of the spectrum must be made with care.

Frequency planners for future amateur radio satellites must consider all of these issues and more, in addition to a very important one which this paper does not attempt to address: the preferences of satellite users and the members of our various AMSAT organizations. Hopefully, the analysis in this paper will provide an objective technical framework within which these factors may be considered.

Note 1: This paper was first presented at the Eighth AMSAT-UK Colloquium, held at the University of Surrey, Guildford, England, July 29 - August 1, 1993.

Table 1
LEO Satellite, 2,500 km range, 10 deg elevation, omni antenna at ground station:

Frequency Band (MHz)	21.0-21.45	24.89-24.99	28.0-29.7	144-146	435-438	1260-1270	2400-2450	5650-5670	5830-5850	10450-10500	24000-24050
Uplink/downlink	UD	UD	UD	UD	UD	U	UD	U	D	UD	UD
Path loss	127	128	130	144	153	162	168	175	176	181	188
Daytime absorption	17	13	8	0.4							
Uplink power (dBW) for -100 dBm:											
Night	-3	-2	0	14	23	32	38	45		51	58
Day	14	11	8	14	23	32	38	45		51	58
Noise (kelvins):											
Cosmic:											
Cold sky	27000	19000	10000	165	11						
Average	48000	35000	18000	290	19						
Man-made & atmospheric:											
Quiet	100000	36000	7000								
"Residential"	1200000	900000	600000	7000	360						
Earth	290	290	290	290	290		290		290	290	290
Receiver	80	80	80	80	80		80		80	80	80
Total noise power (dBm/Hz)											
Quiet	-148	-151	-156	-171	-173		-173		-173	-173	-173
"Residential"	-138	-139	-141	-160	-170		-173		-173	-173	-173
Downlink S/N ratio for 1W output, 2.4 kHz, night:											
Quiet	17	19	23	24	16		1		-7	-12	-19
"Residential"	7	7	7	12	13		1		-7	-12	-19
Downlink S/N ratio for 1W output, 2.4 kHz, day:											
Quiet	0	6	15	23	16		1		-7	-12	-19
"Residential"	-10	-6	-1	12	13		1		-7	-12	-19
Downlink C/N ratio for 1W output, 15 kHz:											
Quiet				16	8		-7		-15	-20	-27
"Residential"				4	5		-7		-15	-20	-27
Max Doppler shift, kHz	0.5	0.6	0.7	3.4	10.3	30.0	56.7	133.7	137.9	247.4	567.4

Table 2
LEO Satellite, 2,500 km range, 10 deg elevation, tracking ground station:

Frequency Band (MHz)	21.0-21.45	24.89-24.99	28.0-29.7	144-146	435-438	1260-1270	2400-2450	5650-5670	5830-5850	10450-10500	24000-24050
Uplink/downlink	UD	UD	UD	UD	UD	U	UD	U	D	UD	UD
Path loss	127	128	130	144	153	162	168	175	176	181	188
Daytime absorption	17	13	8	0.4							
Antenna gain (dBi)	6	6	6	12	17	20	20	20	20	20	20
Uplink power (dBW) for -100 dBm:											
Night	-9	-8	-6	2	6	12	18	25		31	38
Day	8	5	2	2	6	12	18	25		31	38
Noise (kelvins):											
Cosmic:											
Cold sky	27000	19000	10000	165	11						
Average	48000	35000	18000	290	19						
Man-made & atmospheric:											
Quiet	100000	36000	7000								
"Residential"	1200000	900000	600000	7000	360						
Earth	290	290	290	290	290		290		290	290	290
Receiver	80	80	80	80	80		80		80	80	80
Total noise power (dBm/Hz)											
Quiet	-148	-151	-156	-171	-173		-173		-173	-173	-173
"Residential"	-138	-139	-141	-160	-170		-173		-173	-173	-173
Downlink S/N ratio for 1W output, 2.4 kHz, night:											
Quiet	23	25	29	36	33		21		13	8	1
"Residential"	13	13	13	24	30		21		13	8	1
Downlink S/N ratio for 1W output, 2.4 kHz, day:											
Quiet	6	12	21	35	33		21		13	8	1
"Residential"	-4	0	5	24	30		21		13	8	1
Downlink C/N ratio for 1W output, 15 kHz:											
Quiet				28	25		13		5	0	-7
"Residential"				16	22		13		5	0	-7
Max Doppler shift, kHz	0.5	0.6	0.7	3.4	10.3	30.0	56.7	133.7	137.9	247.4	567.4

Table 3

Phase 3 Satellite, 40,000 km range, 45 deg elevation, tracking ground station:

Frequency Band (MHz)	21.0-21.45	24.89-24.99	28.0-29.7	144-146	435-438	1260-1270	2400-2450	5650-5670	5830-5850	10450-10500	24000-24050
Uplink/downlink	UD	UD	UD	UD	UD	U	UD	U	D	UD	UD
Path loss	151	152	154	168	177	187	192	200	200	205	212
Daytime absorption	6	4.5	3	0.1							
Antenna gain (dBi):											
Satellite	3	3.5	4	11	15	18	20	20	20	20	20
Earth station	6	6	6	12	17	21	23	30	30	30	30
Uplink power (dBW) for -100 dBm:											
Night	12	13	14	15	15	17	20	20		25	32
Day	18	17	17	15	15	17	20	20		25	32
Noise (kelvins):											
Cosmic:											
Cold sky	27000	19000	10000	165	11						
Average	48000	35000	18000	290	19						
Man-made & atmospheric:											
Quiet	100000	36000	7000								
"Residential"	1200000	900000	600000	7000	360						
Receiver	80	80	80	80	80		80		80	80	80
Total noise power (dBm/Hz)											
Quiet	-148	-151	-156	-175	-179		-180		-180	-180	-180
"Residential"	-138	-139	-141	-160	-172		-180		-180	-180	-180
Downlink S/N ratio for 5W output, 2.4 kHz, night:											
Quiet	9	11	16	33	37		33		33	28	21
"Residential"	-1	-1	0	18	30		33		33	28	21
Downlink S/N ratio for 5W output, 2.4 kHz, day:											
Quiet	3	7	13	33	37		33		33	28	21
"Residential"	-7	-5	-3	18	30		33		33	28	21
Downlink C/N ratio for 5W output, 15 kHz:											
Quiet				25	29		25		25	20	13
"Residential"				10	22		25		25	20	13

Table 4

Phase 3 Satellite, 40,000 km range, 45 deg elev, omni antenna at ground station

Frequency Band (MHz)	21.0-21.45	24.89-24.99	28.0-29.7	144-146	435-438	1260-1270	2400-2450	5650-5670	5830-5850	10450-10500	24000-24050
Uplink/downlink	UD	UD	UD	UD	UD	U	UD	U	D	UD	UD
Path loss	151	152	154	168	177	187	192	200	200	205	212
Daytime absorption	6	4.5	3	0.1							
Antenna gain (dBi):											
Satellite	3	3.5	4	11	15	18	20	20	20	20	20
Earth station	0	0	0	0	0	0	0	0	0	0	0
Uplink power (dBW) for -100 dBm:											
Night	18	19	20	27	32	38	43	50		55	62
Day	24	23	23	27	32	38	43	50		55	62
Noise (kelvins):											
Cosmic:											
Cold sky	270000	190000	100000	165	11						
Average	480000	350000	180000	290	19						
Man-made & atmospheric:											
Quiet	100000	36000	7000								
"Residential"	1200000	900000	600000	7000	360						
Earth	290	290	290	290	290		290		290	290	290
Receiver	80	80	80	80	80		80		80	80	80
Total noise power (dBm/Hz)											
Quiet	-148	-151	-156	-171	-173		-173		-173	-173	-173
"Residential"	-138	-139	-141	-160	-170		-173		-173	-173	-173
Downlink S/N ratio for 5W output, 2.4 kHz, night:											
Quiet	3	5	10	18	14		4		-4	-9	-16
"Residential"	-7	-7	-6	6	11		4		-4	-9	-16
Downlink S/N ratio for 5W output, 2.4 kHz, day:											
Quiet	-3	1	7	18	14		4		-4	-9	-16
"Residential"	-13	-11	-9	6	11		4		-4	-9	-16
Downlink C/N ratio for 5W output, 15 kHz:											
Quiet				10	6		-4		-12	-17	-24
"Residential"				-2	3		-4		-12	-17	-24

Table 5
Figure-of-Merit Mode Comparisons
Day/"Residential" Location

Uplink/Downlink Frequencies		LEO Satellite Omni Antennas at Earth Stn.	LEO Satellite Tracking Ants. at Earth Stn.	Max. Doppler for LEO Satellite	P3 Satellite Tracking Ants. at Earth Stn.	P3 Satellite Omni Antennas at Earth Stn.
21/24		-20 dB	-8 dB	0.1 kHz	-23 dB	-35 dB
21/29	K	-15	-3	0.2	-21	-33
21/145	T	4	16	2.9	0	-18
21/435		-1	22	9.8	12	-13
24/21		-20	-8	0.1	-25	-37
24/29		-14	-2	0.1	-20	-32
24/145		-20	-2	2.9	1	-17
24/435		-29	-6	9.7	13	-12
29/21		-18	-6	0.2	-24	-36
29/24		-14	-2	0.1	-22	-34
29/145		4	22	2.7	1	-17
29/435		5	28	9.6	13	-12
145/21		-24	-6	2.9	-22	-40
145/24		-20	-2	2.8	-20	-38
145/29	A	-15	3	2.7	-18	-36
145/435	VU (J)	-1	28	6.9	15	-16
145/2.4	VS	-13	19	53.3	18	-23
145/10	VX				13	-36
435/145	UV (B)	-11	18	6.9	3	-26
435/2.4	US (S)	-22	15	46.4	18	-28
435/5.8	UC	-30	7	127.6	18	-36
435/10	UX	-35	2	237.1	13	-41
435/24		-42	-5	557.0	6	-48
1.2/145	LV				1	-32
1.2/435	LU (L)				13	-27
1.2/2.4	LS				16	-35
1.2/5.8	LC				16	-42
1.2/10	LX				11	-47
1.2/24					4	-54
5.6/145	CV				-1	-43
5.6/435	CU				11	-38
5.6/2.4	CS				13	-46
5.6/10	CX				8	-58
5.6/24					1	-66

Table 6
Figure-of-Merit Mode Comparisons
Night/Quiet Location

Uplink/Downlink Frequencies		LEO Satellite Omni Antennas at Earth Stn.	LEO Satellite Tracking Ants. at Earth Stn.	Max. Doppler for LEO Satellite	P3 Satellite Tracking Ants. at Earth Stn.	P3 Satellite Omni Antennas at Earth Stn.
21/24		22 dB	34 dB	0.1 kHz	-1 dB	-13 dB
21/29	K	26	38	0.2	4	-9
21/145	T	27	45	2.9	21	0
21/435		19	42	9.8	25	-4
24/21		18	30	0.1	-4	-16
24/29		24	36	0.1	3	-9
24/145		25	43	2.9	20	-1
24/435		17	40	9.7	24	-5
29/21		17	29	0.2	-5	-17
29/24		19	31	0.1	-2	-14
29/145		24	42	2.7	19	-2
29/435		16	39	9.6	23	-6
145/21		3	21	2.9	-6	-24
145/24		5	23	2.8	-3	-21
145/29	A	9	27	2.7	1	-17
145/435	VU (J)	2	31	6.9	23	-13
145/2.4	VS	-13	19	53.3	18	-23
145/10	VX				13	-35
435/145	UV (B)	1	30	6.9	18	-14
435/2.4	US (S)	-22	15	46.4	18	-28
435/5.8	UC	-30	7	127.6	18	-36
435/10	UX	-35	2	237.1	13	-41
435/24		-42	-5	557.0	6	-48
1.2/145	LV				16	-20
1.2/435	LU (L)				20	-24
1.2/2.4	LS				16	-35
1.2/5.8	LC				16	-42
1.2/10	LX				11	-47
1.2/24					4	-54
5.6/144	CV				14	-32
5.6/435	CU				18	-36
5.6/2.4	CS				13	-46
5.6/10	CX				8	-58
5.6/24					1	-66

Table 7
Current Usage of
145.800-146.000 MHz

	Uplinks	Downlinks
AO-10 General Beacon		805-813
AO-10 Mode B Transponder		821-979
AO-10 Engineering Beacon		983-991
UO-11 (UoSAT 2)		822-830
RS-10 Mode A Transponder	856-904	
RS-10 Robot A	816-824	
RS-10 Mode T Transponder		856-904
RS-10 Beacon/Robot		853-961
RS-10 Beacon/Robot		899-907
RS-11 Mode A Transponder	906-954	
RS-11 Robot A	826-834	
RS-11 Mode T Transponder		906-954
RS-11 Beacon/Robot		904-911
RS-11 Beacon/Robot		949-957
AO-13 General Beacon		808-816
AO-13 Mode B Transponder		821-979
AO-13 Engineering Beacon		981-989
FO-20 Mode JD	840-920	
FO-20 Mode JA Transponder	896-004	
AO-16 Mode JD	890-970	
DO-17 DOVE Beacon		820-829
WO-18 Webersat	890-910	
LU-19 Mode JD	830-910	
RS-12 Mode A Transponder	906-954	
RS-12 Robot A	827-835	
RS-12 Robot T		908-916
RS-12 Mode T Transponder		906-954
RS-12 Robot T		955-963
RS-13 Mode A Transponder	956-004	
RS-13 Robot A	836-844	
RS-13 Robot T		858-866
RS-13 Mode T Transponder		956-004
RS-13 Robot T		904-912
RS-14/AO-21 CW Beacon		815-823
RS-14/AO-21 BPSK/FM		942-962
RS-14/AO-21 BPSK/SSB		979-990
RS-14/AO-21 RUDAK 2		973-993
RS-14/AO-21 Mode B (Transponder 1)		848-936
RS-14/AO-21 Mode B (Transponder 2)		862-950
UO-22 (UoSAT 5) ch 1	890-910	
UO-22 (UoSAT 5) ch 2	965-985	
KO-23 Channel 1	840-860	
KO-23 Channel 2	890-910	

Implementing the PACSAT Broadcast Protocol on Terrestrial Networks.

by John A. Hansen, WAØPTV

The PACSAT Broadcast Protocol currently used on most of the amateur digital satellites provides a mechanism under which large amounts of data can be transferred at a much faster rate than would be possible using standard "connected" packet techniques. This paper describes some work in progress that is geared toward applying a modified version of the PBP to terrestrial packet radio networks.

I. Background

When planning was underway for the first generation of Microsats which were to be launched in late 1989, it was originally envisioned that they would contain store and forward BBS capabilities that would be similar (though not identical) to the WØRLI BBS model. While composing text on line would be discouraged, individual users would connect to the satellite to upload and download files. In fact, in the early days of Oscars 16 and 19, downloading while connected was the principle means of getting data from the birds. Furthermore, this basic technique had been the one employed in a modified form on both of the Fuji satellites.

Even before the satellites were launched, however, it was realized that given the high level of expected usage and the relatively short passes involved, this mechanism simply would not work well. Individual users would require very large amounts of connect time to download a lengthy file only to have other users come along and request the same file immediately afterwards. With only 4 uplink frequencies and 10 to 15 minutes passes this clearly would not work, even if the user load was fairly light.

In response to this perceived need, Harold Price, NK6K and Jeff Ward, now GØSUL, developed the PACSAT Broadcast Protocol (PBP). First implemented on UoSat 14, this software became standard for virtually all digital satellites. The principal features of the PBP are:

1. File broadcasts are requested by unconnected users sending UI frames from a KISS protocol terminal program (generally using "PB.EXE").

2. The satellite sets up a que in which each request receives a time slice that partially fills the file request after which the user is returned to the end of the que.

3. The satellite fills requests by transmitting PBP data encapsulated in unconnected frames.

4. Individuals who have not requested individual files may still accumulate these files by eavesdropping on the file broadcasts generated by other stations.

5. Since the packets are sent in UI frames, no acknowledgement packets are sent by the ground stations. Thus data flows from the satellite server in a continuous stream uninterrupted by return ACK frames or by the usual transmit/receive turnaround time that slows down conventional networks.

6. Each groundstation automatically keeps a list of the parts of each file that it has not received. When a request for a file is transmitted, only that part of the file that is missing is actually requested.

The advantage of the PBP is that it radically speeds up the transfer of data from the satellite to groundstations. This occurs for two reasons:

1. It dispenses with the ACK packets and the associated transmit/receive turnaround time.

2. It allows more than one groundstation to obtain a given file at once, thus radically cutting down the number of file requests.

II. The Development of Digital Satellite Nodes

As experience with the satellites accumulated it became clear to me that much of what was carried in onboard memory would be of interest to the users of my traditional terrestrial BBS. As a result I began to take files that I had obtained from the satellite and put them in the messages or files section of the BBS as appropriate. During 1992 I developed a software suite that allowed this to occur automatically and also allowed BBS users to have full access to the digital satellites just as if they had their own groundstations. This system became quite popular and is now in use in a number of locations around the world. It did, however, create yet a new problem. My groundstation was capable accumulating quite large files (over 300K for some image files) either automatically or at the request of specific users. However, those users found it to be virtually impossible to download those files from my BBS at 1200 baud over a standard (sometimes congested) 2 meter packet frequency. As a result I began to search for alternative mechanisms of providing those files to users.

My first thought was to put a 9600 baud user port on the BBS. My situation here was fairly unique in that I installed 9600 baud user facilities before I installed 9600 baud forwarding links. Usage on this port was fairly light, however, because few users had 9600 baud capability (this is still the case). Those with 9600 baud capability were often also active themselves on the digital satellites. I conducted a survey of my users and discovered that often those most interested in satellite access were those least likely to have the means to put together a 9600 baud station (that is, young people). One of my most devoted digital satellite node users, for example, regularly accesses my node with a Commodore 64 and an HT.

One stopgap measure that has been relatively effective is the addition of a telephone port to the BBS. Unfortunately I live in the middle of nowhere and for almost all my users this involves a toll call. Furthermore, one begins to wonder about the "amateur radio" content of a system that depends upon telephone links.

Basically the problem that I have is similar to that faced by the PBP designers: vastly more data needs to be transferred than can be accomplished with the old technology. Furthermore, as in the case of the satellites, most of the files that one individual wishes to obtain are also desired by others. Clearly a solution similar to that designed for the satellites would work well here. So I began to think about creating a protocol similar to the PBP for terrestrial operations.

How fast could this system be? Take a 100K binary file, for example. Suppose it is compressed to, say, 50k and downloaded from a BBS using the standard YAPP protocol. I have heard the figure of 300 bits/sec used as an estimate of the data throughput on such a path. If we take that as a working figure, it would take about 25 minutes to download this file using conventional means. My experience is that this number is about what I typically see, assuming an average level of congestion, node retransmissions, etc. Now suppose we do the same thing in broadcast fashion. The mechanism for doing this will be discussed in the next section, but for the moment suppose we have picked a frequency such that the server does not compete with other transmitters. Again, assume a 1200 baud transmission rate and the same 100K file compressed to 50K. We must make some allowance for the overhead added by the PBP system itself, though I expect this to be less than for the satellite PBP for reasons discussed below. Given these assumptions, the transmission time will be roughly 8-9 minutes. At this rate 100K (and larger) files transfers begin to look practical. Think how fast this might proceed at 9600 baud!

III. Design Parameters

All of this caused me to begin to think about implementing such a system as a server on my BBS. The following design parameters influenced my thinking about how to construct such a system:

1. It should require no hardware upgrades by current BBS users. That is, a user with a 1200 baud 2 meter packet station should be able to access the system. There are a number of implications from this. First, the satellite system that requires users to have full duplex capabilities on 2 meters and 70 centimeters is too complex for my purpose here. While many users do have dual band radios, most often they keep them in their cars. Furthermore, the system is optimized when users leave their stations on all the time, and the ability to use cheap, simple equipment will encourage

them to do so. Furthermore, users should not be required to upgrade to 9600 baud (though a 9600 baud channel could easily be added to the design if that became desirable).

2. The system should operate alongside a standard packet BBS of whatever design, and therefore will initially not be integrated with any particular BBS design. This system is designed to be a file server. While it is hoped that the technology demonstrated here would later be incorporated by BBS authors into their software, doing so at this point or writing a whole new BBS program would be prohibitively complex. The server must run simultaneously with the BBS and should receive its file requests on the same frequencies that users generally use to access the BBS. The simplest way to do this is to run it under Desqview as a G8BPQ node application.

3. The system should be relatively easy for users to access. Digital satellite users tend to be among the most sophisticated of packet operators. The same cannot be said of typical terrestrial BBS users. Thus the user interface must be quite simple. The user should see file names, not hexadecimal numbers and the process of stripping PACSAT file headers should be automatic. Furthermore, while some have suggested TCP/IP as a reasonable way to pursue development of a file broadcast system I have opted not to use that approach in part because of the difficulties that average packet users experience getting up and running on TCP/IP.

4. The broadcast site should be in a high location that is visible to as many users as possible. While it would be possible to set up repeaters to relay the signal further, starting with as high a site as possible would alleviate much of the need for this.

IV. System Overview

The PBP server will run under Desqview as a G8BPQ application. It will receive input (file requests) from users on any of its ports (the same ports users now use to access the BBS), though users will not connect to the BBS to make requests. The server will fill those requests on a single dedicated G8BPQ port. The dedicated port will be on some band other than 2 meters and will have only a transmitter (no receiver) on that frequency. The transmitter, of course, must be capable of a continuous duty cycle over long periods of time but will have relatively low power and a directional antenna.

It will transmit the data to a central distribution site which will be at a very high location. At this site there will be a receiver for the link frequency, a bit regenerator, and a transmitter on a clear channel on 2 meters. This transmitter will be a relatively high power device and must also be capable of continuous duty. Broadcast data will come out of the server in a continuous stream and be linked to the central distribution point from which it will be retransmitted on 2 meters. Thus, any user who can program an appropriate split on 2 meters will be able to access this system.

There will be some substantial differences between the proposed system and the one that flies on the PACSATs. First, no provision is made for uploading files. BBS's already have provisions for file uploads and using the protocol that is built into the PACSAT system will not result in substantially greater efficiency. Bear in mind that this is not supposed to be a message handling system as the PACSAT BBS is, but merely a way of efficiently transferring files. Thus there is no real reason that uploaders should have to go to the trouble of adding a PACSAT file header to their files before uploading them.

Secondly, the file header that is applied at the BBS before transmission will be substantially simpler as well. I suspect that if Harold and Jeff were designing this system today they would have done some things differently as well. For example, even on the satellites there is no real reason to incorporate all the fields currently in the header about downloading (downloader, number of times downloaded, etc.). When the PBP was conceived it was envisioned that files would actually be downloaded as well as broadcast. As it turns out this has not been the case because downloading is much less efficient than broadcasting. Other information in the header will not be needed as well, consequently it is anticipated that the headers will have to be redesigned somewhat for this project.

Third, the current satellite-based system also permits users to request directory broadcasts. In fact, a significant proportion of the bandwidth is used bringing users' directories up-to-date. This is partly due to the fact that all information put into the satellite generates a file directory entry, thus the directory itself changes very rapidly. One of the popular BBS programs, F6FBB, has picked up on this and allows the broadcast of UI frames that contain listings of the messages that are available on the BBS. Messages, however, tend to be much shorter than files and are not the subject of the file server that is envisioned in this project. The file directories themselves change much more slowly on BBSs and while it might be desirable to occasionally broadcast to users a listing of the files available, it does not make a great deal of sense to allow users to initiate these broadcasts as is done on the satellites. Thus, I envision this system to be somewhat simpler in that it will not routinely service requests for directory broadcasts.

A fourth key difference between this server and a satellite is that there is no LOS... the BBS never sets. With the satellite server it is necessary to make a number of accommodations to let all potential users have a turn during the nominal 15 minutes of the pass. Thus, much attention has been paid to optimizing the length of the que and determining whether those who requested shorter files should be moved in front of those requesting longer files. I am not even certain that a que will be necessary initially. When a user requests a file instead of getting a message that says "OK WAØPTV", it might be better to have it say "OK WAØPTV: 32:14", indicating that it is estimated that the file transmission will be completed in just over 32 minutes. Then WAØPTV could go off and do something else for a half hour and come back to find his file completed. As server demand grows it may become necessary to institute a que, but initially I do not think it will be essential.

V. Software Development

It is surprisingly easy to program a G8BPQ application that will broadcast a continuous stream of data in KISS format. Listing 1 shows a small program written in Turbo Pascal that will take any file and broadcast it through a G8BPQ port. The G8BPQ software must be up and running for this program to work. To run this program you would compile it into a program called "BPQSERV.EXE" or whatever and then use the syntax BPQSERV {filename} where filename is a parameter indicating which file you want to broadcast. I purposefully tried to make this program as simple as possible to demonstrate the KISS mode interface to the G8BPQ switch so at this point it does not contain the code which would allow users to request files. The lines in the body of the program are numbered for reference purposes. The first two lines open the file specified on the command line so that it can be broadcast. Line 3 specifies the data that G8BPQ will need to construct an AX.25 packet. The first seven terms are to "TO" field. Six spaces are allowed for a callsign plus one for an SSID. In the case in listing 1 I have used TEST_ _0. Note the full six places must be used so pad on the right with spaces as needed. You can not simply look up the letters "T", "E", etc. in an ASCII table to find the values to plug in here because the AX.25 protocol has them shifted one place to the left. So what you do is look up each letter in the ascii table (T=84, E=69, S=83, space=32, Ø=48) and then double the decimal value. The second seven terms in ovhbuff are the sender's callsign constructed the same way (in this case, WAØPTVØ, except that you add one to the SSID (96+1=97) to set the HDLC address extension bit. The next term (chr(3)) is the control field that specifies that you are sending a U frame. The final term (chr(240)) is the Protocol identifier (PID) which is always F0 in hex (240 decimal) indicating that no layer 3 is implemented. The chr() function for each of these terms returns the character with this ordinal value. This is all the information that needs to be furnished to G8BPQ to construct KISS frames. The KISS protocol embedded in G8BPQ takes care of more thorny issues like flags, bit-stuffing, and the frame check sequence.

Listing 1:
Sample Code for Broadcasting through a G8BPQ Switch

```
Program BPQServ;
uses dos;
var
        Inp : Integer;
        Regs    : Registers;
        BPQbuff,ibuffer   : Array [1..256] of byte;
        ovhbuff   : String[255];
        infile    : file;
        numread   : word;
BEGIN
{1}     Assign(infile,paramstr(1));
{2}     reset(infile,1);
{3}     ovhbuff := chr(168)+chr(138)+chr(166)+chr(168)+chr(64)+chr(64)+chr(96)+
                chr(174)+chr(130)+chr(96)+chr(160)+chr(168)+chr(172)+chr(97)+
                chr(3)+chr(240)
{4}     For Inp := 1 to Length(ovhbuff) do BPQbuff[Inp] := Ord(ovhbuff[inp]);
{5}     Repeat
{6}             Blockread(infile,ibuffer,239,numread);
{7}             inp := 1;
{8}             for inp := 1 to numread doBPQbuff[length(ovhbuff)+inp] := ibuffer[inp];
{9}             regs.cx := numread+16;
{10}            regs.si := Ofs(BPQbuff);
{11}            regs.ES := Seg(BPQbuff);
{12}            regs.ah := 10;
{13}            regs.al := 3;
{14}            intr($7F,regs);
{15}    until eof(infile);
END.
```

The data that is to be sent to G8BPQ will be stored in an array called BPQbuff that will be 255 bytes long. The first 16 bytes are the AX.25 overhead discussed above. Line 4 puts them into BPQbuff. We then enter a loop that repeatedly takes 239 bytes from the file to be transmitted, puts the AX.25 overhead on them and sends it out the G8BPQ port. Line 6 reads 239 bytes (if there are that many left), and lines 7 and 8 put them into BPQbuff. Lines 9 through 13 set the registers that BPQ uses to transmit KISS frames. Line 9 sets the packet length, 10 and 11 tell where to find the data, 12 specifies that we want to send UI KISS frames, and 13 specifies that we want to use BPQ port number 3 (as specified in the BPQCFG.TXT file). This could be any defined port. In the case of real file broadcasts one port will be defined within BPQ that will accept all of the data to be broadcast. Line 14 calls the interrupt that actually transmits the data.

That's all there is to it. The advantages of using the G8BPQ protocol to do this are that it permits a BBS to operate simultaneously on the same ports as the server receives requests and the programming required to actually send the data is extremely simple. Note that I never actually have to interact with the serial ports themselves here.

VI. Remaining Work

Obviously much remains to be done before this system can be brought on line. The three main software tasks are:

1. Add a revised version of the PBP to the server program including a modified file header and encapsulate the transmitted KISS packets so that holes can be readily identified.

2. Build the interface between BPQ and the users so that file requests can be made. This will include both code to permit the receipt of file requests and to acknowledge those requests on the broadcast port.

3. Build a fairly simple KISS terminal program that can be run by end users.

Anyone wishing to become involved in this project, particularly with respect to task number 3, should contact the author.

AUTOMATIC PACKET REPORTING SATELLITE SYSTEM

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

There is a need in the Amateur Radio Service for a satellite system dedicated to mobile communications. To date there are a variety of amateur communication satellites operating on most of the VHF and UHF bands. All of these channels either require sophisticated antenna systems (AO-10,13) or sophisticated modems and computers (AO-16,19,23) and all rely on tracking programs for access prediction. Except for an occasional cumbersome contact, none of the satellites is readily available for mobile communications. Since only satellites can provide the connectivity anywhere on the earth necessary to support world wide mobile communications, we seem to have our space assets focused on the wrong applications.

What is needed is a single AX.25 satellite channel dedicated to position and status reporting. Mobiles anywhere in the world would beacon their position and status once about every 5 minutes on the uplink channel and be digipeated to all stations in the footprint on the downlink. Each satellite supporting this network would provide every mobile a good chance of being reported at least twice a day. Using readily available software, all packet stations in the footprint of a satellite pass would capture the position and status of all mobile, portable, emergency, and special packet stations within a thousand miles. To implement such a system, a mobile only needs a packet TNC and two meter radio. He enters his position and one line status into the TNC BText and sets the beacon to once every 5 minutes. During the satellite pass, his position and status will be digipeated back home, or wherever as needed.

Since a position and status report only takes .2 seconds at 9600 baud AX.25, the total channel capacity over four minutes would support a theoretical maximum of 1200 users within the footprint. Since this would be an ALOHA type multiple access protocol, the channel should actually be loaded to no more than 18% of that figure to assure reasonable throughput in the presence of collisions. To account for this contention on the uplink, four uplink channels would be operated simultaneously and combined into the single downlink. Since the useable footprint of one of the amateur microsats covers about half of the US at a time, this results in about 2400 mobile, emergency, or special event stations at any time.

USING APRS FOR SPACE COMMUNICATIONS

The Automatic Packet Reporting System could be a solution to the effective use of orbiting terrestrial style packet radio digipeaters in the amateur satellite program. To date there have been three standard AX.25 1200 baud FM transponders flown in space. The first was on the Space Shuttle STS-35, the second was on the space station MIR, and the third has been via the FM transponder mode of AO-21. The problem with a space based digipeater is the total saturation on the uplink channel which makes the use of a normal CONNECTED protocol impractical. For the SAREX robot QSO mode, a total of five successive and successful packet transmissions were required to constitute a successful contact. Of an estimated thousands of uplink stations, only about 250 were successful. Recognizing the stringent requirements for success using the CONNECTED protocol, provision was also made to recognize those stations which were successful in getting only one packet heard onboard the shuttle. Over 700 stations successfully completed single uplink packets.

APRS takes advantage of this unconnected, one packet, mode to demonstrate successful uplinks to the shuttle. In addition, however, it capitalizes on the most fascinating aspect of the amateur radio hobby, and that is the display on a map of the location of those stations. Historically, almost every aspect of HAM radio communications has as its root, the interest in the location of other stations. Look at DX maps, countries worked, counties worked, grid squares, mobile chatter; everyone is quite interested in where other stations are.

If, instead of every station attempting to CONNECT with the Space Shuttle, all stations were encouraged to simply insert his/her LAT/LONG as the first 19 characters of his beacon text, everyone within the satellite footprint would not only see when he made a successful uplink, but also where he was. Since the shuttle is a rapidly moving object, the locations of successful uplink stations will move progressively along the ground track. The weakest successful stations will almost certainly be immediately below the spacecraft. Stronger and more viable ground stations can show up further to the side of the ground track. If there is a skew in the spacecraft antenna pattern, the pattern of successful uplink stations on the map will clearly make that evident. The exact format of an APRS position report is as follows:

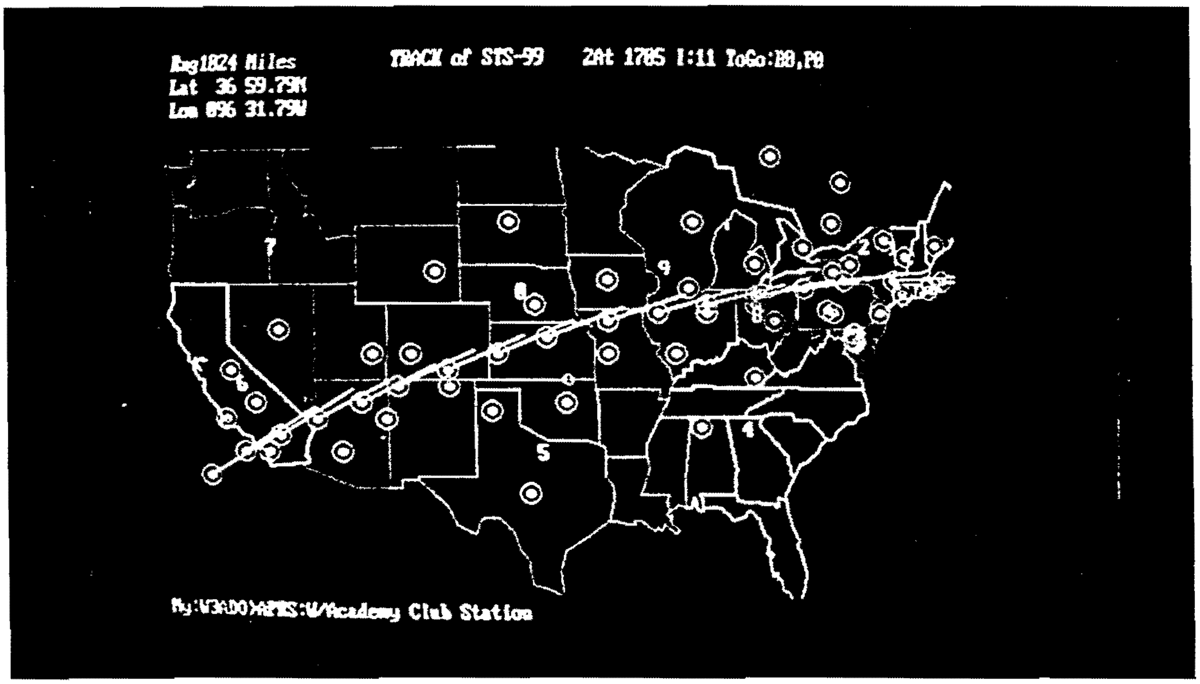
```
Beacon Text:   !DDMM.HHN/DDDMM.HHW/CQ comments etc.....
For example:   !3959.11N/07629.12W/Naval Academy Radio Club
```

To implement this experiment on the next shuttle mission, it would only take a single AMSAT news bulletin to ask all stations to insert their LAT/LONG in their beacon text. No changes onboard the shuttle or MIR would be required. Those stations that had APRS could then watch the successful uplink stations plotted in real time. Even without real time APRS, playback of a captured text file containing all the successful uplink packets would still give an excellent map display after the fact. Analysis of antenna pointing anomalies on every orbit could be accomplished with ease. On future missions, the UI beacon frame might completely replace the current CONNECTED robot mode. Without all of the connect requests, acks, and retries at least a five fold increase in the number of successful uplinks would be realized, and the data exchanged would be more meaningful by a similar factor.

To demonstrate the expected results of this experiment, I have created a track history file that can be replayed using the Ctrl-R command. Simply replay the SHUTTLE.HST file and watch the contacts appear as the shuttle moves across the country. You may enhance the demonstration by selecting to see only the Shuttle, STS-99, or by turning off TAGS using the Alt-T command to reduce the clutter of callsigns on the display. The replay can be speeded up or slowed down by hitting the F or S keys. Obviously, in this SHUTTLE.HST file, I assumed that the Shuttle had its TNC connected to a GPS navigation receiver so that it was also beaconing its position once per minute in the APRS format.

This capability also demonstrates the practicality of using a space based AX.25 digipeater for routine position and status reporting. Imagine a constellation of three AX.25 digipeater satellites all on one FM channel. It would not matter what satellite was in view, or when. Mobile and portable stations could beacon their position once every 5 minutes and be tracked nationwide! Just using 1200 baud AFSK, up to 1000 stations could probably be supported just in the US and have a reasonable chance of getting a position report through at least once every 3 hours! Going to 9600 baud FSK would support almost 8000 users.

The Automatic Position Reporting System (APRS) software was developed to permit the rapid exchange among packet stations of one line status and position reports which contain information of interest to all stations on frequency. It is ideally suited for tracking objects on a nationwide basis via a satellite transponder. AMSAT should consider supporting such a payload on one of the future microsat projects.



This photo shows the APRS display for a simulated track of the Space Shuttle across the US sending its GPS position about every two minutes. All stations who are beaconing their LAT.LONG and were digipeated by the SAREX show up in real time. Callsigns have been suppressed to keep the picture uncluttered.

BALLOON PROJECTS POTENTIAL IN AMATEUR SATELLITES

by

Doug Howard - KG5OA
North Texas Balloon Project

I have just returned from the first annual National Balloon Symposium held in Denver, CO and sponsored by the Edge of Space Sciences (EOSS). First of all, I'd like to commend Jack Crabtree, AA0P, and the EOSS group for putting on such a fine symposium. It was a fantastic kickoff for a facet of Amateur Radio which is really just in it's infant stages! A high level of interest was shown by the attendance of balloon groups from 10 different states and one Canadian group. EOSS even performed a very well executed dual balloon launch for us on Sunday morning!

For those of you who don't know, Amateur Radio Operators have been launching payloads that operate in the Amateur bands on small weather balloons since 1987. These payloads stay airborne for about 2-3 hours and provide communications ranges of up to 900 miles! It is kind of a poor man's satellite project. (See AMSAT Journal, September 1991, "The Poor Man's Satellite", by Andy MacAllister - WA5ZIB) These payloads have included simplex 2m repeaters, crossband repeaters, digipeaters, 10m QRP beacons, telemetry packages (including GPS, LORAN, and VOR), and ATV (color & B/W), among other things. And almost all payloads launched have been recovered utilizing standard Dfing techniques.

There are many similarities between the Amateur Satellite Program and balloon projects. Increase of technology is a main concern, but it also lends itself very well to the education of students of Middle School through College in the areas of electromagnetics, physics, and meteorology, to name a few. The EOSS group, in particular, has been very active in these educational projects.

There have been concerns expressed over the past few years from many parties pertaining to the loss of talent in constructing amateur satellites within AMSAT-NA and also a lack of training of the "new blood" for construction of future AMSAT-NA sponsored satellites. Since the environments are similar in nature, it seems obvious that balloon projects may very well serve as a good first exposure in training of the next generation of amateur satellite experimenters.

Several reports at the National Balloon Symposium indicate that NASA is beginning to realize the potential of weather balloon launches as relatively low cost flight test vehicles for their space-bound experiments. The same potential exists for AMSAT-NA, and in several cases, from within the ranks of it's own membership.

So, it appears that there exists a great potential for coordinated efforts between AMSAT-NA and any number of balloon projects all over the nation. If you are interested in launching a balloon project, please feel free to contact Bill Brown, WB8ELK, at the address below. Also, if you would like a copy of the National Balloon Symposium Proceedings, contact Jack Crabtree, AA0P, at the EOSS address below.

Bill Brown - WB8ELK
12536 T. R. 77
Findlay, OH 45840
(419)422-8206

Edge of Space Sciences
c/o Jack Crabtree - AA0P
4327 W. Bellewood
Littleton, CO 80123
(303)795-7736

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Walter K. Daniel KE3HP
PO Box 1686
Bowie, MD 20717-1686
Internet: ke3hp@amsat.org

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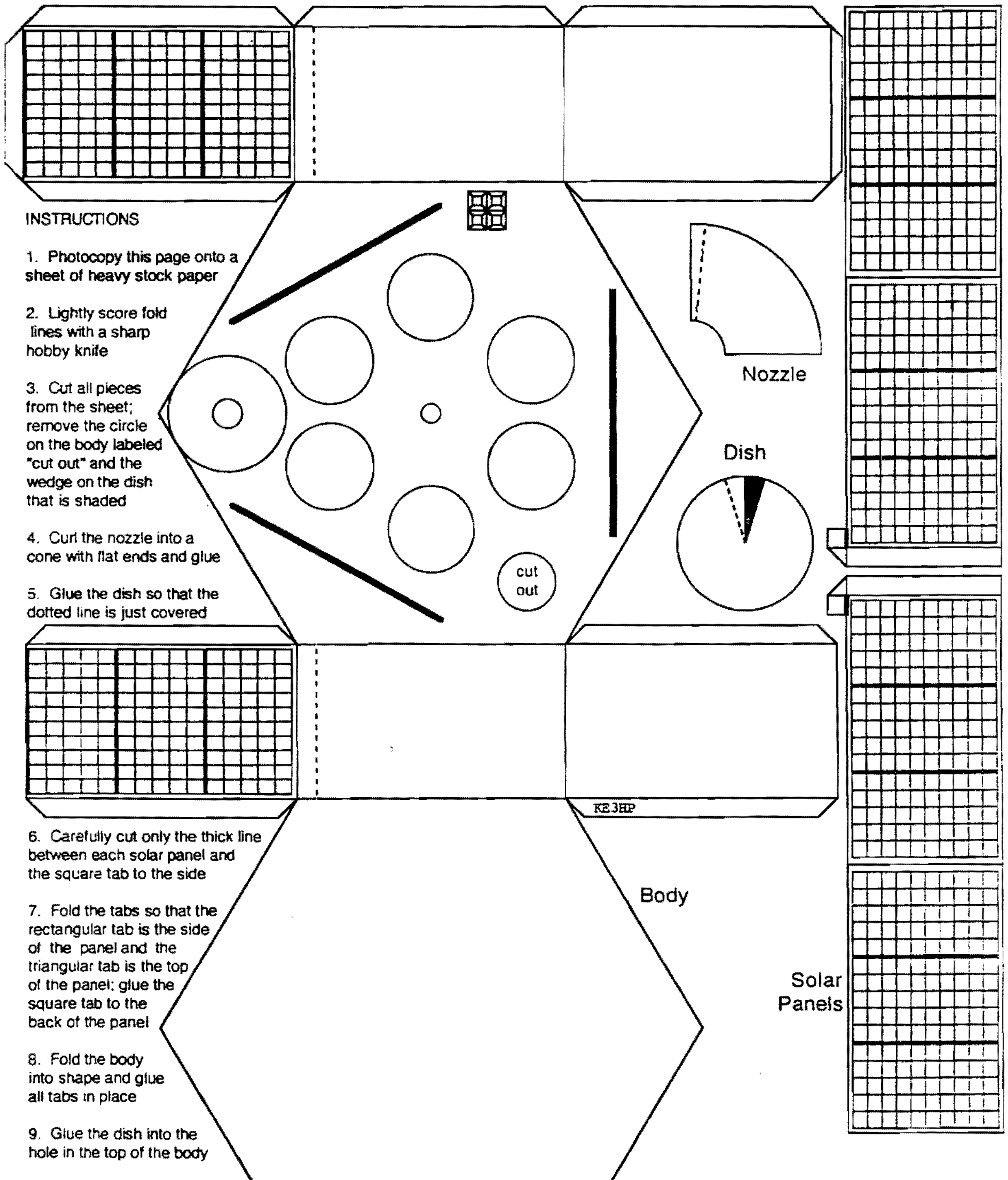


INSTRUCTIONS

1. Photocopy this page onto a sheet of heavy stock paper

2. Lightly score fold lines with a sharp hobby knife

3. Cut all pieces from the sheet; remove the circle on the body labeled "cut out" and the wedge on the dish that is shaded

4. Curl the nozzle into a cone with flat ends and glue

5. Glue the dish so that the dotted line is just covered

6. Carefully cut only the thick line between each solar panel and the square tab to the side

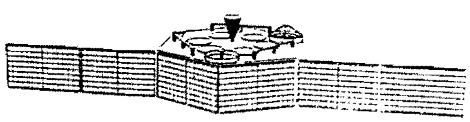
7. Fold the tabs so that the rectangular tab is the side of the panel and the triangular tab is the top of the panel; glue the square tab to the back of the panel

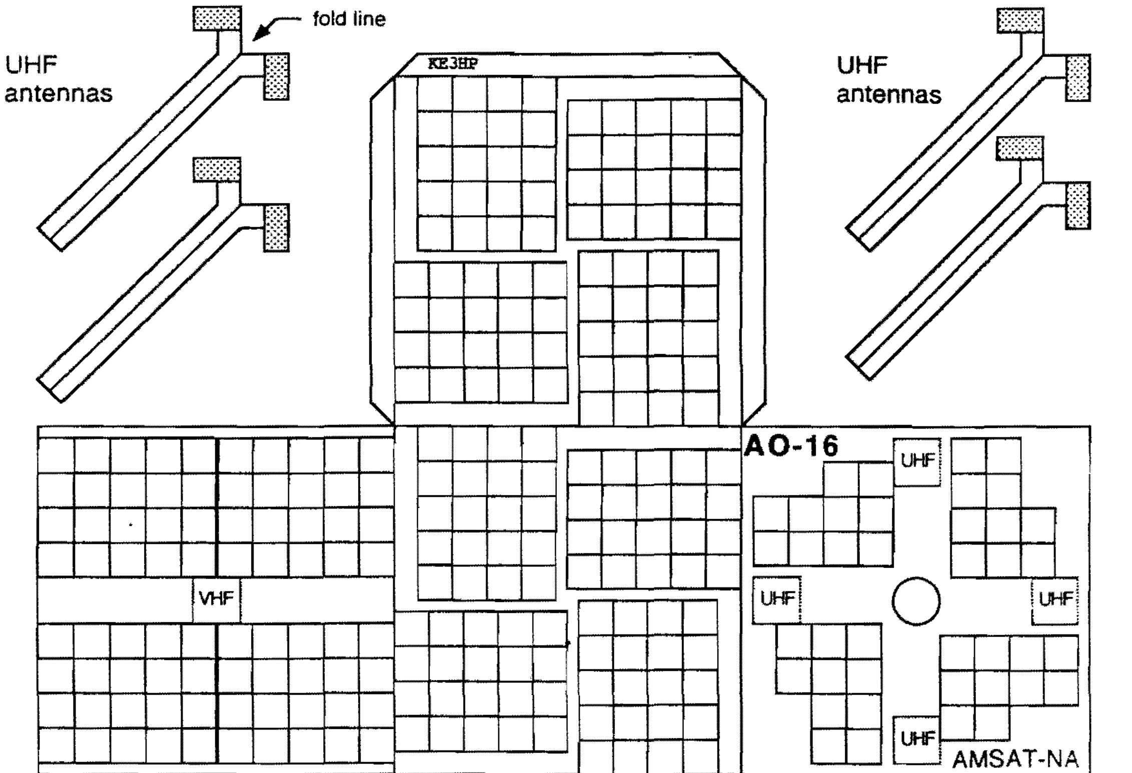
8. Fold the body into shape and glue all tabs in place

9. Glue the dish into the hole in the top of the body

10. Glue the nozzle to the center of the top of the body

11. Glue the solar panels to the sides of the body





INSTRUCTIONS

1. Photocopy this page onto a sheet of heavy stock paper

2. Lightly score fold lines with a sharp hobby knife

3. Cut all pieces from the sheet

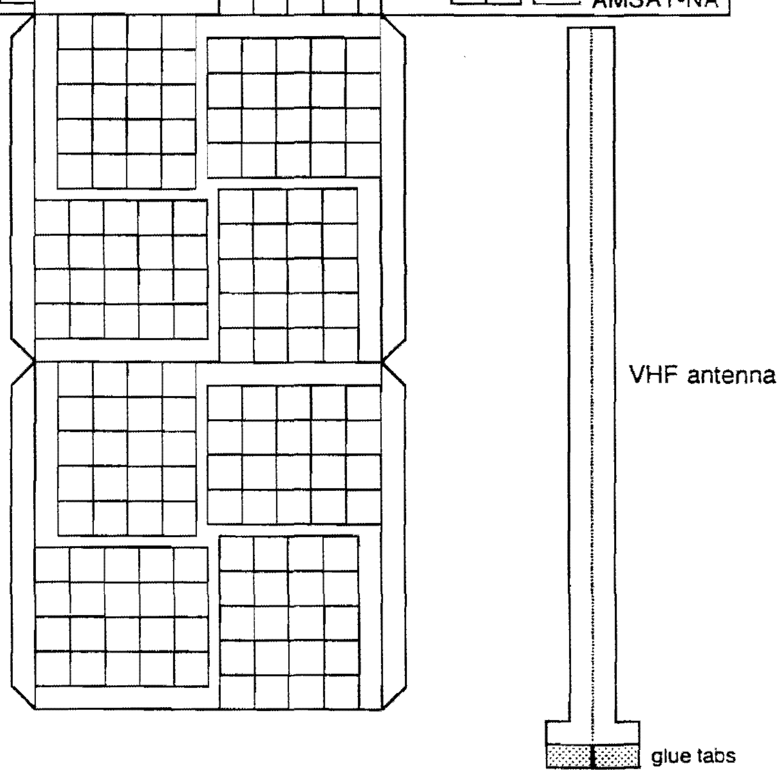
4. Cut the thick line between the two glue tabs on the bottom of the VHF antenna. Fold the antenna along the dotted line and glue. Keep the glue tabs perpendicular to the antenna.

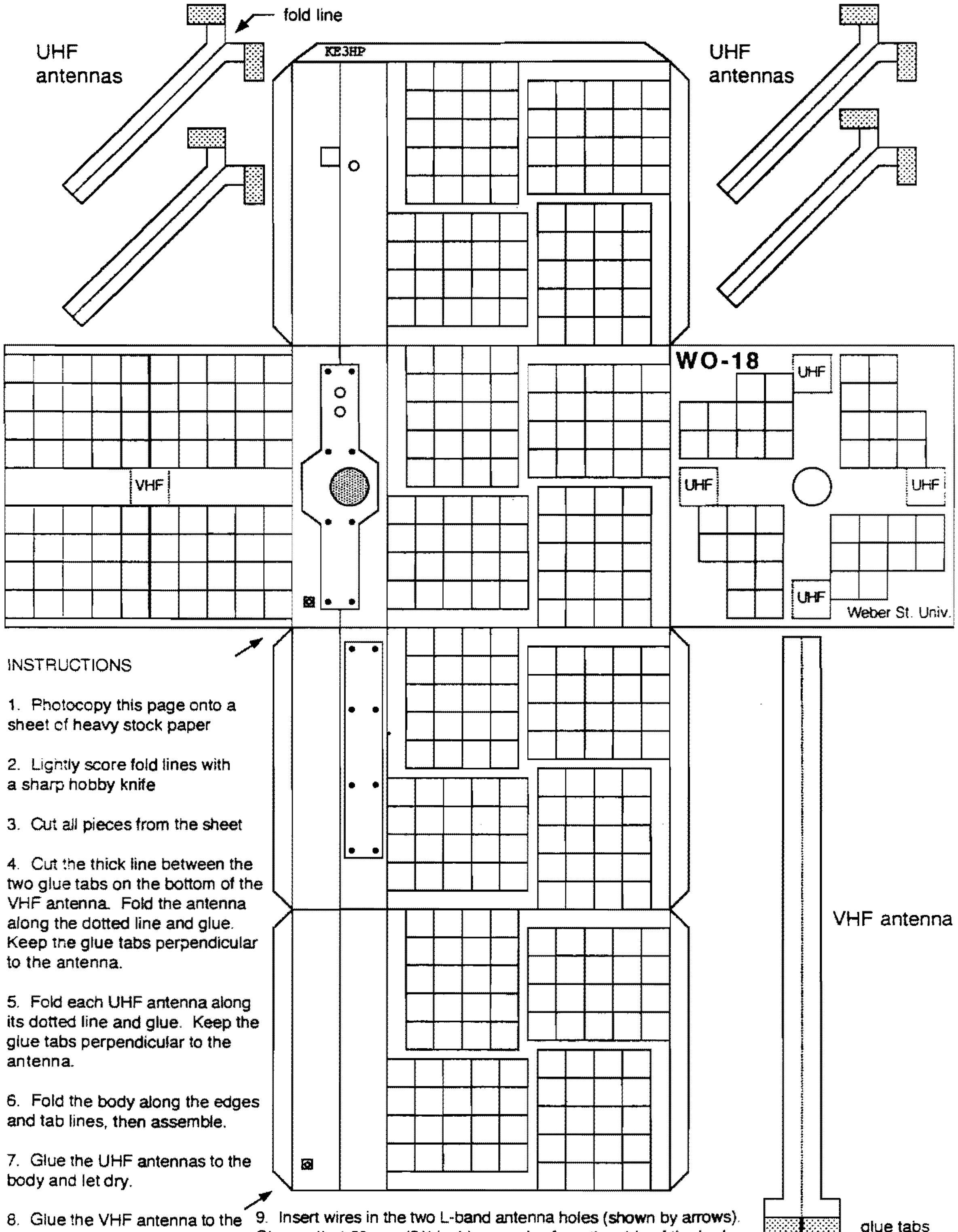
5. Fold each UHF antenna along its dotted line and glue. Keep the glue tabs perpendicular to the antenna.

6. Fold the body along the edges and tab lines, then assemble.

7. Glue the UHF antennas to the body and let dry.

8. Glue the VHF antenna to the body.





INSTRUCTIONS

1. Photocopy this page onto a sheet of heavy stock paper

2. Lightly score fold lines with a sharp hobby knife

3. Cut all pieces from the sheet

4. Cut the thick line between the two glue tabs on the bottom of the VHF antenna. Fold the antenna along the dotted line and glue. Keep the glue tabs perpendicular to the antenna.

5. Fold each UHF antenna along its dotted line and glue. Keep the glue tabs perpendicular to the antenna.

6. Fold the body along the edges and tab lines, then assemble.

7. Glue the UHF antennas to the body and let dry.

8. Glue the VHF antenna to the body.

9. Insert wires in the two L-band antenna holes (shown by arrows). Glue so that 20 mm (3/4 inch) protrudes from the side of the body.