The AMSAT Space Symposium Proceedings

October 19, 20 and 21, 1990
$20.00

The Johnson Space Center, Houston, Texas

The Johnson Space Center (JSC) Amateur Radio Club welcomes you to this year's AMSAT- NA Annual Meeting and Space Symposium. The site is the JSC Visitor's Center which includes numerous exciting space related exhibits including the Lunar Lander and a satellite-capable Amateur station. Regularly scheduled tours of the Center's facilities, frequently including the Shuttle mock-up and Mission Control are available Monday through Friday. Self-guided walking tours are also available Saturday and Sunday.

This year's Space Symposium is taking place in the JSC visitor's Center auditorium beginning at 8:00 A.M. Saturday, October 20th and features talks on many aspects of Amateur space communication and related subjects. See the accompanying agenda of papers and events to the right and the Table of Contents listing of documents.

Saturday evening's activities include a very reasonably priced Texas barbecue and the AMSAT-NA Annual Meeting; featuring reports on the status of AMSAT-NA and its future plans for furthering the Amateur space program, as well as the presentation of awards of appreciation to many who have made important contributions to AMSAT and its related activities. These affairs will be held at the JSC Employee Recreation Center.

Sunday's program consists of a series of talks at the King's Inn, emphasizing fundamentals of Amateur satellite operation.

JSC and AMSAT welcomes everyone with an interest in the Amateur Radio Satellite Program to this year's event.

AMSAT-NA
ANNUAL MEETING AND SPACE SYMPOSIUM AGENDA

Friday King's Inn		
3:00 - 3:50 PM	Jeff Wallach, N5ITU	Satellite Image Processing for the Amateur
4:00 - 4:50 PM	Rich Ensign, N8IWJ	AMSAT-NA Education Activities: Accomplishments, Possibilities and Prospects
5:00 - 5:50 PM	Dick Campbell, N3FKV	AMSAT Orbital Data Management
Saturday		
7:00 - 7:45 AM	King's Inn	CSDP Breakfast
Saturday (day)	**Johnson Space Center Visitors' Center Auditorium**	
8:00 - 8:10 AM	Chuck Biggs, KC5RG	Welcome and Announcements
8:10 - 8:35 AM	Gould Smith, WA4SXM	Decoding Telemetry from the Amateur Satellites
8:40 - 9:15 AM	Jan King, W3GEY	In-Orbit Performance of 4 Microsat Spacecraft
9:20 - 9:40 AM	Tom Clark, W3IWI	AO-13 Orbit
9:40 - 10:00 AM	Break	
10:00 - 10:40 AM	K. Meinzer, DJ4ZC	Report on the Phase 3D Project
10:40 - 10:55 AM	Dick Jansson, WD4FAB	Phase 4 Technology as it Applies to Phase 3D
10:55 - 11:15 AM	David Liberman, XE1TU & Arcadio Poveda	Macromets and Microsats
11:20 - 11:40 AM	Courtney Duncan, N5BF	PACSAT Demonstration
11:40 - 12:15 PM	Jim White, WDØE	Microsat Motion, Stabilization, and Telemetry (and Why We Care About it)
12:15 - 1:00 PM	Lunch	
1:00 - 1:35 PM	John Champa, K8OCL	Full Motion Digital Video Via Amateur Satellites
1:40 - 2:15 PM	Lou McFadin, W5DID	SAREX Hardware for STS-35 and 37
2:20 - 2:55 PM	Ron Parise, WA4SIR	STS-35 SAREX Flight Results
3:00 - 3:25 PM	Bill Clapp, KB7KCM	Astronaut Deployable Satellites
3:25 - 3:45 PM	Break	
3:45 - 4:10 PM	Steve Jackson, WD8QCN	WEBERSAT Operations and Experiment Results
4:15 - 4:40 PM	Courtney Duncan, N5BF	AMSAT-NA Operations Organization
4:45 - 5:30 PM	Bob McGwier, N4HY	The Development of 2 DSP Modems
Saturday (evening)	***JSC Employee's Recreation Center***	
6:30 - 7:15 PM	Attitude Adjustment	
7:15 - 9:00 PM	Texas Bar-B-Que Dinner Honored Guest Speaker Mr. Aaron Cohen Director Johnson Space Center	
9:00 - 11:00 PM	AMSAT-NA Annual Meeting Presidents's Report Current Status of AMSAT-NA Future Plans ARRL Activities (Rosalie White) Status Reports on Various Amateur Space Programs SEDSAT (John Champa) Solar Sail (Emerson La Bombard World Space Found.) DOVE (Bob McGwier) Award Presentations Prize Drawings	
Sunday King's Inn		
7:30 - 8:45 AM	Field Operations Breakfast	
9:00 - 9:55 AM	Keith Pugh, W5IU	Getting Started in Amateur Satellites
10:00 - 10:30 AM	Ed Krome, KA9LNV	Design of an Easy to Build, Versatile, Homebrew Satellite Ground Station
10:30 - 10:55 AM	Allan Fox IV, N5LKJ	Poor Boy Satellite Station
1:00 PM Til	Open house at the world's largest amateur antenna, W5UN	

Note: A shuttle bus will be available to transport attendees between the King's Inn, the Visitors' Center and the Recreation Center.

The AMSAT Space Symposium Proceedings

October, 1990

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Contents of the AMSAT Space Symposium 1990

The Phase IV Project - A Transition to Phase IIID

The Amateur community has not responded sufficiently to the Phase IV program financial needs to continue the spacecraft development at this time. The Phase IV technology that has been developed over the last three years is directly applicable, however, to the Phase IIID program, proposed by ASMAT-DL. The global Amateur community can be well served by Phase IIID, and AMSAT-NA expects to be playing a key role in this effort.

By Dick Jansson, WD4FAB

Phase IV Program Development Effort

The Phase IV program development effort for the academic year (AY) 1989-90 was conducted at Weber State College (soon to be called Weber State University) in Ogden, UT. This effort concluded the second year of such activity at Weber State, which has been very educational for the students, the school and for AMSAT-NA engineering personnel.

Our efforts for AY 1988-89, reported at last year's Space Symposium, helped us evolve a basic spacecraft frame for one concept of a Phase IV called a "pass through" structure, see Fig. 1. Spacecraft structural concepts will be discussed later in this paper. This past year's efforts were aimed at building upon that base of information and to add some important items to the structure. At the start of the academic year, the program plan included the following major goals:

1. Develop the design and manufacturing techniques for deployable antenna arrays for the spacecraft.

2. Develop a Finite Element structural Analysis technique to be employed as an engineering design tool.

3. Develop the manufacturing techniques for fabricating and installing spacecraft system subassemblies.

4. Evaluate improvements in materials and fabrication methods of the spaceframe structural elements.

We did not achieve all of these goals, but the achievements that were made on items 1 and 2 were significant and worthy. The proof of the effort was in performing a low frequency vibration test of the antenna structural elements on the Top Plate of the spacecraft.

Program Accomplishments

A great deal was learned in the engineering and fabrication of light weight composite spacecraft structures. A simplified tubular design of the microwave Helical antenna for L and S band operation was evolved and shown in *The ARRL Handbook*, 1990 edition, Chapter 23. The design lent itself to being fabricated of thin walled fiberglass-epoxy composite material that is readily formed on standard machinery used for making ski poles, etc. Antenna supporting struts were also similarly formed of both fiberglass and carbon fiber epoxy composites and are shown during assembly in Fig. 2.

The assembled Phase IV spacecraft Top Plate with the antenna structures in the (latched) launch position is shown in Fig. 3, and in the on-orbit deployed position in Fig. 4. The long black tube seen in these assemblies is the 2.8m (9ft.) long UHF antenna boom, shown here without elements. Compression moulded UHF antenna element mounts were fabricated as part of this project, but not used in these particular assemblies. Seen in these illustrations is a light weight aluminum supporting frame for the Top Plate which provided excellent access to working on the Top Plate without being bothered with having the main spacecraft structure in the way. Not illustrated here is a large overhead lifting assembly that was built by students to permit the maneuvering of the entire assembled Top Plate from the spacecraft and to place it onto the support frame. This lifting device also permitted the rotation of the Top Plate so that either side would be available for assembly activities. Fig. 5 shows the entire spacecraft with the Top Plate and antennas.

Another item that was needed for the program was an adaptor frame to interface the Top Plate assembly to the large shaker facility at the Air Force's Little Mountain Survivability & Vulnerability Test Center, located near Ogden, UT. The installation of this shaker adaptor is shown in Fig. 6. The environmental area of interest for this test was the vibration regime below 200 Hz, the adaptor did not need to be excessively massive and was formed from 4 in. channel aluminum stock.

The Top Plate assembly is shown in Fig. 7 being lifted onto the shaker table by many hands, and in Fig. 8 ready for test. The actual shake test was almost anticlimactic in the process of just getting the test article to the facility, although some of the

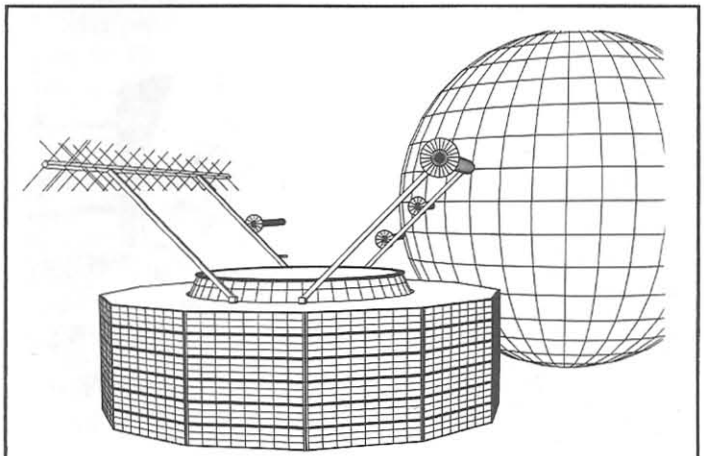


Fig. 1 — 3-D view of Phase IV as might appear in orbit.

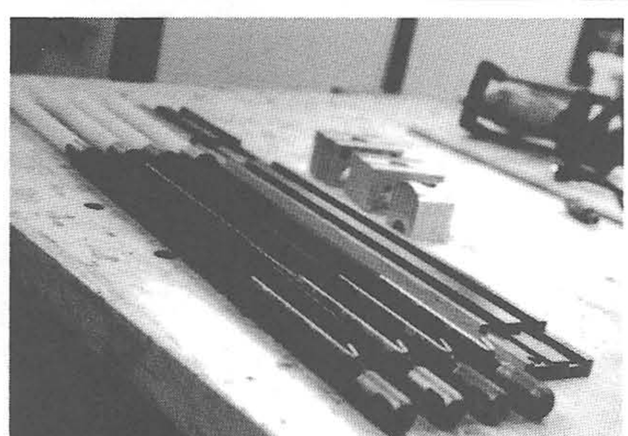


Fig. 2 — Phase IV tubular support strut sub-assemblies.

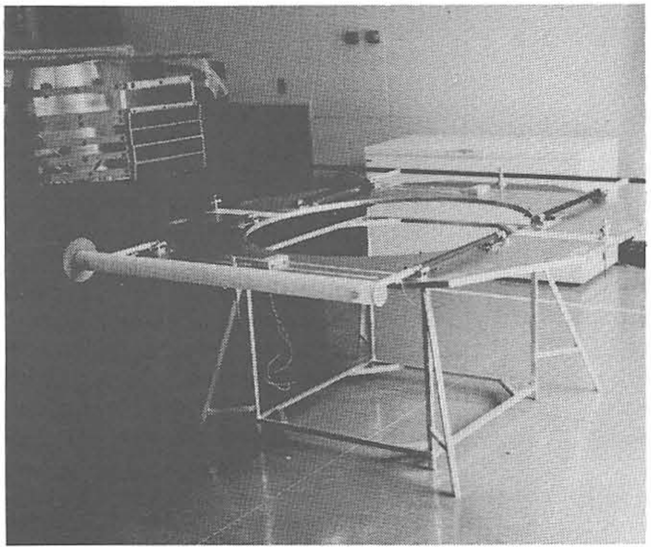


Fig. 3 — Phase IV Top Plate Assembly with antennas in latched launch position.

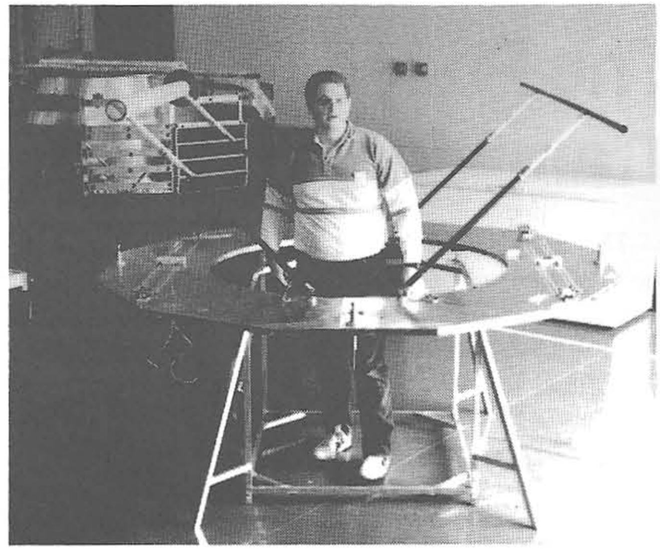


Fig. 4 — Phase IV Top Plate Assembly with antennas in deployed position, student Ken Hill inspecting the assembly.

antenna parts did get pretty excited in the process.

This FEA analytic technique, that was sponsored as part of the Weber State effort, is a computer structural analysis technique that predicts spacecraft responses to dynamic mechanical vibration environments, such as those induced by launch vehicles. Getting into the FEA activities involved another department in the school of Engineering Technology, at Weber State, and another set of students doing that part of the project. This was a timely effort, as we had some of the real hardware for them to examine and evaluate, allowing a feel-and-touch addition to an otherwise paper analytic activity.

The logical conclusion of these two efforts was a mechanical shaker test of the antenna structures to see how their responses agreed to the FEA predictions. Fig. 9 shows the predicted vibration frequencies for several sizes of supporting struts. The model that was shaken used 25mm diameter struts and the L antenna was excited into a severe resonance at 19.5 Hz, not far from the predicted 1st mode resonance projected by the FEA. The UHF antenna assembly also had a pronounced resonance at 25 Hz. Typical launch vehicle requirements are that the payloads have no vibration responses below 50 Hz, as the primary launch vehicle mode is in the 35 Hz range. Clearly, AMSAT engineering needs to do more work in stiffening the antenna supports and a substantial improvement in the antenna restraint hardware and methods, needed for launch. The entire effort was very educational.

In addition to evolving spacecraft design elements and techniques, applicable to nearly any moderately sized spacecraft, we have also added some very useful management and software tools. Program planning and progress tracking computer software tools have been usefully employed in the Phase IV program effort this year. While such steps may seem superfluous for this effort, the Weber State program had a considerable amount of complexity and the resulting Gantt chart had 82 elements. Using such tools, however, requires a considerable degree of dedication by all personnel, and the management information so generated is only as good as the data input. The degree of dedication required is no different than that required in the commercial work place. Obtaining such attention in the student academic environment is another matter, despite good intentions on the part of all parties. For all parties, this has also been quite an educational process.

Aside from the program planning

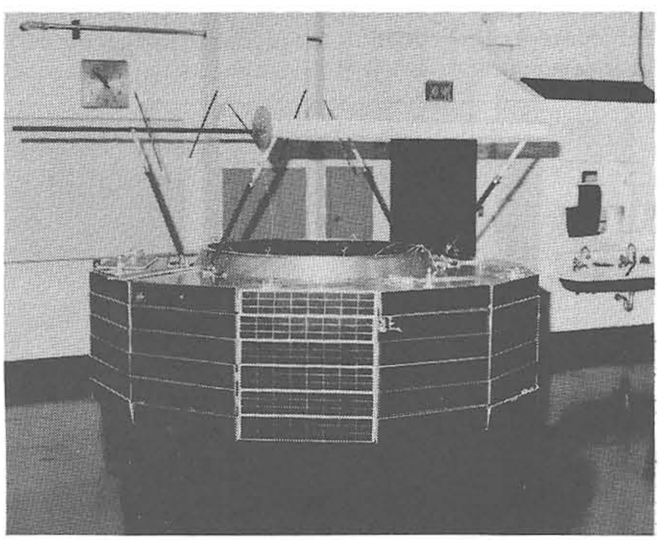


Fig. 5 — Phase IV Top Mounted onto spacecraft.

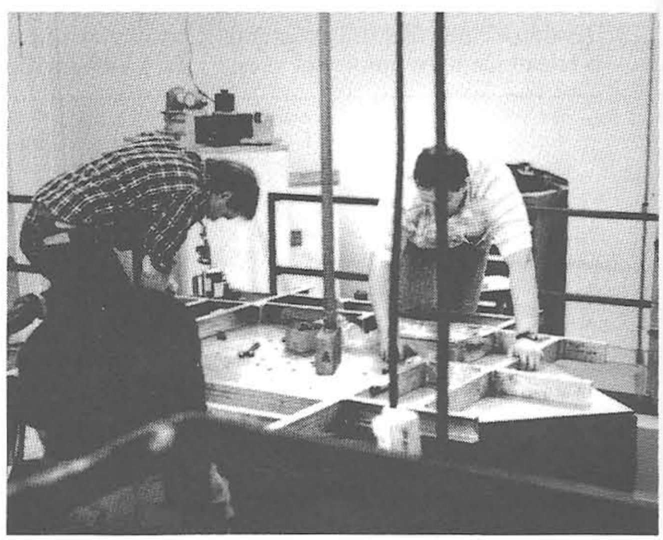


Fig. 6 — Students mounting shaker adaptor structure to shaker table.

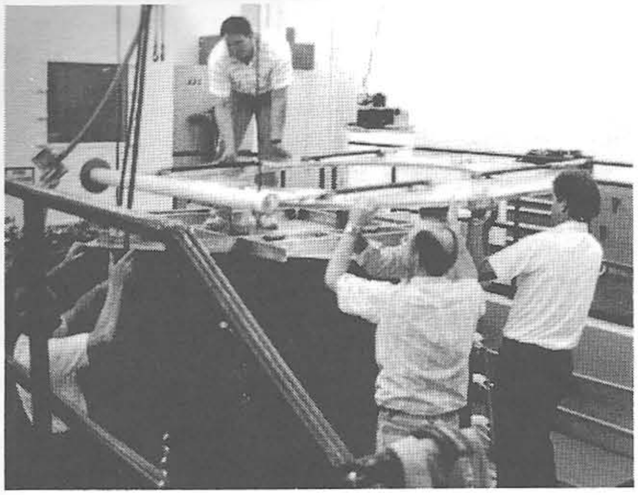


Fig. 7 — All hands mounting Top Plate assembly to shaker. Project student leader, Tracy Rose is on top of the job.

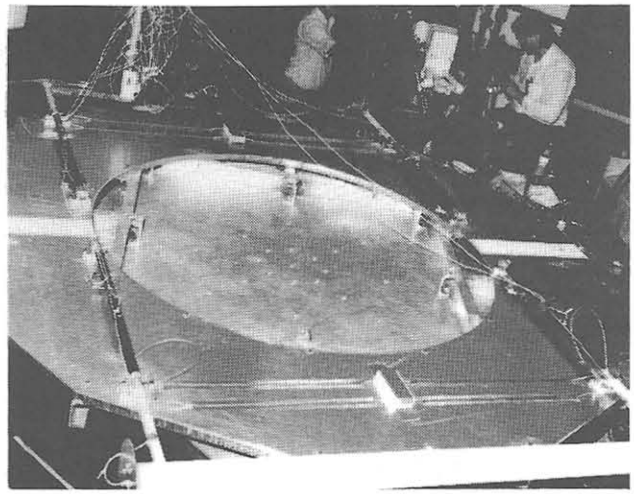


Fig. 8 — Phase IV Top Plate mounted to shaker ready for test.

software, noted above, and an upgrade in the AutoCAD software used for designing AMSAT spacecraft, some major improvements have been made in the thermal design area. A Thermal Analysis Work System (THAWS) package has been made available for us by Weber State College. This software package has a large, fast version of the SINDA thermal analyzer that has been used on Microsat and the Phase IV analyses done to date. The size and speed increases will be very useable for complete, complex model Phase IV (and other spacecraft) analyses. This analytic capability was demonstrated on a non-AMSAT spacecraft project in early 1990. THAWS also has a very sophisticated thermal radiation interchange computation capability, which is an absolutely essential part of a spacecraft thermal analysis. It is expected that we will have a precise knowledge of thermal performance for any future spacecraft long before they are launched. We will not have any hot batteries, as was the case with OSCAR 7.

The Phase IIID Program

Other papers at this Symposium will discuss the Phase IIID mission and operations. It is useful to discuss herein the possible configurations for such a spacecraft. These possibilities boil down to two structural candidates. Based upon the launch vehicle constraints these are: a pass-through design, very much like the Phase IV design studied to date (see Fig. 1); and a stand-alone design that does not contain parts of the launch vehicle within its shell.

As we have studied the pass-through design extensively, and we are prepared to implement such a design if needed, we have not done any equivalent studies on the stand-alone design. Fig. 10 is an engineering drawing for this design, which has been termed (with a little tongue-in-cheek) a cubic 2 meter. Indeed the internal volume is just about 2m³ and it has the power generation capabilities of 3m² of solar panel area, or about 300 Watts, six times that of OSCAR 13. Figs. 11 and 12 are two views of a three dimensional drawing of this configuration.

There are a number of advantages to the stand-alone configuration of spacecraft that seriously argue for its use. This design would only require 32% of the solar cells of the cylindrical spacecraft, as they would be actively oriented for optimum power generation. This would represent a significant cost saving. Spacecraft mass is another issue. The pass-through design is burdened by some 45+kg of launch vehicle hardware and an added 35+kg of added solar panels and cooling heat pipes. All of these added masses require a corresponding increase in propellant mass, used to get the spacecraft to its final orbit. It would be difficult to have a pass-through design spacecraft any less than a launch mass of 400kg and more probably it would be 450+kg. The stand-alone spacecraft design could be as low as 200kg, but it will probably be sized for an expected 250kg launch mass.

The global AMSAT design team is

Fig. 9 — L band antenna vibration performance predictions.

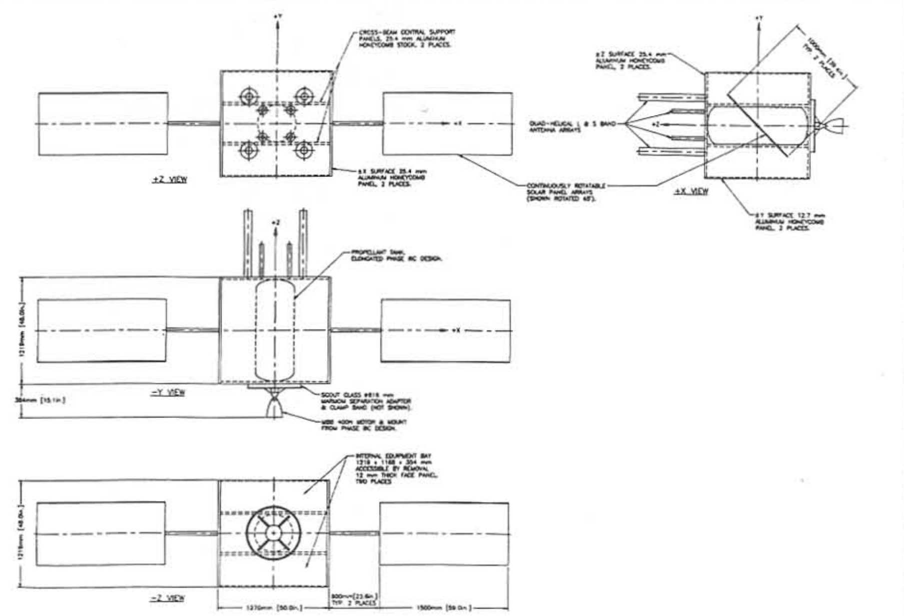


Fig. 10 — Engineering drawing of Phase IIID "Configuration Study."

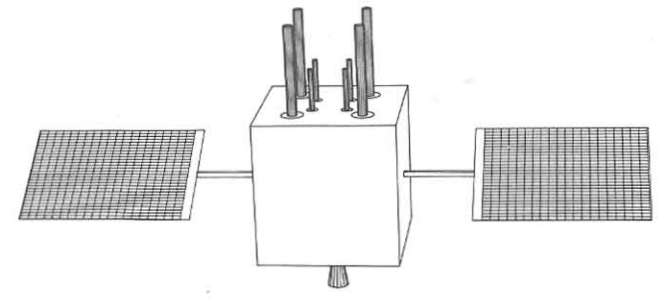


Fig. 11 — 3-D view of Phase IIID.

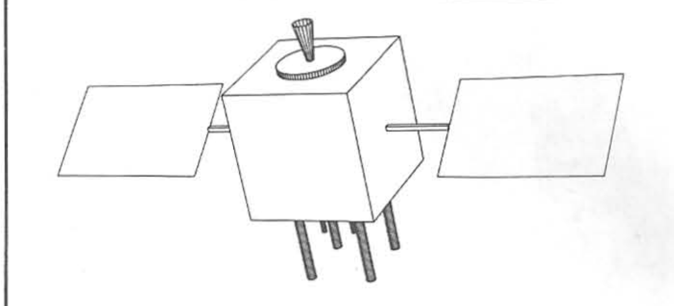


Fig. 12 — Another 3-D view of Phase IIID.

studying many aspects of this mission and it is a really fun part of Amateur radio. Within AMSAT-NA we are studying (among other aspects) the mechanical and thermal designs of such a spacecraft. As a result of the engineering networking done on the Phase IV project, we have members studying the mechanisms for deployment and rotation of the solar panels. Our team is also assembling preliminary FEA models to guide the initial structural designs, and antenna issues. The illustrations shown on these views of Phase IIID contain the tubular Helical antenna design of Phase IV, but in a fixed, non-deployable configuration. Recent investigations have brought to light some possibly useful CP antenna designs that could be implemented on a flat printed circuit board.

Conclusions

Engineering efforts on the Phase IV project have given us a lot of insight into the construction of "small" satellites that are clearly larger than the early OSCARs and the Microsats. While we had hoped to find enough support for us to get one of these satellites into a geostationary orbit, it does not appear that we will be able to achieve that goal.

The Phase IIID project provides us some really new opportunities to show the satellite world that AMSAT is truly THE small satellite innovator and leader in satellite communications technology. Our engineering experience with Phase IV is very directly applicable to Phase IIID.

AMSAT Orbital Data Management

By Dick Campbell, N3FKV
AMSAT Operational Coordinator for Orbital Data Management

Nothing is nearer and dearer to the heart of a satellite chaser than a current set of accurate Keplerian orbital elements. AMSAT responded to this need as personal computers began to proliferate in Ham shacks, pushing aside the *OSCARLocator* as the primary satellite tracking means. The first programs were limited in capability, and data entry was accomplished manually by most users. Vern Riportella, WA2LQQ, then President, began the original distribution of the AMSAT element set format via the weekly Nets and the AMSAT *Amateur Satellite Report (ASR)*. The format with which everyone is now familiar grew out of a desire to make the two line element sets distributed by NASA an easily readable tool for the manual user.

The Keplerian numbers do not appear out of thin air, of course. NORAD has the mission to keep track of all objects in orbit, and it is their radar tracking that generates the weekly data. This is passed to NASA for further distribution to the public. Anyone can obtain a printed weekly listing simply by asking, but this is a service provided by AMSAT to all. With the advent of packet radio and the growth of that distribution network, it was logical to proceed to an electronic format. Two new volunteers emerged on the scene, Courtney Duncan, N5BF, and Ralph Wallio, WØRPK. Courtney would write the software to create the bulletins and Ralph would see that they were put together every week for distribution. For the past several years, you would have been quite familiar with Ralph's call sign if you were catching the weekly AMSAT orbital bulletins. The hard part of all this - element sets still had to be transcribed manually from the NASA mailings. Certainly it was a tedious undertaking, and inefficient in this day of ""workaholic"" PCs, but necessary nonetheless.

Call For ODM

In late 1989, Ralph was unable to continue the weekly chore as Orbital Data Manager, and the duty fell to Courtney, who had assumed duties as the Vice President of Operations in the meantime. When he called for help, I raised my hand (I obviously had been listening to too much telemetry) and took over the weekly duties of distributing AMSAT element sets to the world. The good news was that now all element sets were available electronically from T.S. Kelso and his Celestial BBS. He is participating in a pilot program with NASA for their eventual electronic mailing system. The bad news was that all sets from Celestial were in the 2-line format and no software or standard existed to guide me in the conversion. Those first few releases generated several howls from software users whose files would crash because of extra white space, carriage returns, and extraneous text. However, once those bugs were identified, I was able to put together a software package that makes the whole process automatic and relatively painless, and is compatible with existing tracking programs.

This automated distribution software is written in C and compiled BASIC, and is running on an OS-9 system. Once the elements are downloaded from Celestial BBS, the AMSAT birds are sorted out and the checksum of the NASA 2-line is verified. Then the sets are translated into the AMSAT human readable text and packaged into the packet bulletin format we all know and love. I then place this file on AMSAT's electronic mail service where it is picked off by a host of dedicated volunteers, packet sysops, Net Controls and the *OSCAR Satellite Report* (*ASR's* unofficial successor). This gets the weekly bulletins into the networks and on the air for your use. The whole process takes about 30 minutes, hands off.

My final act is to archive that week's file in the event elements are needed for research, such as the recent AO-13 orbit studies. I am retaining all element sets I have generated in my tenure, and will pass them along whenever needed. I also try to keep my eyes open for new launches and include them in the bulletin when they are of interest to the amateur community, such as the launch of the Pakistani satellite, BADR-1. I am always open to suggestions if we are not carrying something the users would like to see on a regular basis. I do not, however, have control over editing processes that take place down the line, so if your source does not carry a particular set, you need to advise them directly.

Still Some Problems

The current system is not without its problems. There is no documented standard for our format, thus someone else could not easily take over the duties. NASA does not always have correct values for some of our birds, and in fact reports erroneous data on occasion. Witness the FO-20 confusion last spring. NASA/NORAD still has the orbit number of AO-10 wrong in their sets (but the AMSAT release shows the correct value). The weekly release of every element set puts a burden on the packet network when it is not really necessary to update every set every week. But we do like to have the most recent set, don't we? Probably the most glaring omission is the lack of error checking on the user end. While I checksum what I receive from Celestial to ensure I'm starting with a good dump, the user has no way of knowing if the numbers obtained via packet or voice net were transmitted correctly. Finally, I presently do not have the manpower or the means to check the reasonableness or consistency of element sets from week to week. This would be a nice service to provide, and would identify problems early, such as the FO-20 confusion.

The Standard

The need for a published format Standard is obvious, and has been the main thrust of my efforts this year. Not only would a Standard facilitate software developers of new tracking software, it would guarantee compatibility to existing software. It would also allow the easy transfer of duties in our volunteer organization without causing major ripples in the bulletin content. This Standard should provide for future expansion while retaining backward compatibility. It would be nice to eventually add error checking, transponder schedules, and perhaps even Bahn coordinates to the sets. The proposed "AMSAT KEPLERIAN ELEMENT SET STANDARD" is being reviewed by software developers, users and AMSAT Officers for ultimate approval and implementation. Once approved by AMSAT, it will be published, and copies will be available to users and software authors. I mention this here to solicit comments and suggestions from you, the ultimate target, before being etched in stone.

The AMSAT User Community

Early in 1990, I conducted a survey on the voice Nets and via a packet bulletin. The response was international in scope and represented a good cross section of our membership. In this age of high speed turbo megabuck PCs, why (you ask) do we still bother with the inefficient, redundant verbose format that eats up bulletin space and is not conducive to machine manipulation? I'm glad you asked. Surprisingly, the majority of respondents still enter their data manually, therefore the format must be human readable. Also, there is something to be said for "looking" at the Keplerian elements and understanding what the bird is doing. Besides, you should be doing your own reasonableness checks. How else will you know something is amiss? The type of computer used was split between 50% IBM (or clone) and all others. But "all others" is still 50% of the user group, so we have to retain compatibility with a number of machines. The key is not to get machine dependent. The other surprising result was that the most popular source of data was packet and the voice nets, about an even split. Also, many are still using printed media. It is important to serve the entire community, and hence the wide variety of distribution means. The most remarkable comment I received concerned garbled packet data. You would think this would not be possible but apparently it happens. This, more than anything else, dictates the critical need for an error checking "checksum" function at the user end, and has been included in the proposed Standard. Hopefully these and future surveys will steer us to always providing the best service possible. So, the onus is on you, the end user, to respond!

So What's Reasonable?

When you look at your new element set, how can you check that the elements appear correct? And what do they tell about the orbit of this bird? You can gain a better understanding of orbits in general and your operating success in particular if you know something about the parameters and their effect on the orbit. So, a short tutorial is in order.

The first thing you should do is compare the new set to a previous set. The best way to do this is to run the bird on both sets for the same time and make sure the results are nearly equal. Then take a look at each of the parameters. On all types of orbits, the inclination and mean motion will not change appreciably. The highly elliptical orbits of AO-10 and AO-13 will change very slowly, so all parameters should show only a slight change. The argument of perigee precesses only a fraction of a degree per day on these orbits. You should also be aware that NASA (actually NORAD) normalizes all parameters to the ascending node (equator crossing) for the epoch time in the set. That is, the elements reflect the position of the bird at the ascending node at that time. Let's look at each parameter:

a. Catalog Number: this is the reference number assigned by NASA and will not change. Some tracking programs use this to update element sets when reading a Keplerian file.

b. Epoch Time: this number should show the current year and the three digit Julian day (which should be greater than the day in a previous set). The fraction is the time of day in decimal days, and can be converted to hours, minutes and seconds.

c. Element Set: increases sequentially to identify the most current set. This is also modulo 999, so after set number 999, the next set will be number 1.

d. Inclination: by definition, is between zero and 180 degrees measured at the ascending node from the equator. If this number is zero, the orbit is equatorial (and is probably a geo-stationary satellite). A low value indicates the bird stays in the low latitudes. If you live far north or south, your visibility windows would be limited. Most Space Shuttle missions will use a 28 degree orbit and stations above about 45 degrees latitude will never see the shuttle above their horizon. Stations above 28 degrees will never have an overhead pass. Conversely, an inclination near 90 degrees is a polar orbit which will cover the entire earth several times in 24 hours. If it is slightly greater than 90 degrees, the Microsats for example, the orbit will be near sun-synchronous, meaning the bird will appear at approximately the same times every day.

e. Right Ascension of Ascending Node: this is the equator crossing point measured easterly from the first point of Aries and can have a value from zero to 360 degrees. It is this parameter that ties the satellite position to the clock and the earth's rotation. The epoch time given in the set is the time of the ascending equator crossing (node) at this angular position.

f. Eccentricity: describes the ellipticity of the orbit. A value of zero is a perfectly circular orbit, but it must always be less than 1.0 for the spacecraft we are tracking.

g. Argument of Perigee: The angle measured from the ascending node (equator crossing) forward in the orbit to the perigee. This will have a value between zero and 360 degrees and will be the location of perigee at the epoch time.

h. Mean Anomaly: This angle is measured forward in the orbit from perigee to the satellite position, zero to 360 degrees. In a circular orbit, it is the number of degrees from perigee around the circle. Remember we said that the RA of node was the position of the satellite at the epoch time. In other words, the satellite is at the equator at this time. Therefore, the mean anomaly in this set will also be the angle from perigee to the equator. This means that, for circular orbits only, the sum of argument of perigee and mean anomaly will always be equal to 360 degrees (plus or minus a small fraction due to the slight eccentricity). This is another check you can make, but it is only valid for those normalized sets promulgated by NASA.

i. Mean Motion: the number of revolutions (orbits) the bird makes in one solar day. Dividing this number into 1440 minutes / day will give you the orbital period in minutes. It should not vary to two or three decimal places, unless the spacecraft is conducting orbital maneuvers, such as the Space Shuttle or Mir, or if it is near re-entry.

j. Decay Rate: the first derivative with respect to time of the mean motion. Its magnitude varies inversely with the satellite altitude. This parameter will have a very small effect on your output, but can skew results if you are using a set that is several months old. Simply make this value zero in your tracking program if you have an old set, and your solution will be close enough for normal amateur operations. This value represents all of the unmodeled but observed perturbation factors in an orbit. For a new launch, it is useful only after several weeks of data are taken.

k. Epoch Rev: the revolution or orbit number for the given epoch time. It is a nice number to put on your QSL card and tells you something about the age of the satellite, but it does not enter into tracking computations. The orbit number theoretically increments at perigee, but NASA increments at ascending equator crossings. Significant differences will be seen only in the low orbit birds, whose perigee precession laps the equator more often.

The Future

What is in the future for AMSAT orbital data? With the Microsats and FO-20 flying high and providing good signals, it would be relatively easy to include each bird's own current elements in its beacon. Software could automatically read that transmission and update your tracking software. Establishing a corps of volunteers to track and check the elements we release would validate our data and could even lead to a capability to compute our own element sets, a technical challenge that may be appealing to some. On the bulletin side, I will investigate modifying the release schedule so that current sets are available only as often as necessary for the type of orbit, thereby relieving congestion on the distribution network. There will be many fun things to do, but all requiring volunteers who like to write software, reduce telemetry, operate packet and landline BBSs, or verify orbits. I will be receptive to all takers, and if you have a favorite bird you would like to start watching, let me know and I will get you involved. My first real requirement is for an assistant or two, someone who can also pick up the weekly duties on occasion (so I can go on vacation and you still get your data!).

All in all, I have really enjoyed this job and hope you will get involved too. We are part of a great organization and it needs your active support. We have a challenging future ahead of us as we upgrade our capabilities. Catch me "on the birds", I look forward to meeting you and discussing these issues.

How Can I Help?

AMSAT-NA Operations

AMSAT-NA Operations has initiated or continued several membership service and involvement programs during the past year. They include: AMSAT News Service: Dave Cowdin (WDØHHU) Director; Command Station Development Program: Bruce Rahn (WB9ANQ) Coordinator; Digital Gateways: Harry Morton III (WB2IBO) Coordinator; DX Operation: John Fail (KL7GRF/6) Coordinator; HF Nets: Wray Dudley (W8GQW/7) Manager; Operations Net (AO-13): Courtney Duncan (N5BF/6) Acting Manager; Orbital Data Management: Dick Campbell (N3FKV/5) Coordinator; Pacsat Management: Courtney Duncan (N5BF), Trustee; Software Exchange: (manager position currently vacant); Telemetry Archive: Reid Bristor (WA4UPD) Coordinator; and Telephone BBS Network: John Wisniowski (N6DBF) Coordinator. Expansion of these and other programs and projects is planned. In this talk, these Operations activities will be discussed and those not covered in their own Symposium talks will be presented in greater detail. Discussion from the floor is welcome.

By Courtney B. Duncan, N5BF
AMSAT-NA VP Operations

Introduction

One of the most common questions asked by new AMSAT members and old hands alike is, "What can I do to help out?" Making an effective contribution to an organization depends largely on knowing what needs it has compared to the talents, skills, and time the members have; being able to connect them together; and being realistic about all of them. In this paper, I'll describe several ongoing projects within AMSAT-NA Operations where satellite operators can be involved from their own stations. I'll also briefly mention AMSAT-NA Field Operations and AMSAT-NA Engineering as areas where participation is possible. Of course, no list like this can be exhaustive but the intention here is as much to inspire new ideas and suggestions as to advise about current opportunities.

As AMSAT continues to evolve and personnel come and go, the names and contact points will, naturally, change. For the latest information on contacts, contact me directly or contact AMSAT-NA Headquarters.

I am:
Courtney Duncan, N5BF
AMSAT-NA Vice President Operations
4522 Ocean View Blvd.
La Canada, California 91011-1419
Headquarters is:
The Radio Amateur Satellite
Corporation
P. O. Box 27
Washington, DC 20044
301-589-6062

So, what can you do to help out? It depends basically on two things: Where are you (geographically, temperamentally, financially, in terms of training and abilities, amateur radio, amateur equipment, satellite equipment) and what are your interests. This second question - What are your inter-

The Author, N5BF, shown at his operating position.

ests - may seem simple, but for most it is the most difficult and elusive question of all, particularly in volunteer settings.

In deciding what you would like to do to help out, think about what you are doing now. When you have free moments for your hobby, what do you do? Do you design circuits? Work on kits? Make contacts on the air? Pass traffic or run phone patches? Go to club meetings or conventions? Write articles? Write software? Chances are your best areas of service will be extensions of activities you already enjoy and already know something about how to do.

For the past couple of years, several of us in AMSAT Operations have been working to make the whole process of getting involved and of making important contributions to the amateur satellite cause somewhat less painful, though it is not yet totally painless. The idea is to consciously think about what needs to be done and how it can be accomplished, then to set up programs designed to make the incremental steps smaller, the individual encouragement greater, and the overall product coordinated.

Operations

AMSAT Operations comprises many diverse departments encompassing virtually everything not handled by Engineering, the branch that builds the satellites and gets them launched; Field Operations, the branch that represents AMSAT at hamfests and provides localized Elmering; and business management.

(1) AMSAT News Service: Dave Cowdin, WDØHHU, Director

The people involved with the AMSAT News Service (ANS) collect information about amateur radio space activities (primarily amateur satellite and manned space projects), compile them weekly, and provide a set of bulletins that are distributed via packet radio and telephone bulletin boards, and that are read on various AMSAT nets. The news sources are generally reports from electronic mail users, personal contacts, trips, and occasionally other amateur publications. Due to attrition and the fact that ANS bulletins are expected every week, though some of the writers have jobs, personal lives, and vacations to attend to, there is always a need for more reporters.

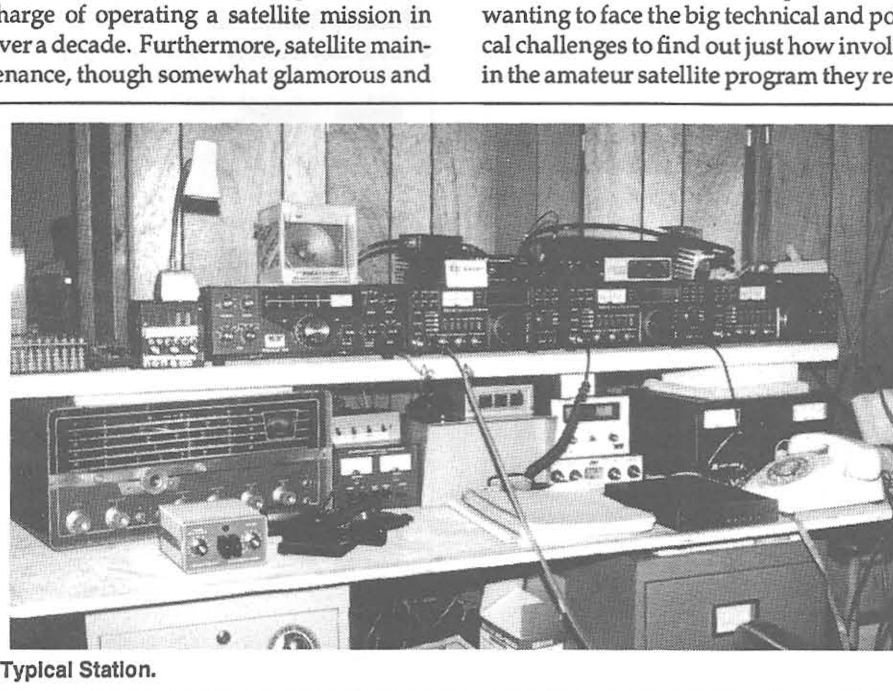
To volunteer, contact:
Dave Cowdin, WDØHHU
8325 S. Yukon St.
Littleton, Colorado 80123-6144

(2) Command Station Development Program: Bruce Rahn, WB9ANQ, Technical Coordinator

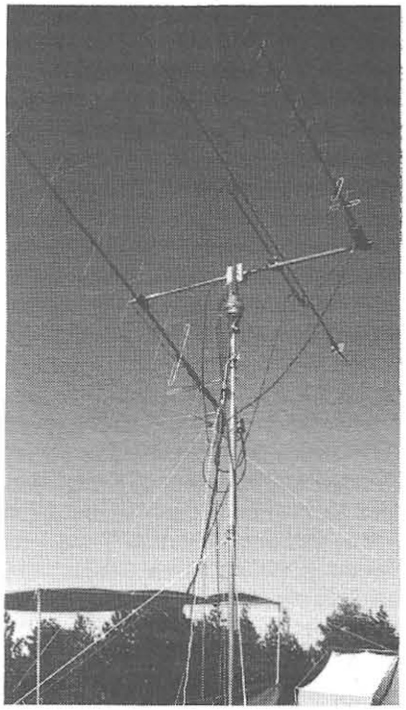
Up until AMSAT-OSCAR 16 was launched in January of this year, AMSAT-NA had not been the lead organization in charge of operating a satellite mission in over a decade. Furthermore, satellite maintenance, though somewhat glamorous and shrouded in high-tech mystery, is actually a nitty-gritty job requiring the utmost devotion for long periods of time. In short, it is normal to burn out amateur command stations. Meanwhile, many "middle level" jobs that require some technical competence and could be very interesting and beneficial to the whole satellite community simply don't get done because the command personnel are too busy keeping up with satellite operation and no one else knows what needs to be done. Also, the working structure within AMSAT-NA is rather intimate and intense. Thus, it is often difficult for new volunteers to overcome the personal and technical obstacles that exist between the state of being a satellite enthusiast and the state of being an integrated participant in the overall program.

The Command Station Development Program (CSDP) was established to address these issues. Through a series of challenging, graded "Levels," a candidate operator progresses from the basic ability to make contacts on or with satellites, through an overview of satellite telemetry and maintenance, culminating in a specialization in some area of study or performance of interest to both the operator and AMSAT. They are expected to be the main sources of in-depth information about satellite operation and status in AMSAT within their special areas of concentration.

This has really worked well. Several current project coordinators and other key Operations volunteers were initially identified and tasked as a result of CSDP applications. Several others have been able to make important contributions that would have been much more difficult without the CSDP structure. CSDP is the place for those wanting to face the big technical and political challenges to find out just how involved in the amateur satellite program they really



Typical Station.



Field Day antennas.

can be.

To volunteer, send an SASE to:
Bruce Rahn, WB9ANQ
410 Coronado Trail
Enon, Ohio 45323

(3) Digital Gateways: Harry Morton III, WB2IBO, Technical Coordinator

With the advent this year of four new satellites intended primarily for use as "PACSATs," UO-14, AO-16, LO-19, and FO-20, one of the main uses envisioned for the first three is to serve as the medium for worldwide packet mail forwarding and bulletin dissemination. Also, DO-17 and WO-18 are expected to transmit digital information of a general or educational nature. As the protocols, special techniques, and software are now under development for these tasks, the Digital Gateways project is in its infancy. WB2IBO is currently maintaining a list of stations worldwide who would like to configure as Earth-to-satellite gateway nodes, and he will be working with them to get the nodes established and into operation as the techniques develop. Though a little out of the individual operator-to-satellite tradition in the satellite service, Digital Gateways promise to have an impact on amateur radio as great as anything ever done with satellites. And, now is the time to get in on the ground floor.

To participate, contact:
Harry B. Morton, III, WB2IBO
261 N. Chestnut Street
North Massapequa, NY 11758

(4) DX Operation: John Fail, KL7GRF/6, Operational Coordinator

One of the biggest avocations within the world of amateur radio is DXing. We can tell that amateur satellite operation is beginning to make inroads into the mainstreams of amateur radio because of the increasing popularity of operational activities like DXing. KL7GRF/6 is a central figure in a widespread effort to encourage, enable, and Elmer satellite operators in DX locations, including both DXpeditions and local permanent residents. Currently, over 120 countries are represented among the thousands of AO-13 and AO-10 operators worldwide. Several amateurs have earned satellite DXCC or even AO-13 DXCC. In tackling this hefty challenge, the DX intensive operators provide considerable general and popular support for AMSAT projects and pragmatic knowledge of satellite operating conditions and access windows.

The best way to get involved in satellite DXing is to just show up on AO-10 or AO-13 Mode B on 145.890 MHz, or on AO-13 Mode J/L on 435.960 MHz, and simply join the group. Or, contact:

John Fail, KL7GRF/6
6170 Downey Ave.
Long Beach, California 90805

(5) HF Nets: Wray Dudley, W8GQW/7, Manager

Camaraderie and information are important to AMSAT members as is AMSAT's exposure to active amateur radio operators who are not yet satellite operators. For this reason, AMSAT manages or recognizes several regional HF and localized VHF/UHF nets around North America and around the world. As with the AMSAT News Service, running a net week after week, or running it alone, can prove to be a difficult personal burden. There is always a need, therefore, for new Net Control and Bulletin Stations to service and back up the vast array of AMSAT nets. The AMSAT Net in your region or local area undoubtedly needs extra Bulletin Stations or Net Control Stations for the rotation, and if your region or local area doesn't have an AMSAT net, it should!

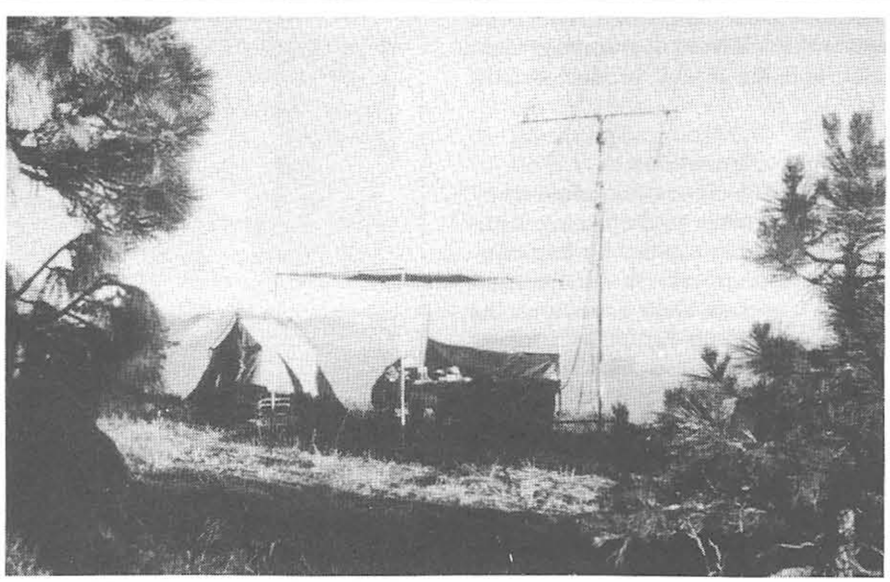
If your station is adequate to the task of supporting a net and if you are so inclined, this is an important way in which you can help out and be on the leading edge of the AMSAT information all at once.

Contact:
Wray Dudley, W8GQW
P. O. Box 1521
Tubac, Arizona 85646

(6) Operations Net (AO-13): Courtney Duncan, N5BF/6, Acting Manager

With the advent of hemispherical coverage satellites like AO-10 and AO-13, hemispherical nets and round tables have now become possible. Although these Molniya-orbit transponders do not allow the convenience of a net "every Saturday at 7 p.m.," it is still possible to draw and maintain a crowd on a regular basis on these satellites. The AMSAT-NA Operations Net exists for the purposes of demonstrating that this can be done, assisting and informing participants, and acquainting satellite operators with each other and with AMSAT managers. Over 250 different stations have participated in over 50 sessions over a period of two years. Topics have ranged from satellite DXing, to Mode S, to general round tables and late breaking news. We hope that other nets with different purposes or in different geographic locations will be established on the satellites following the model of the existing Operations Net.

The Operations Net is in need of volunteers for Net Manager and Net Control



OSCAR Field Day setup.

Station duty. This is another opportunity to get in on the ground floor of something new and beneficial in amateur radio.

Contact:
Courtney Duncan, N5BF
4522 Ocean View Blvd.
La Canada, California 91011-1419

(7) Orbital Data Management: Dick Campbell, N3FKV/5, Technical Coordinator

Each week, in parallel with the AMSAT News Service, AMSAT releases into amateur packet radio and AMSAT nets orbital element sets for satellites of interest to radio amateurs. While this process as it now exists is semi-automated, there is much potential for expansion and enhancement, and for coordination with other AMSAT projects. Soon, for instance, the digital satellites may begin to carry orbital elements furnished from this department. Later, AMSAT may develop a tracking network capable of providing or refining this data. There is currently a need for an assistant Orbital Data Manager to fill in for N3FKV as required and to help with forward-looking, developmental programs.

Contact:
Dick Campbell, N3FKV/5
216 Coventry Dr.
Hewitt, Texas 76655

(8) PACSAT Management (under development): Courtney Duncan, N5BF, Trustee

As the Microsats transition from developmental to operational status, many tasks must be undertaken by AMSAT Operations to monitor and regulate all facets of the AO-16 mission, and to assist and to cooperate with the other OSCAR satellite operators worldwide in managing their missions. Many interesting tasks are anticipated including station automation (possibly standardized) for telemetry collection and data exchange. Entry paths into these activities largely fall in other areas (such as CSDP, Digital Gateways, or the Telemetry Archive) but many odd or currently unanticipated jobs are expected to arise as well, which will be handled by new subsets of the Operations organization. Three new operational command stations: WB9ANQ, WDØE, and N5BF have been commissioned to supplement and eventually take over the Pacsat management now done by engineering development stations N4HY and NK6K. Watch this space for further developments.

(9) Software Exchange: (manager position currently vacant)

The AMSAT-NA Software Exchange serves as the clearinghouse for computer programs relevant to amateur satellite operation. This includes tracking, telemetry, scientific, and utility programs for a variety of personal computer systems. Most of this software is donated or assigned to AMSAT, and it is distributed for fund raising donations.

Although mechanisms are in place for adding software packages to the exchange and for producing and distributing copies, there is a need for a program manager. This manager will set and maintain standards, oversee submissions and distribution, work with publications, keep up with AMSAT programmers, deal with other organizations, and generally keep an eye on the personal computer scene as it applies to amateur satellite work so as to provide the best possible match between the needs of the users and the work of the programmers.

(10) Telemetry Archive: Reid Bristor, WA4UPD, Technical Coordinator

With the simultaneous launch of four microsats and two new UoSATs early this year, AMSAT-NA decided to start maintaining computerized archives of satellite telemetry data. This provides a centralized point for telemetry watchers to send the data they take, and for engineers, researchers, and educators to access collated and organized data for various sorts of study. Amateurs have been making regular contributions to the Archive for several months and a few volunteers have conducted very interesting studies. Examples are the Microsat Dynamic Stabilization analysis performed by Jim White (WDØE) with assistance from Jan King (W3GEY) (presented in another Symposium paper) and a statistical analysis of Microsat telemetry parameters performed by Edwin Albert (KF8EE).

WA4UPD can use some assistance in maintaining and expanding the Archive, but at this time the greatest need is for regular, consistent contributors of data. AMSAT is developing an awards program to recognize consistent and regular telemetry data submissions.

For details on data submissions, requests, and Archive management, contact:
Reid Bristor, WA4UPD
4535 Deerwood Trail
Melbourne, Florida 32935

(11) Telephone BBS Network: John Wisniowski, N6DBF, Operational Coordinator.

Amateur radio alone does not yet offer the speed, reliability, and universal coverage desired by some for distribution of AMSAT news and information. Amateur satellite based techniques for handling such information are now within reach but are not yet implemented. Many dial-up BBSs around the country and around the world carry the information, however, and their efforts are coordinated and standardized by N6DBF. There are needs for bulletin board or packet bulletin board outlets in many places.

To be included in the land-line based system contact:
John Wisniowski, N6DBF
1706 Roanoke St.
Placentia, California 92670

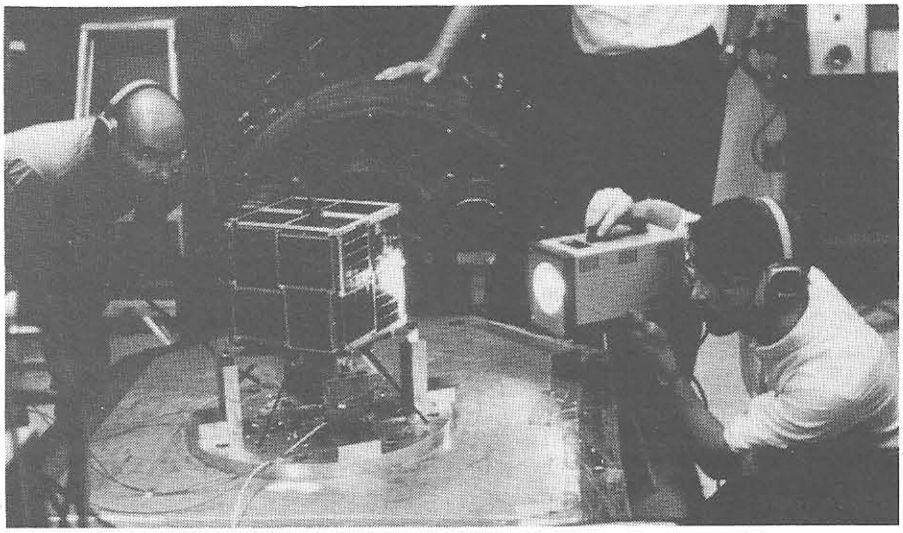
Other Operations Projects

Long standing programs which deserve recognition and support but which I've not discussed at length include (but are not limited to) the AMSAT Awards Program under Andy MacAllister (WA5ZIB) and the Satellite QSL Bureau under Perry Yantis (WB8OTH).

A number of other projects are currently dormant for lack of time or volunteers. These include Frequency Coordination Representation and Education Team, Techno Sports (except for the ZRO test program which is quite active and popular), Speaker's Bureau and Video Library, and Analog Gateways.

One new area where progress is being made is in Inexpensive Product Development (such as low end satellite capable stations, DSP hardware and software, and phased array antennas). Ed Krome (KA9LNV) is presenting a talk at this Symposium about his work with such equipment. Over the next year development work here may lead to hardware kits and new software available from AMSAT.

One exciting development in this vein is the advent of very low cost microwave components and circuit board techniques. Years ago, a microwave transmit or receive converter strip was a delicate and expensive piece of equipment. Each stage had to be carefully tuned with specialized test gear and optimized with a combination of skill, intuition, and luck. Today, a circuit performing the same functions can be built from $50 or less worth of parts. Although size and dimension are still critical, most of the delicate work is done through innovative integrated circuit fabrication and printed circuit board design techniques. Simple active devices known as "Microwave Monolithic ICs" or MMICs are physically very small and have four leads. Two are grounds, one is RF input, and the other is RF output-DC input. Each stage whether oscillator, amplifier, multiplier, or mixer consists of one of these MMICs, a supply resistor and coupling capacitors. In most cases there are no tuned or tunable parts. The remarkable thing about MMICs is their cost: about $1 apiece, $3 or more for higher power versions. Filtering is done by special trace patterns printed on the host circuit board. Construction is simple. Test-


The process of building a satellite.

ing can be done with a VOM.

Power generation at microwave frequencies is still expensive but, because of the elegance, simplicity, and low cost of the MMIC-with-PCB-filter technology, I now recommend that satellite operators contemplating the next move beyond the basic Mode A/B/J capability go next to Mode S. As with all weak signal work, good preamplification is required, but antennas are simple and good success with a 2.4 GHz receive converting system is easily within reach for anyone now able to operate Mode B. Further, this is another investment in the future. Most new satellite projects now being planned will include and even emphasize 2.4 GHz downlinks.

AMSAT also welcomes discussions with other organizations and other hobbyists with similar goals. For example, AMSAT may provide amateur radio command and telemetry equipment for an experimental, non-profit, solar sail demonstration vehicle under development by the World Space Foundation with sponsorship from the Planetary Society and other organizations. If you are connected with an educational or non-profit institution or project like this and think that cooperation with AMSAT might be mutually beneficial, speak up!

As you can see, virtually all departments within AMSAT Operations need additional workers, leaders, and innovators.

Field Operations

Field Operations is the organization within AMSAT-NA that comprises our main interface to the rest of amateur radio in general. Active satellite operators in various geographic areas throughout North America (Canada, Mexico, and the U. S.) are appointed "Area Coordinators" for AMSAT-NA. They then represent AMSAT by giving talks at club meetings; sponsoring booths featuring AMSAT demonstrations and materials at nearby hamfests, conventions, and swap meets; passing out information on local and regional nets (HF and VHF); and making themselves generally available as satellite "Elmers" within their area.

The "Areas" (usually defined by the QTH of the Area Coordinator and the distance he is willing to drive to do these duties) are grouped into several regions on the continent which are managed by Regional Coordinators. These in turn report to the AMSAT-NA Vice President for Field Operations, Jack Crabtree, AAØP, who is appointed by the AMSAT-NA Board of Directors. Regional and Area Coordinators also work closely with Martha Saragovitz, the AMSAT-NA Headquarters Office Manager, arranging for AMSAT materials which are distributed for donations at amateur radio meetings and conventions.

To volunteer as an Area Coordinator, contact:

Jack Crabtree, AAØP
AMSAT-NA Vice President for Field Operations
4327 West Bellewood Dr.
Littleton, Colorado 80123

Engineering

Most amateur satellite enthusiasts are fascinated by the prospect of working on a piece of hardware that will actually fly in space, then potentially being able to use it once in orbit. This is sometimes seen as the "ultimate trip" within AMSAT. You have read by now that now that there is much more to the Radio Amateur Satellite Service than designing, building, and launching satellites and that there are many ways to be involved as deeply as you want and have as much fun as you want without ever getting near any orbiting hardware. There are some peculiarities to the satellite construction business that you should know about, but, if you are in the right place at the right time with the right abilities, you too can help to "build a bird."

Satellite construction tends to be much more geographically localized than satellite operation does, though the trend recently has been away from this whenever possible.

The Microsats, for example, were designed and built in modules all over North and South America. The receivers were designed and prototyped by Tom Clark, W3IWI, in Maryland. The power modules were designed and prototyped at ARRL Headquarters in Connecticut by Jon Bloom, KE3Z. Thermal and mechanical design and specification and most of the working drawings were done by Dick Jansson, WD4FAB, in Florida. The computers were designed and constructed by Lyle Johnson, WA7GXD, with significant assistance from over a dozen other people. The transmitters were designed and prototyped in Colorado by Mataj Vidimar, YT3MV, a visiting Rhodes Scholar from Yugoslavia. Special Microsat "payloads" came from Argentina, Utah, and other locations. Much of the mechanical work was done at Weber State University, which was, of course, sponsoring its own satellite, WEBERSAT.

Assembly actually spanned North America in several marathon sessions. Integration occurred in the AMSAT-NA lab in Boulder and space qualification testing was done in commercial facilities donated by Martin Marietta, Littleton, Colorado, a deal arranged by a key AMSAT volunteer, Jack Crabtree, AAØP.

This project description is representative but not an exhaustive account of who and what was involved.

A satellite construction project is very involved and challenging. It must meet a hard deadline, the time and place of a free or affordable launch. To pull this off in an environment of donated materials and volunteer labor, a seasoned, cognizant, knowledgeable, dedicated, and firm project leader is needed. He must be able to lead local and long distance volunteers, interface with professionals in the field, and work cooperatively with international partners in similar organizational structures. AMSAT-NA has been very fortunate to have had such a person in place for over two decades.

To get involved in satellite construction, the person to contact in North America is Jan King, W3GEY, the perennial AMSAT-NA Project Manager. Parts of the satellite projects are farmed out to various locations, but to be really involved, you will either need to live within driving distance of Jan and the AMSAT lab, or will have to plan on making several trips to that area to be involved in key integration and testing activities. Also, a significant communications effort utilizing electronic mail, amateur radio, and telephone long distance accompanies any effort. (But, let's face it, amateur radio is not as dependable, nor as QRM free, nor as secure as some of these communications need to be. Also, many of the main players in a satellite construction effort may not have ready access to a sufficient amateur station. Their contribution to the hobby is not a world class amateur station in their home, it is satellite engineering. By contrast, everybody has a telephone.) Often, as was learned with Microsat testing, these activities can drag out and consume more vacation, leave time, and money than projected and desired. The necessary sacrifices can be excessive.

Often, there is talk of putting together another AMSAT related satellite construction center in another location with a different core group. Most times, these efforts start out strong and look good for a while, but when it gets to the point of real commitment, the efforts evaporate and disappear. AO-13, for example, took the volunteers Wednesday evening and all day Sunday every week for a year! Imagine having your basement as the local gathering place for two dozen hams with daily visits by one or two for that long. And, of course, everything has to be perfect in every detail. Once the satellite is closed out at the launch complex, no one will ever be able to touch it again!

Beginning efforts that look good right now include a satellite construction project in the Detroit, Michigan area and the World Space Foundation Solar Sail Project in the Los Angeles, California area. If you are located in one of these areas and have an interest, contact AMSAT for more detail. (Other projects are in various stages of startup at many locations overseas, under the auspices of other AMSAT organizations.)

There are specific needs for specific talents in satellite construction. Find out from W3GEY or one of the other project managers what they are, then plan to be very busy for the next several years.

Conclusion

It is my desire that all who read this can find within AMSAT programs that will allow them to be involved as much or as little as they are able while being meaningfully and enjoyably integrated into a forward-looking and forward-moving movement.

The department coordinators, directors, managers, and I are waiting to hear from you!

Digital Video for ATV Via Phase 3 & 4 Satellites

By Dr. John Champa, K8OCL

On May 7-9, 1990, AMSAT-DL hosted the first international meeting of Amateur satellite experimenters in Marburg, Germany in order to begin the development of the plans to construct an advanced communications satellite in the Phase 3 Series. Starting prior to this meeting, the AMSAT-NA Phase 4 Project Study Team has been developing suggested communications criteria for geostationary Amateur satellites. Both groups are considering the inclusion of a hard limiting wide bandwidth digital transponder generally in the range of 56-64 Kbps, but up to and including a full T1 (1.544 Mbps) has been discussed.

This paper examines the design of a PC based coder/decoder (codec) which can be used to digitize the baseband video output from a NTSC source, such as a home video camera or VCR. Using data compression techniques such as vector quantization, the digitized video can be taken from its uncompressed digital form of approximately 92 Mbps to as little as 56 Kbps. Current techniques, even at this tremendous compression ratio, provide acceptable color contrast and image resolution, and moderate motion compensation. This type of highly compressed digital video signal is more than sufficient for Amateur television (ATV) contacts, but more pertinent to this paper, is the suitability of digital video for relay through Amateur satellite transponders, with acceptable signal to noise ratios for Amateur ground stations. It could also provide a type of terrestrial digital ATV transmission which is considerably more spectrum efficient than the presently used AM or FM analog video transmissions.

In the effort to get even more data into the signal, it may be necessary to use quadrature phase shift keyed (QPSK) or a comparable modulation scheme. This is similar to BPSK, which is a type of modulation with which Amateurs are already somewhat familiar, however it uses two additional phase angles to impress more data onto the signal.

Some of the current experiments being conducted using commercially produced codecs at both 56 and 112 Kbps are briefly reviewed, plus the time frames in which the cost of such equipment is expected to come within range of the Amateur community.

Just How Efficient Is Voice Communications?

Researchers in the field of psycholinguistics have observed that in the typical face-to-face meetings of human beings, as much as 80% of the communications which takes place is non-verbal in nature. This important observation causes us to wonder just how efficient is a voice only contact in communicating ideas and concepts. Yet, when we are not meeting face-to-face, this is the most personal mode of two-way communications modern telecommunications technology generally provides. When we converse via the telephone we are somewhat limited (perhaps unconsciously) in the extent to which we can most clearly communicate. In the typical Amateur QSO it's even worse. Most on-the-air conversations between Amateur Radio operators are half-duplex in nature. This is true even when Amateur Radio satellite communications allows a much more interactive full duplex method of operating. Only the more experienced satellite operators are normally observed adjusting their equipment so that a "normal" voice conversation can take place.

But, no matter how it is structured, voice only communications has its limitations. Try this simple experiment to illustrate my point. Pick up a July 1990 copy of the *AMSAT Journal* (Volume 13, No. 3) and turn to page 4. Now try to describe to a friend who has never seen a Lindenblad antenna the exact appearance and functionality of this device. I suggest you use the telephone and time your experiment. You can use a local repeater, if you have a very cooperative one such as the AMSAT oriented repeater we have here in Detroit, but that will take even longer. If you really have a lot of time on your hands, try doing the same thing via packet radio or RTTY. How about CW?! Packet radio and other text communications methods certainly have their place, and there is no current efficient

PictureTel Corporation's video conferencing systems make two-way digital video communications possible over special dial-up digital phone lines (two "Switched 56" Kbps circuits = 112 Kbps total bandwidth). The system is based on a specialized computer called a codec (coder/decoder) which does the digitalization of the video and audio and then compresses the signal. (PictureTel Corporation photo)

substitute for them in the case of non-real time communications, but you can see by this example that they do have limitations.

Let's get back to the typical Amateur one-on-one voice contact. There is no illusion in my mind that after reading the above you are all going to go out and assemble ATV stations. If for no other reason, there is no Amateur satellite on the drawing boards that could handle wide bandwidth analog television signals, so your maximum range would be limited to 50-100 miles at best, under normal terrestrial propagation conditions.

As an aside, this discussion may make some wonder, from a purely communication attractiveness point of view, what is the attraction of Amateur Radio to today's population? After all, we've grown up with a worldwide telephone system, which can now even be accessed via cellular phones from automobiles or just about anywhere else. Newer highway signs even tell you to dial 911 instead of the old "State Police monitor CB Channel 9" type. Well, you might say, "Packet radio will hook that new, blood Amateur Radio so badly needs. It involves computers and we know how much people are fascinated by computers!" Oh yea? Have you checked what landline based BBS systems can do and where they can reach? Yes, you say, but Amateur Radio is "free". It's "free" only after you've obtained a license, a TNC, a transceiver, associated antenna system, PLUS the computer. Then there are certain subjects which should not be discussed on the air, remember. Etc., etc.

Before I get taken out of context and classified as "anti-" something, let me explain that I've operated about every mode Amateur Radio has to offer and I try to sell everyone I meet on the fascination of the hobby. What I've described above are merely some of the arguments I've received in my efforts to recruit new Hams, and the argument has some merit in every area except one: ATV. There is no readily available commercial substitute for the two-way ATV contact. True, businesses have been using digital video for video teleconferencing for years, but this equipment has tended to be very expensive to obtain and to operate. Even after equipment costs have come down, it will be years before an effective videophone is used by a substantial percentage of those presently using telephone service. Perhaps it will be a blessing if cellular car phones are never replaced with cellular digital videophones. Most people driving the Detroit freeways at 80 mph don't need the distraction!

There are more uses we can put to ATV than local two-way contacts. But before that can be done, the nature of how we handle the television signal must be changed in order for it to be used within the practical power and bandwidth limitations placed on the Amateur Satellite Service. Investigations are being carried out into the feasibility of digital video instead of the current bandwidth hungry analog methods, either AM or FM, for conducting ATV contacts.

You have been watching digital video for years and probably didn't know it! To digitize an analog video signal takes about 92 Mbps. The national TV broadcast networks take this digitized video signal, compress it 2:1, and broadcasts it to their affiliated stations.

Why Digital Video?

For the national television networks, the digitalization and compression of their video broadcasts allows them to send their programming over special terrestrial circuits known as DS-3, T-3, or sometimes T-45 circuits because they will handle the 2:1 data compression which results in a 45 Mbps digital video signal. Digital video compression at this level, when converted back to analog, retains nearly all of the characteristics of the original video (NTSC).

It didn't take industry long to realize that if video signals are further compressed, say by a factor of 60:1 to 1.5 Mbps, that there is still more than sufficient quality remaining to use digital video for relatively economical two-way communications without having to travel to the distant location. True, you would probably not want to use this medium for sending images of a fast action football game, but for purposes of meetings and presentations, it's more than adequate. Further developments in data compression techniques have allowed for the commercial use of digital bandwidths down to 768 Kbps (120:1 compression ratio), and recently, even to 384 Kbps (240:1 compression ratio) while still maintaining acceptable quality.

Although these developments are impressive from a commercial perspective, they do not provide many alternatives for Amateurs. However, Amateurs are more resourceful and deal more effectively with reduced quality of communications, in order to put a new technology to use in a different way or in a manner they can afford. Thus recent developments to reduce the video bandwidth to as little as 56 Kbps start to look promising. In case you haven't realized yet what an accomplishment digital video compression to this level means, stop to think about what data compression ratio is required, i.e. nearly 1700:1. This is roughly equivalent to putting a truck load of sand into a grocery bag!

At the bandwidth of 56-64 Kbps the

television image quality is significantly less, but it is still more than adequate for most Amateur television communications. More importantly for the Amateur Satellite Service, future OSCAR satellites may be able to transpond such a signal. Because of bandwidth and signal to noise requirements of present ATV analog signals it is not feasible for either current envisioned Phase 3D or 4A satellites to transpond these signals. Digital video techniques must be used. According to Dr. Karl Meinzer, DJ4ZC, based on a guideline of 350 bps per watt EIRP, approximately 64 Kbps are achievable on the Phase 3D satellite. By using QPSK or some similar method of modulation, such a transponder would probably be suitable for digital ATV purposes.

It is clearly possible by the time either the Phase 3D or 4A satellites are launched, acceptable digital video may be possible down to a compression ratio of almost 5000:1. This would be equivalent to a digital bandwidth of 19.2 Kbps. Although this is twice the speed of the highest Amateur satellite communications accomplished to date, it is only about one third of the digital transponder bandwidth now considered feasible for the next generation of high flying OSCAR satellites. This means that three digital video transmissions could be handled at the same time. More likely, one or two digital video channels would be used, with the balance of the digital transponder for high speed packet communications trunks. There are tremendous possibilities in the Amateur satellite community for technology which allows handling of television signals in this manner.

What's All This Cost?

Presently, the commercial codec with the largest installed base used for digital video conferencing sells for approximately $65,000! This figure is expected to drop to approximately half over the next 18 months. Newer codec manufacturers are introducing models of codecs which operate satisfactorily at 384 Kbps and currently sell for about $35,000. These prices are well beyond the Amateur market, but as all of you who may have long ago purchased a 300 baud modem for $200 well know, that's not the end of the story.

Within the next few months, a codec chip set is expected to be introduced which will initially sell for between $1500 and $2500. This price will fall rapidly as supplies become plentiful, other manufacturers enter the market, and the initial supplier has recouped its research investment. Digital video codecs which are PC based are already on the market, but their bandwidth requirements for good images are too high (384 Kbps) and they tend to be expensive ($20,000, including the PC). That all will change too, with the increasing availability of the codec chip sets. Further along, it is likely that a codec-on-a-chip will be introduced which will make PC based systems even more economical.

In addition, a new international standard (CCITT) for digital video telecommunications was recently passed. All these and other factors will quickly combine to drive prices rapidly downward. I expect that by the time either the Phase 3D or 4A satellites are launched there will be available for well under $1000, a card which can be inserted in a slot on your PC (See Figure 1). This card, coupled maybe with a minor modification to your satellite transceiver, will allow you to receive a full motion digital video transmission from an Amateur satellite or terrestrial source. The output would be displayed on your CGA, EGA or VGA video monitor, and you could do this without interfering with an application you may have running on your PC at the time, such as satellite tracking for automatic antenna pointing, etc. By connecting a small one-chip CCD camera or other NTSC video source such as your home VCR, you can digitize the video and uplink it for a two-way digital ATV QSO via satellite. With the current developments in commercially manufactured Amateur Radio equipment, perhaps even the minor modification to your radio will not be necessary in order for it to handle the wide bandwidth data channel. Even if it is, this shouldn't be much more difficult than the simple modifications now being made to allow radios to handle the 9.6 Kbps signals used by UoSAT-OSCAR 14.

Compressed Digital Video Opens a New Realm for Amateurs!

Digital ATV contacts will not only be possible via future OSCAR satellites, but the terrestrial use of ATV could be handled in a much more spectrum efficient manner. This would allow far more users to be accommodated in the increasingly popular 440 MHz and 1.2 GHz bands. Once the feasibility, efficiency and economy of digital video is demonstrated, existing AM ATV operations will go the way AM voice communication did when SSB was introduced. Just as importantly, it will be possible to have a wide area digital ATV telecast via a Phase 3D or 4A satellite. Spacecraft, such as the solar sail, could send back full motion images (instead of packet video still frame images as WEBERSAT-OSCAR 17 does) of the sail, the Earth, or the moon, from the sail's onboard camera. Digital ATV from the space shuttle or the space station could be uplinked to an OSCAR for viewing directly by Hams or digital ATV satellite gateway stations. This would give new meaning to the phrase "See you on the bird!".

Anyone for an ATV contact with the astronauts?

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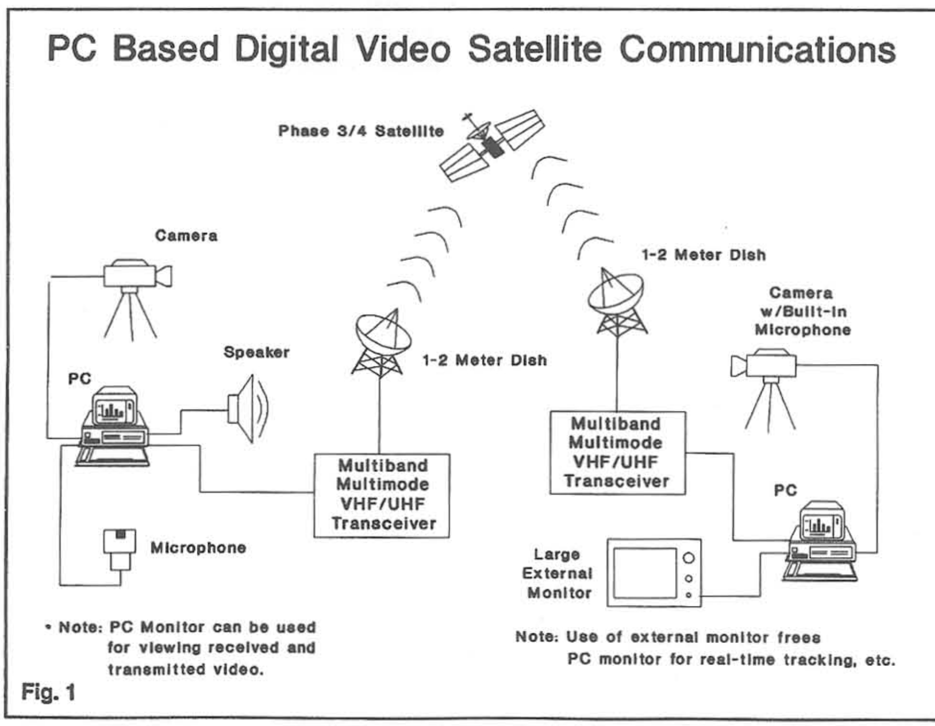

Fig. 1

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Satellite Image Acquisition for the Amateur

By Jeff Wallach, N5ITU
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A new and exciting facet of amateur radio that has been continually evolving over the past several years is that of satellite image acquisition and digital processing. Satellite enthusiasts have long been fascinated by the concept of receiving imagery from various platforms orbiting the Earth, displaying pictures in real-time mode, and digital+ processing and enhancing this imagery on their home computers. APT and WEFAX weather satellite images are now being received by many thousands of amateurs around the world. With the recent launch of the OSCAR Microsat constellation, and the CCD color camera capabilities of the Webersat platform, a renewed interest in satellite imagery and interpretation has arisen in the amateur community. Adding to this excitement is the recent introduction of a low cost, super-high resolution HRPT (High Resolution Picture Transmission) weather satellite image system for the IBM PC bus developed by Dr. John DuBois and Ed Murashie. This exponential growth in the capabilities of the "amateur" to receive imagery from space and digitally process the telemetry in real time on personal computers has generated both excitement and a critical need for information on 'how to get started'.

This treatise will provide a solid foundation in the basics of satellite image acquisition and processing. Weather satellite APT, WEFAX, HRPT, and Webersat downlink protocols will be discussed, along with basic ground station and computer requirements that are logically constructed to bring the AMSAT satellite operator from ground zero to a fully operational station with professional capabilities. At this juncture, it is very important to point out that the majority of AMSAT members ALREADY have the basic station equipment required for satellite image reception and processing. Satellite stations currently working the OSCAR 13 and Microsats with two meter omnidirectional or beam antennas, preamp, two meter transceiver or scanning receiver, personal computer, packet terminal node controller (TNC), and satellite prediction software may upgrade their stations (at a fairly low incremental cost) for weather satellite and WEBERSAT imagery. Of primary importance will be the resolution capabilities of personal computer display system and hard disk storage availability. Hardware and software requirements for specific satellite imaging platforms will now be discussed in greater detail.

Weather Satellite APT Imagery

The United States (NOAA), Soviet Union (Meteor), and most recently China (Feng Yun 1-2) operate polar orbiting weather satellites that transmit Automatic Picture Transmission (APT) weather images in real time format that may be received and reproduced by relatively inexpensive ground station equipment. The APT imagery is transmitted in the VHF band from 137 MHz to 138 MHz FM. The FM signal contains a subcarrier, the video image itself, as a 2400 Hz tone which is Amplitude Modulated (AM) to correspond to the light and dark areas of the Earth as detected from the visible and infrared (IR) sensors on the polar orbiting platform. Fig. 1 details the frequency and NORAD catalog number of the currently active polar orbiting meteorological satellites.

The higher amplitude component of the 2400 Hz tone represents the lighter portions of the Earth image, while the lower amplitude represents the darkest areas of the image. Intermediate amplitudes represent the shades of grey scale needed to produce the complete image of the Earth. The APT signal is thus an ANALOG format. This analog signal is actually derived from original digital data of the Advanced Very High Resolution Radiometer (AVHRR) instrument on the NOAA and Chinese weather satellites. The APT signal is transmitted continuously by all of the polar orbiting weather satellites. This results in a strip of image as long as the transmission is received by the ground station and is about 2200 km wide at an altitude of 870 km. A typical 14 minute pass would result in a continuous image approximately 5800 km long, and ends when the satellite signal is blocked as it crosses over the horizon relative to the specific ground station (loss of signal).

Satellite	Catalog #	Frequency (MHz)
NOAA 9	15427	137.620
NOAA 10	16969	137.500
NOAA 11	19531	137.620
METEOR 2-16	18312	137.850
METEOR 2-17	18820	137.300
METEOR 2-18	19851	137.300
METEOR 3-2	19336	137.300
METEOR 3-3	20305	137.850
METEOR 2-19	20670	137.850
FENG YUN 1-2	20788	137.795

Fig.1 — The frequency and NORAD catalog number of the currently active polar orbiting meteorological satellites.

RF Receiving Equipment

OSCAR satellite operators essentially have the basic equipment necessary to receive the APT VHF downlink signal. Commercial receivers specifically designed for weather satellite reception, or scanning receivers covering the 137 MHz to 138 MHz range will work just fine. The IF bandwidth should optimally be 40 kHz, but even the wideband FM (150 kHz) IF bandwidth of popular scanners will result in an acceptable image if a full quieting signal is presented to the receiver. Two meter omnidirectional antennas or beams, 145 MHz GasFet preamps, and low-loss coax cable will provide outstanding APT imagery. This author routinely uses two meter KLM OSCAR beams, 145 MHz GasFet preamps with the 137 MHz receiver and obtains exquisite visible and infrared images of the Earth, several times a day, from 870 km in space! These images are downlinked from U.S., Soviet, and Chinese APT imaging satellites. Thus, an operational OSCAR satellite station is easily adapted to receive the VHF weather satellite signals. Once the signal is received, the 2400 Hz amplitude modulated tone needs to be converted to a digital format and displayed as a visible image consisting of multiple shades of greyscale. This leads us to a discussion of the actual APT data format.

The analog APT image produced by NOAA and Chinese polar orbiting platforms (Soviet Meteor slightly different) is actually a derivative of AVHRR digital data containing two images and corresponding calibration and telemetry data. The two images are selected by ground control stations for APT from the five possible spectral bands provided by the AVHRR imaging instrument (Soviet Meteor satellites only transmit a single visible image or near infrared without the higher digital format). The spectral ranges detected by the AVHRR are as follows:

Channel	1	0.58-0.68uM	(visible)
	2	0.72-1.10uM	(near IR)
	3	3.55-3.93uM	(thermal IR)
	4	10.3-11.3uM	(thermal IR)
	5	11.5-12.5uM	(thermal IR)

Each video scan line is 0.5 seconds in length, containing two equal components. Each 0.25 second segment contains:

1. Specific synch pulse (832 Hz IR, 1040 Hz visible)

2. Space data with 1 minute timing marks (NOAA 11 calibrated to WWV time signal)

3. Earth imagery from a selected AVHRR spectral channel

4. A telemetry frame segment

The 120 line per minute (LPM) image on NOAA satellites usually contains video from AVHRR visible Channel 1 and IR channel 4 during daylight passes. At night channel 2 and channel 5 typically are present. The newest Soviet Meteor birds transmit a single 120 lpm visible image during daylight passes, and a single 120 lpm near IR image at night. The Chinese FY 1-2 satellite is currently transmitting two visible channels during daylight, and no imagery (just greyscale and minute marks) during nighttime passes. Apparently the IR detector (if present) has not yet been commanded on.

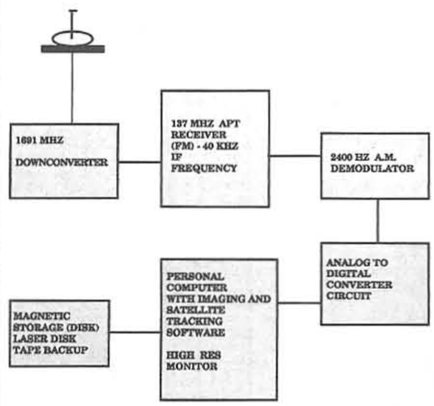

Fig.2 — Basic components of an APT/WEFAX Digital imagery ground station with image enhancement and storage capabilities.

Image Display Equipment

In order to display the APT image, the analog FM signal must be demodulated to remove the 2400 Hz subcarrier, then have the demodulated signal digitized by an analog to digital converter which changes the analog voltage into a discrete digital value. The 8 bit APT data can then be displayed as pixel elements on a monitor with one of 256 levels of greyscale, corresponding to the original brightness of the weather satellite image. This process of demodulation and A-D conversion is most often done by a personal computer adapter card with AM demodulator, proper filtering, and 8 bit A-D converter chip all on a single circuit board. This card may either be connected to the 8 bit parallel printer port (available on almost all PC's), or inserted directly into a slot on the PC bus architecture. Software will provide the proper 120 lpm scanning and positioning of the pixels on the monitor screen.

Once the 137 MHz signal is received, the audio tones are simply fed from the receiver speaker jack into the input jack on the AM demodulator board. The radio volume control can adjust the contrast of the incoming image. Fig. 2 represents a typical APT ground station including antenna, receiver, AM demodulator board, and personal computer for image processing and storage. Figs. 3 & 4 show a typical APT visible and corresponding IR image of the European continent as imaged by NOAA 11 and captured at the ground station of I4GU. Fig. 5 is a Soviet Meteor satellite APT image of Europe. Note the difference in format.

Various AM demodulator cards with associated A-D circuitry and imaging software are commercially available for a variety of personal computers (Complete listings of vendors for APT receiving equipment and display systems may be obtained from the Dallas Remote Imaging Group BBS at 214 394 7438).

A critical component of the APT image display station is the resolution of the PC monitor and display card. There is a vast difference in picture detail, quality, and resolution obtained from APT data when comparing 2 bit (4 colors on screen), 4 bit (16 shades of grey scale) and 8 bit (256 shades of greyscale on screen) PC display systems. In the IBM PC domain, the older CGA display cards only display 4 colors (no shades of grey and worthless for APT imagery). The standard 16 shade VGA adapter cards give good APT images with a somewhat limited detail of lakes, rivers, and major cities. The newer Super VGA cards can display 256 shades of greyscale on screen, which gives truly outstanding APT images and very fine detail of small lakes, islands, and geographical features in the 4 km. per pixel limit resolution of the APT image.

Most APT software will display 640 pixels per line (4 km. per pixel), 480 lines on the screen, with 256 levels of greyscale for each pixel. With one megabyte of memory on a super VGA display card, 1024 pixels by 768 lines at 256 levels of grey give professional quality images on the home PC. (Most A-D converters are 8 bits, therefore the hardware is NOT the limiting factor).

A typical APT image, sampled at 9600 samples per second, for 16 minutes, will result in a digital file over 9 megabytes large. Adequate hard disk space (minimum of 40 meg. to be safe) is a must on any personal computer system used for satellite imagery.

Thus, with the simple addition of an AM demodulator card, A-D converter chip, software, and perhaps a super VGA display system for the PC, the current OSCAR satellite station may be easily upgraded to the fascinating world of APT weather satellite reception and image processing!

GOES WEFAX Imagery

In addition to the low earth orbiting (LEO) weather satellites, the U.S., Japan, and European Space Agency also operate several satellites in geosynchronous orbits (35,800 km.) above the equator, providing

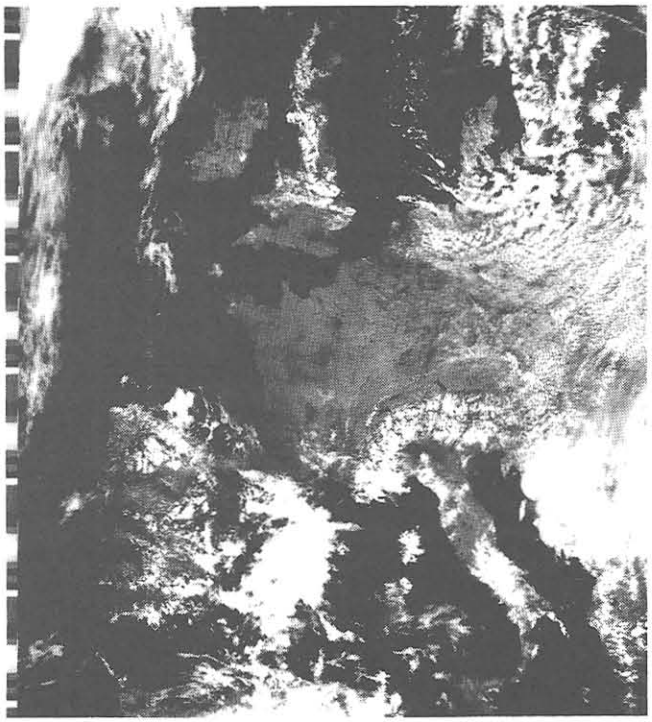
Fig. 3 — NOAA-11 VIS showing Europe.

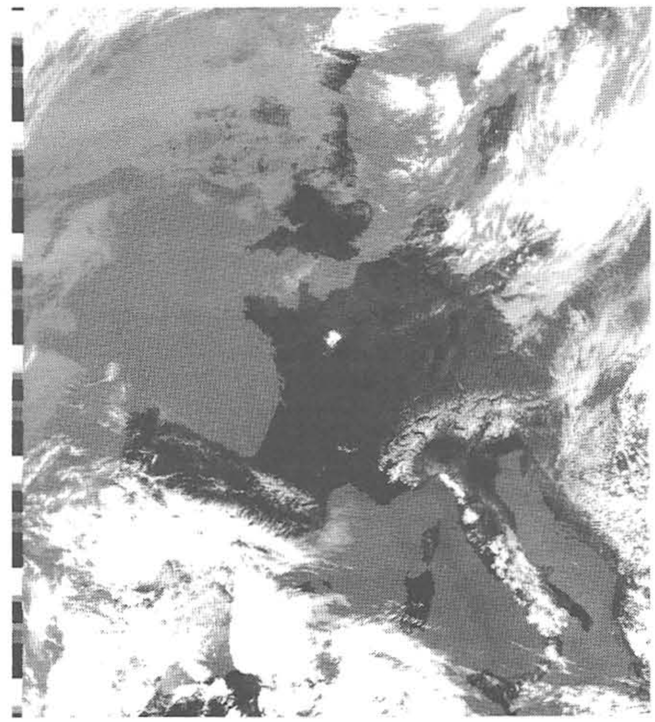
Fig. 4 — NOAA-11 IR showing Europe.

continuous hemispheric meteorological coverage. The WEather FAcsimile (WEFAX) images transmitted by the U.S. GOES satellites contain lower resolution analog images and charts transmitted at 240 lpm format similar to the analog APT data product. This aspect of WEFAX is important because image display systems that can reproduce the APT signals can be easily modified to display (8 km. per pixel) WEFAX images from GOES satellites. The WEFAX images are formatted in a 240 lpm transmission as compared to the 120 lpm rate for APT satellites. The WEFAX transmissions contain images of large quadrants of the Earth (visible and IR) that are transmitted on a pre-determined schedule 24 hours daily. These images are derivatives of a higher resolution product on the Visual Atmospheric Sounder (VAS) on the GOES platform.

In order to receive WEFAX images from GOES, additional components will need to be added to the APT system previously described. The WEFAX signal is transmitted at 1691 MHz. To capture this signal, a four foot parabolic dish (24 dB gain factor) is required to reflect the signal into a feed horn located at the focal point of the dish. A preamp and down converter are used to convert the 1691 MHz signal to 137.5 MHz, since there is a very significant attenuation and signal loss in coax cable at 1691 MHz. The 137.5 MHz output of the down converter is fed into the antenna jack of the 137 MHz APT receiver used in the APT station. The signal now carries the 2400 Hz subcarrier, and the audio output is now fed into the standard APT AM demodulator circuit board and reproduced in a manner similar to the APT signals. The difference is the controlling software scans at 240 lpm, with an image consisting of 800 lines during a 200 second transmission (800 lines / 200 seconds) = 240 lines per minute. Geopolitical

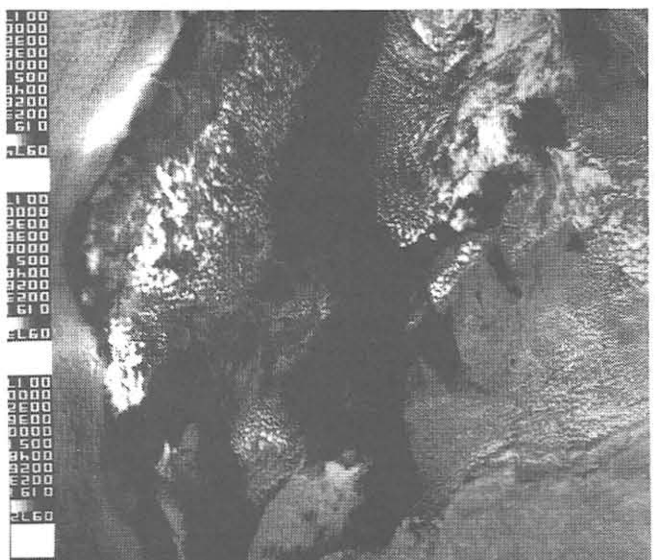
Fig. 5 — Soviet Meteor satellite APT image of Europe.

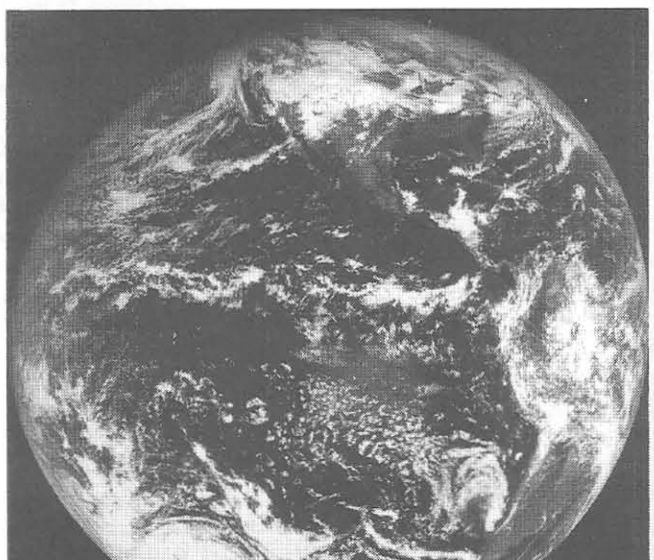
Fig. 6 — Visible WEFAX type image of North and South America.

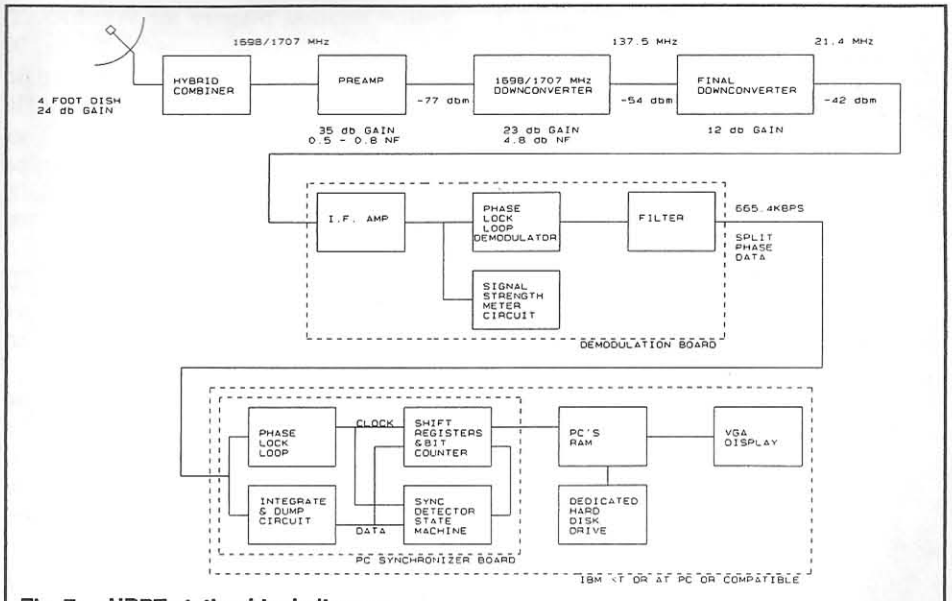

Fig. 7 — HRPT station block diagram.

boundary overlays and digital image preprocessing are provided by NOAA command data acquisition stations prior to uplinking the processed WEFAX image to end user ground stations through GOES satellites. A listing of 1691 down converter equipment, antennas, preamps, and software may be obtained from the Dallas Remote Imaging Group. Fig. 6 shows a visible WEFAX type image of North and South America during a daylight scan.

HRPT Imagery: The Next Evolution

The AVHRR instrument on the NOAA polar orbiters provides a higher resolution (1.1 km per pixel) High Resolution Picture Transmission (HRPT) product containing all five spectral channels. The HRPT signal containing the entire digital data set is a 665.4 Kilobits per second split phase encoded phase modulated signal. It is transmitted at 1707 MHz (NOAA 9 & 11), or 1698 MHz (NOAA 10), or 1695.5 MHz (Chinese Feng Yun 1-2).

For the AMSAT experimenter, reception of HRPT imaging of NOAA and Chinese platforms can now be achieved with almost the same ground station hardware described for APT & WEFAX imagery. Complete details for building the HRPT station may be found in the April 1990 *Journal of Environmental Satellite Amateur Users Group (JESAUG)*, available from the Dallas Remote Imaging Group. A summary of the building block approach developed by Dr. John Dubois and Ed Murashie will be described below. Fig. 7 shows a block diagram of an HRPT station.

The minimum antenna size using a state of the art LNA with a 0.5 dB noise figure and a 35 dB or more gain factor is a four foot parabolic dish with a gain of at least 24 dB. The dish must be mounted on an azimuth/elevation rotor mount similar to one used for tracking APT or OSCAR satellites (Yaesu 5400B rotors). The feedhorn is basically identical to the 'coffee can' feed widely described for WEFAX, but with two probes, 90 degrees apart for the circular polarized signal on HRPT. The signal output of the preamp is fed into a 1698/1707 to 137.5 MHz down converter (commercially available from Quorum Communications, Richardson, TX). The 137.5 MHz signal then needs to be down converted once again to a convenient frequency for PLL demodulation. Down conversion allows conventional phase demodulation techniques and components to be used, which is the next step in the process. The HRPT data is phase modulated onto the RF carrier with a swing of +/- 67 degrees. A well designed PLL can lock onto a signal and deliver the split phase bit stream from the phase detector. The next step is to separate the clock and data bits by synchronizing a local clock to the clock rate of the transmitted data. Then the local clock is used to process the data and strip away the split-phase (Manchester) encoding used in the HRPT transmission. Following the bit sync and split phase decoding, the data must still be processed to identify the start of each line and to separate the different spectral bands of the HRPT signal. An essential part of this digital

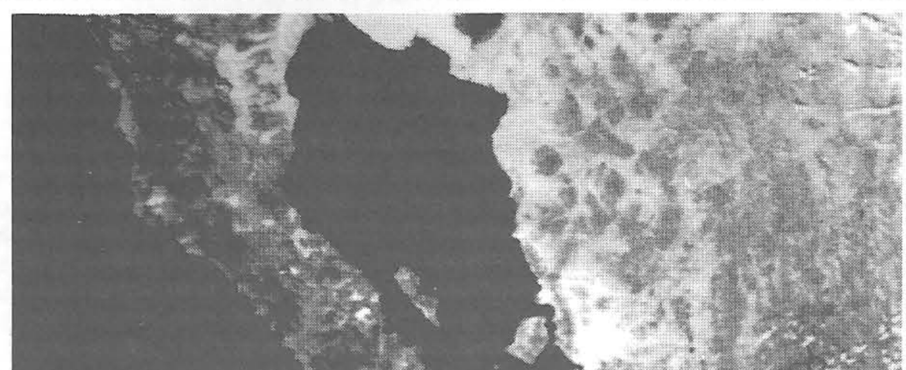
Fig. 8 — Visible HRPT image of the Baja peninsula.

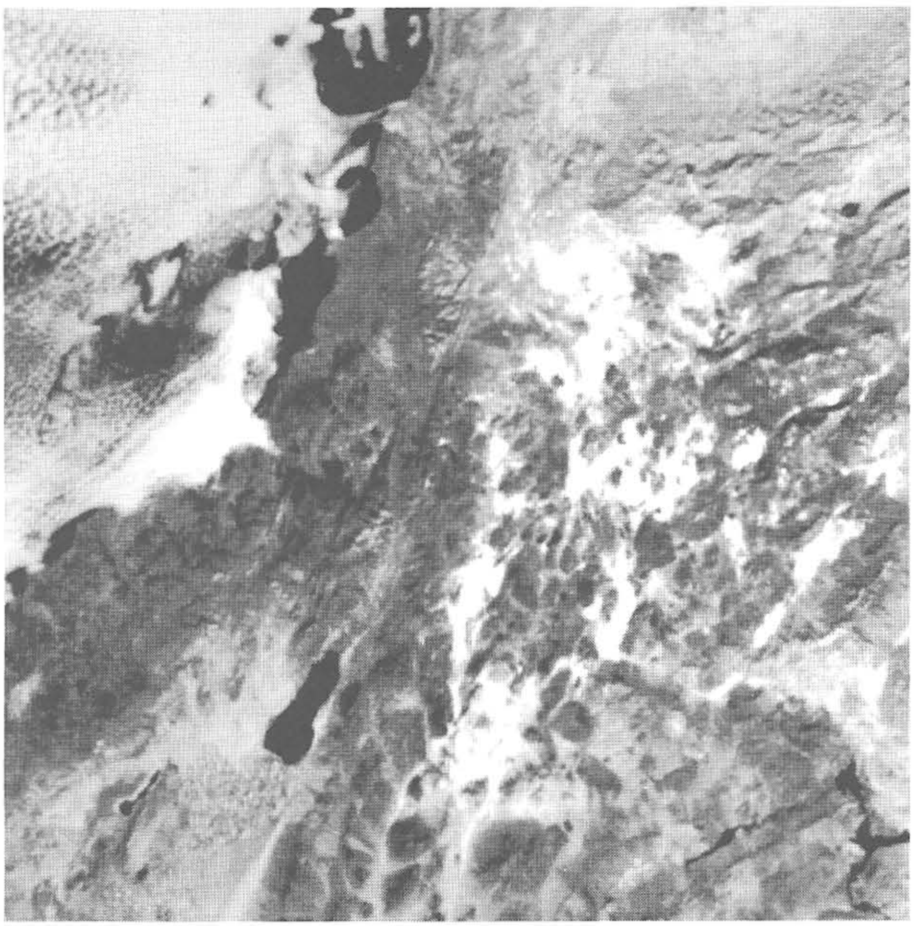

Fig. 9 — An HRPT image of Southern California, the Salton Sea, and Lake Mead.

signal processing is to recognize the fixed bit pattern which identifies the start of each line. The 60 bit pattern is referred to as the frame synch and is the first 60 bits of the HRPT minor frame. The sync pattern also aids in determining which is the first bit of the 10 bit HRPT data words. By counting off the 10 bit words following sync, the desired image pixels can be saved in a format required by the computer display device. For the IBM PC, the desired image pixels can be saved to RAM memory or hard disk (At 665 kbps, a 16 minute pass including all 5 channels would require about 80 megabytes of storage!). Interface cards for standard IBM PC XT computers have been developed by the authors that demodulate, provide bit sync, decoding and synchronization. This IBM PC system brings all the data into the computer by DMA, and the software saves the desired channels on the hard drive during the pass. The selected images can then be displayed on the super VGA display. Fig. 8 is a visible HRPT image of the Baja peninsula. Fig. 9 is an HRPT image of S. California, the Salton Sea, and Lake Mead. Fig. 10 shows an HRPT visible image of San Francisco with fog visible in the Valley. The Sierras and Lake Tahoe are also included in the image. These outstanding HRPT images were captured by Ed Murashie on an IBM PC XT with manual antenna control, utilizing the system he developed with John Dubois. This is the type of unbelievable imaging capabilities available, today, at reasonable cost, to the AMSAT amateur community!

WEBERSAT Imaging: AMSAT'S Eye in the Sky

In June, 1990, a new opportunity for satellite image acquisition was presented to the amateur community by the launch of the WEBERSAT polar orbiting satellite. WO-18 provides radio amateurs with a unique digital store and forward imaging capability. WEBERSAT carries a color CCD (charge coupled device), which is an all solid state imaging system. This Microsat also carries a high speed flash digitizer, L-band television receiver, a particle-impact detector, and Earth detector, a flux gate magnetometer, and a visual light spectrometer. This innovative and educational experimental package was designed and build by students and faculty of Weber State University and the Center for Aerospace Technology in Ogden, Utah. The color CCD camera output is either standard NTSC video with color burst, or separate red, green, and blue signals with horizontal and vertical synchronization. Chris Williams, WA3PSD, a critical mission planner for WEBERSAT, has indicated the camera resolution is 700 pixels by 400 lines. The actual imaging field of view is 19 degrees from an altitude of 810 km. Data from the CCD camera and other experiments are transmitted as beacon type packets using BPSK modulation at 1200 bps. The transmitter frequency is 437.100 MHz, with a backup of 437.075 (SSB).

The format of the picture for the CCD camera color composite signal is as follows as described by Chris Williams last February:

"Call sign (for this transmission scheme) is PHOTO (for the camera). SSID is picture number (modulo 16). We are currently often overwriting a given picture number with different pictures perhaps twice a day. This is done when a picture is clearly black and there is no point in getting all of it.

The first two bytes of data portion of the UI frame (packet) contain the 10-bit X position of the first sample in that packet, the two most significant bits of the X position occupy the two least significant bits of the first byte, the eight least significant bits of X are in the next byte. Legal X values are from 0 to 644. Y values are in third byte and range from 0 to 241. If the two least significant bits of the first byte are both set (forming an X 768..1023), the data beginning with the second data byte is clear text information about the picture (which we call the "picture header") occupying 252 bytes. The six most significant bits of the first byte are reserved for future protocol definitions, only one of which is presently defined.

The data then consists of a sample for every third X value. This has little to do with RGB, but is relevant to color as the NTSC waveform is sampled at precisely 3 times the color burst frequency. A zero byte value indicates a simple compression sequence as follows: 00, the count of repeats, then the value repeated. Actual samples with a value of 0 (hor. sync) are changed to 1 to allow indicating a following compression sequence. When the X value is greater than 644, increment the Y value by two and subtract 645 from the X value. At the end of one of these compression passes, encoding returns to the top of the pic, moves one byte to the right and proceeds. This takes place three times to complete one half pic (every other line). Alternating half pics (even vs. odd) lines are transmitted every 101 minutes (every other visibility pass at these latitudes). There is not vertical sync transmitted. The picture begins at the end of the header.

The 645th byte of a reconstructed line is the count of zeroes which was in the original digitized sample between the 644th byte of that line and the beginning (the first

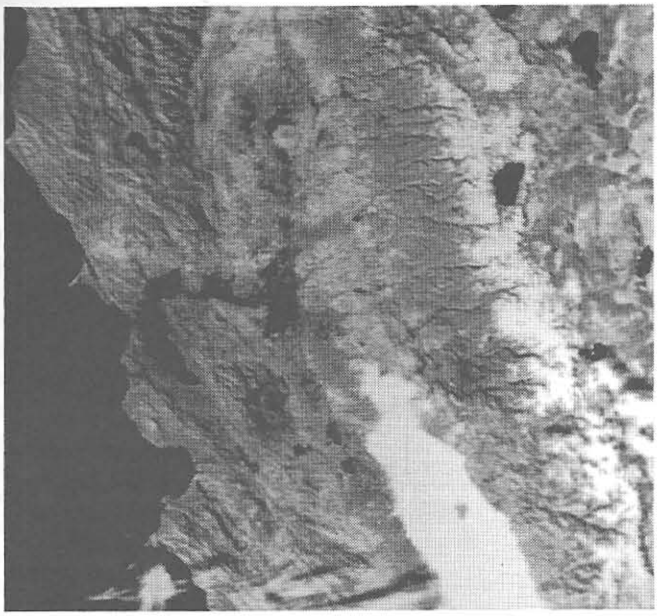

Fig. 10 — An HRPT visible image of San Francisco with fog visible in the Valley. The Sierras and Lake Tahoe are also included in the image.

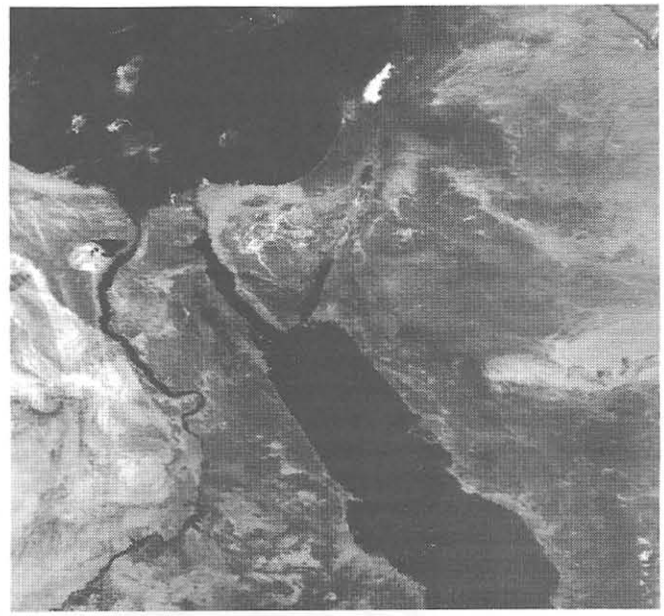

Fig. 11 — A high resolution image from the European Meteosat geosynchronous satellite (similar to GOES VAS) of a very "hot" area of the world.

non-zero) of the next line. If you are reconstructing the original waveform replace that count byte with that many zeroes.

I must again emphasize that this protocol is very temporary and can be expected to change with little advance notice. The compression scheme is poor and was selected only for its simplicity. It also will change. These changes will be handled with WEBERWARE version updates. Also, please note that we have the ability to download individual R, G or B signals from the camera and their protocol may be different. Ditto for the 1.2 GHz experiment. For those, however, you can expect a bit more advance notice of variation."

The high speed flash converter with 8 bit digital-to-analog conversion captures video from the CCD color camera and store the digitized image in random access memory on the satellite. Thus, multiple images may be compressed and stored for later downloading by PSK packet ground stations acquiring the WEBERSAT downlink signal.

A typical WEBERSAT ground station configuration would consist of a 70 cm. omni or directional beam antenna, preamp, PSK modem, packet TNC, 70 cm receiver, personal computer, and WEBERSAT display software package. It should be emphasized that adding imaging capabilities to the average OSCAR station can be implemented at minimal cost, and this fully complements the equipment required for APT and WEFAX reception. The WEBERSAT team has developed a preliminary image display software package (available through AMSAT-WEBERWARE 1.0) that allows display and image processing of the packetized digital image from space. The raw binary picture data from WEBERSAT is received through the PSK modem and TNC configured in KISS protocol mode, and stored on the PC hard disk as an ASCII file. KISS capture software is available on AMSAT BBS systems around the country. It requires two complete passes of WO-18 to display a full image on the PC. Actual picture file size is around 156 Kbyte after merging and processing within WEBERWARE 1.0.

Other Image Processing Software

There is a host of additional image processing software for the personal computer that will fully enhance the display of APT, HRPT, WEFAX, and WEBERSAT imagery. These applications can show histograms of the pixel distributions, conduct low and high pass filtering, eliminate random noise in images, bring out detail not observable in the raw data, do contrast stretch, sliding, and edge detection. Programs such as IMDISP, a public domain application from the Jet Propulsion Laboratory, utilize the same routines used on the Viking, Ranger, and Voyager space missions for digital image processing. Programs costing thousands of dollars just several years ago may now be obtained free of charge through the Shareware concept.

Various GIF viewers (Graphical Interchange Format) are available to view raw 8 bit image files across a variety of PC operating systems, in 256 shades of gray and colors. Many image files can be imported in paint programs for further color enhancement and false coloring to bring out rotation in hurricanes, show the thermal currents in the oceans, give a 3-D effect to cloud heights, etc. Many GIF viewers such as PICEM and VPIC allow for animation of weather satellite imagery in a story board manner.

Several days worth of weather systems may be constructed into a time sequenced motion showing travel of frontal systems, etc. The possibilities are almost endless. These programs may be found on the DRIG BBS and other computer BBS systems around the U.S.

In summary, the amateur satellite sleuth now has a vast array of image acquisition and display systems available to fully complement his OSCAR satellite ground station. This capability can all be added at a very small incremental cost, but provides an exponential growth in professional capabilities. And to leave you with a further enticement, Fig. 11 is a high resolution image from the European Meteosat geosynchronous satellite (similar to GOES VAS) of a very "hot" area of the world. Can you guess where it is?

Here's looking forward to your own personal "View from Space"!

The author encourages all AMSAT members to check into the BBS to gain further information on the exciting world of satellite image processing.

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KISS DSP for Amateur Applications

By Bob Stricklin, N5BRG

This paper presents the design and details of a KISS DSP for Amateur Applications. The original intent was to provide a modem interface for a TNC and Radio to facilitate improved satellite communications. The modem should be capable of supporting all the current forms of amateur satellite modulation techniques and WEFAX.

The DSP is built on a stand alone PC Board that will interface with a PC serial port, radio, and a TNC. This will reduce the complexity of the design and make the KISS DSP compatible with a larger number of PCs.

Figure 1 is a block diagram illustrating one method the DSP would be used. In this case the DSP will be connected to the radio and to the modem disconnect of a standard TNC. The modem will also be connected to a PC serial port which will be used to download programs and control the KISS DSP. With the proper software loaded the KISS DSP will operate as a PSK modem and allow reception of the Microsat satellites.

The heart of the system is TI's second generation TMS320C25 (Note 1). This DSP package has been on the market since 1986. This means the device has matured to a point that amateurs can afford to purchase both the DSP and the required support components. Also you can find a substantial amount of public domain software including many of the routines needed for amateur applications. The TMS320C25 will operate with a 40 MHz clock which results in a 10 MHz instruction cycle rate. The TI unit is a 16 bit processor which can address 64K of Program memory and 64K of data memory. The device also includes a 5 MHz serial IO channel.

Referring to Figure 2 lets review the KISS DSP design. The DSP is supported with the full compliment of 128K of high speed static RAM memory. The serial port of the DSP is used to interface with another TI support chip, the TMS32044C analog IO. In addition an 8250 serial UART IO chip is included for PC interface and EPROMs are provided for a boot strap start-up program. The last section is eight bits of digital IO which is configured to match the TNC2 modem disconnect.

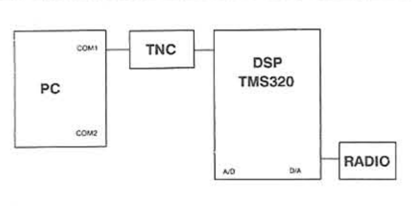

Fig. 1

The normal way a fast processor is interfaced with slower support components is to add buffers and the logic required for introducing wait states. This design utilizes a different approach which reduces the number of "glue logic" chips required. The clock driving the DSP will be shifted to a slower rate by dividing the clock in half when the DSP is interfacing with slower components. The disadvantage is a small amount of time will be lost when the DSP request data from a slow IO device. This time penalty will only be an issue if the serial IO used will not release the data line within 100 nS.

To get the DSP started after a power-up a boot strap routine will be included in the EPROM. This routine will initialize the DSP and the 8250. Then it will either move a program from the EPROM into the program SRAM or download a program from the PC into the program SRAM and then begin execution of the program. The EPROM will only be used during initialization and this will all be done at a slower clock rate. When program execution begins the clock will be at full speed or 40 MHz. At this point only inputs from the serial IO may require the slower clock rate which will be handled with hardware.

A TMS32044C analog interface is employed for the radio interface. This chip uses the 5 MHz interface on the DSP. The TMS32044C is clocked by the CLKOUT1 output of the DSP so its function will be effected if a conversion is in process and the clock rate is shifted. The analog IO chip will support sampling rates up to 19.2K samples per second with 14 bits of resolution. The radio interface is supported with two possible analog inputs which are software selectable. These inputs can be operated in a differential or single ended mode. The TMS32044C includes software selection of gain (1X,2X,4X) and control of an on-chip switched-capacitor filter. For full scale A/D conversion the analog input can be programmed for an input voltage of +/- 6, +/- 3, or +/- 1.5 Volts. To attain +/- 6 Volts the differential configuration must be used.

The output of the TLC32044C can also be configured in a single ended or differential mode. The peak output voltage is guaranteed to swing +/- 3 Volts across a 300 Ohm load in the single ended mode and +/- 6 Volts in the differential mode.

In addition pads for a dip header are included on the PC Board between the TMS32044C and the radio connector for any additional interface circuitry required.

A power supply section is included on the board to produce +5V, -5V, and -12V from a +12V input. The serial IO also has a true RS232 interface with a nine pin plug configured to be compatible with an IBM PC. The serial interface was worked out by Bill Reed WDØETZ. Bill also did a substantial part of the PC Board layout using a CAD PCB layout package.

One of the problems with amateurs developing software for a DSP is the availability of low cost development tools. A very low cost ($30.00) approach being considered is an assembler called TASM (Note 2). This assembler is a two pass assembler which produces executable code for any 8 bit processor. The C source code is also available. The introductory package which may be distributed freely includes the data files required to compile code for a TMS320C10. The plan is to modify the assembler so it will support the 16 bit TMS320C25 and use it as a development tool for the amateur software.

An alternative will be to work with TI or a third parties development software if you have it available. In any case an assembler that will work with the public domain material like that supplied by TI is a requirement.

The first pass PC Board is about 7 inches by 9 inches and will fit in a box like the one used for the TNC2. Alpha boards are currently being fabricated and tested.

Hopefully this board will become a economical tool for amateurs to use to develop flexible and powerful modems for digital communications. The basic DSP requirements are included to provide a modem that can be configured for all the current modes of satellite data transmission.

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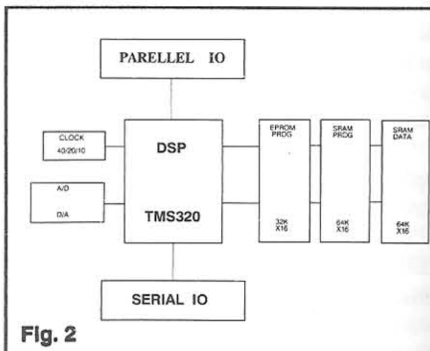

Fig. 2

Amateur Satellite Communications and the SEDS AMSEP Project

The second flight of the Small Expendable-Tether Deployer System, (SEDS) will be flown as a secondary payload on a Delta II 7925 launch vehicle, now scheduled for launch in the middle of 1993.[1] *The SEDS package will be attached to the exterior electronics bay wall on the second stage of the Delta II. It is proposed that a Student Experiment Package (SEP) carrying AMSAT Mode A and J linear transponders along with two student experiments be flown as a replacement for a planned 50 pound dead weight. The SEP and the AMSAT transponders, (AMSEP) will be deployed on a 20 or 40 kilometer tether attached at the other end to the Delta II second stage. The Marshall Space Flight Center Amateur Radio Club is integrating the SEP as well as providing expertise and oversight to the project.*

This paper describes the SEDS, the SEP with experiments, and the proposed AMSAT transponders. Also AMSEP flight operations and the required Amateur Radio support for acquiring and recording the flight data is described. The need for AMSAT support is also discussed.

By

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The University of Alabama in Huntsville SEDS

Ed Stluka, W4QAU
Marshal Amateur Radio Club MARC

Chris Rupp, W4HIY
Marshall Amateur Radio Club MARC

Background

This paper in part is a revisit of the paper delivered at the AMSAT Symposium last year in Des Moines, IA by Chris and Ed.[2] Our proposed mission will be the second flight of the SEDS system, the first being a downward deployment of the tether with the end mass being deorbited by the forces involved in a downward deployment of a tethered system. The first end mass is being built by NASA Langley. Due to the desire of the NASA Tether Dynamics Working Group (TDWG) for an expanded data set of information for the dynamics of tether deployment, the UAH Students for the Exploration and Development of Space, (UAH SEDS) is proposing a new SEP mission with the result being that the SEP will be placed into a permanent orbit after the tether dynamics mission objectives have been met.

The SEDS 2 flight objectives are to demonstrate that the tether can be fully deployed away from the Earth without stopping prematurely, that it can come to a smooth stop on application of a brake, and that over time, the tether and SEP can assume a stable gravity gradient attitude relative to the Earth. NASA data will be down linked over a Delta II S-band telemetry channel. The student experiment's data will be down linked over the AMSAT Mode J transponder. At the end of the tether mission the satellite ownership and operational control will be turned over to AMSAT/NA for use as an OSCAR, serving the AMSAT community which demands the availability of a OSCAR 8 type satellite. This will provide easy to use transponders for those amateur radio operators new to satellite communications. The SEDS was originally planned to deploy a 50 pound dead weight end mass on a 20 km tether. Chris Rupp, W4HIY, the Treasurer of the MARC and the lead engineer on SEDS asked Ed Stluka, W4QAU, secretary of MARC to consider putting a payload of student ex-

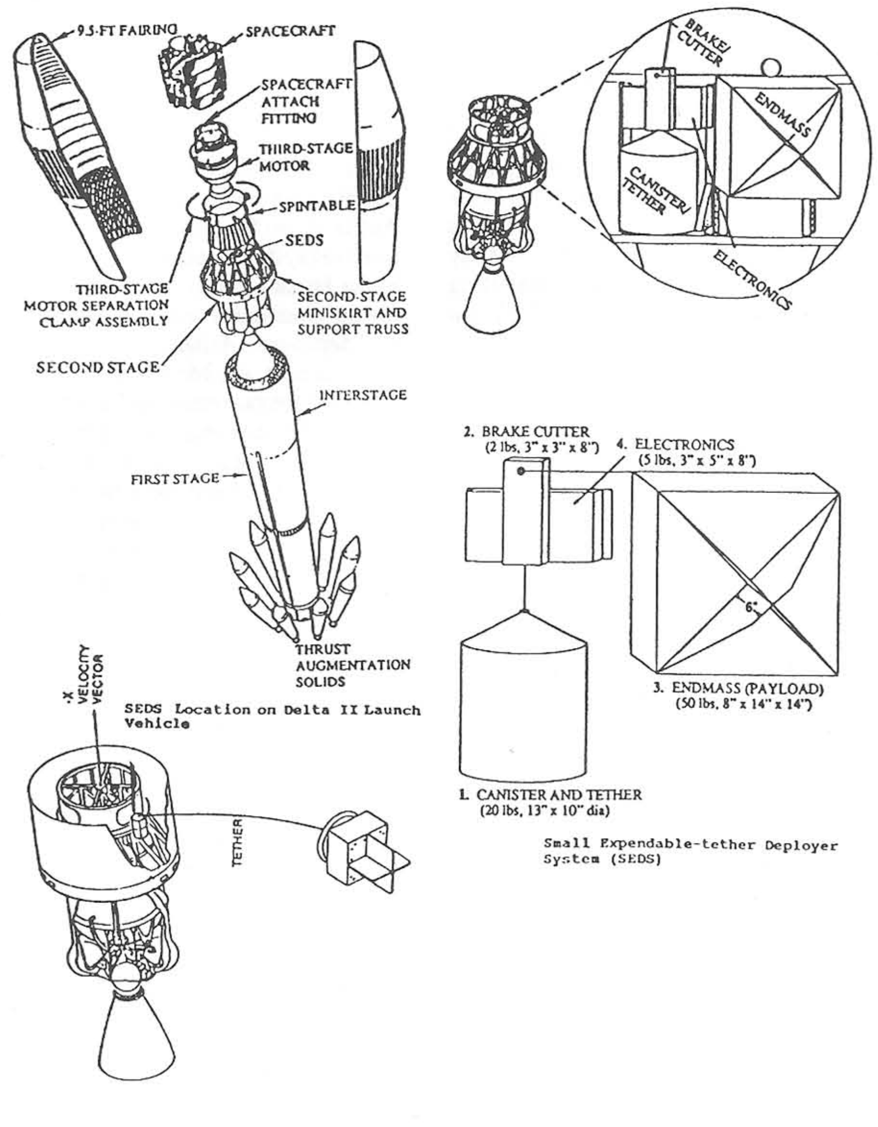

Fig. 1 — System diagram.

periments in the end mass instead of the dead weight. UAH SEDS led by Dennis Wingo, (former WB4KSF) agreed to submit experiments and design and build the SEP package. SEDS also agreed to raise the necessary funding for a Microsat class satellite. Dr. S. T. Wu, Director of the Center for Space Plasma and Aeronomic Research, (CSPAR) at UAH, agreed to provide administrative support to the project. Dr. John Champa, K8OCL, Executive Vice President of AMSAT-NA is working with the Detroit Oscar Users Group, (DOUG). DOUG has agreed to lead the effort to provide the AMSAT Mode A/J transponder pair.

Approach

As of this writing most of the funding has been secured from national and international sources. In addition, support in the form of technology sharing is being sought from AMSAT, and technology sharing and technical support memorandum of understanding is being worked out between UAH SEDS and Weber State Center for Aerospace Technology, (CAST). These agreements are being sought out in order to maintain as much compatibility as possible with the current Microsat software technology. This also shortens the development time associated with the project. This is crucial considering that the launch date is assumed to be April-May 1993. Many conversations have been devoted to settling the issue of uplink and downlink frequencies. DOUG has recommended the Mode A/J combination as the one most desired by a large number of the amateur radio satellite community. UAH SEDS, has agreed to provide funding for the start up of the AMSAT cleanroom in Dearborn MI with the conclusion of a general agreement with AMSAT on participation on this project.

Locally, much volunteer support has been forthcoming from local NASA and industry personnel to support the student effort both with expertise and facilities. The expertise will be used in an advisor/teacher role to give the students first hand knowledge in working in the "real world" of design. UAH SEDS in addition to funding, has a six hundred square foot laboratory dedicated to space flight projects such as this one. CAD/CAM terminals from Intergraph are available and will be used to generate most of the detailed drawings for the project. PC based thermal analysis software worth over ten thousand dollars has been donated to the engineering school by Thompson Associates of Incline Village, Nevada. This software consists of SINDA, NEVADA, and SSPTA. These are the same packages as were used to model the Microsat. This resource is also available to us. The camera for our mission is being constructed in Taiwan by students at the National Cheng Kung University (CKU). This is part of a program of cooperation already in place for our Shuttle Get Away Special Program.

Legal and administrative support and oversight is being provided by Dr. S. T. Wu, of CSPAR and the University's Research Administration Department. Student class credit for participation in this project is available through the departments of Electrical, Mechanical, and Aerospace Engineering. It is planned that this project becomes part of an ongoing program of "hands on" engineering to improve the skills of the graduating engineer at our University. This is perhaps the most important aspect of this project.

Too much is said about improving education and too little is being done. AMSAT cooperation, and participation with Universities such as UAH, University of Surrey, and Weber State College is beneficial to all concerned in improving technology and engineering skills in the experimental world.

Small Expendable-Tether Deployer System (SEDS)

SEDS is managed by the Marshall Space Flight Center in Huntsville, AL. The Tether Applications Co, San Diego CA is the mechanical systems contractor. The Marshall Space Flight Center, (MSFC) is responsible for the electronics systems associated with the deployer. Subcontractors to Tether Applications are McDonnell Douglas for Delta II interface studies; Teledyne Brown Engineering for engineering analysis and documentation; and the University of California in San Diego for fabrication of the SEDS structure. Figure 1 shows the location of SEDS on the Delta II, the AMSEP deployment from the Delta II second stage and the major assemblies of the SEDS and AMSEP.

Mission Operations Concept

SEDS will be activated by a sequencer command from the Delta II telemetry system after the primary payload has been deployed. Via either preprogrammed or ground control, the Delta II second stage will restart and place the stage and SEDS package in an orbit that will be circular at an altitude of between one thousand and fifteen hundred nautical miles.[3] After this orbit is reached the stage will exhaust its fuel in a depletion burn that will gain about one degree of inclination. The final inclination will be approximately thirty five degrees. The envisioned orbital altitude will result in a RF footprint for the AMSEP of between three thousand and thirty seven hundred miles in diameter. This along with the inclination of the orbit will provide satellite communications over almost all populated areas of the Earth.

AMSEP deployment will begin on command from the SEDS Data System. This command will fire pyrotechnic charges, releasing the Marmon clamp. Spring ejection will impart a velocity of 1.5 meters/second to the satellite. This deployment will begin over the west coast of the United States to allow overlapping coverage by dedicated student ground stations at the University of New Mexico, Mississippi State University and UAH. Also this will provide U.S. based amateur radio satellite operators the opportunity to participate in the deployment real time telemetry capture. Software will be provided at cost through the AMSAT software exchange to allow the graphical viewing of the tether experiment data on PC's or MacIntosh computers.

The deployment phase will last between 5800 to 7800 seconds, (96 to 130 minutes) depending on the tether length used. Experiment data will be down linked in real time as well as stored onboard for later playback. During the deployment, the tether position is about 50 degrees below vertical. The polyethylene synthetic fiber tether, (SPECTRA-1000) unwinds from a stationary aluminum core, feeds through a friction brake assembly, a cutter, and is finally attached to the payload. A stepper-motor operated by the SEDS data system applies the brake that controls the tether tension during payout and thus the tether deployment speed. Full deployment is reached at 5100 seconds, (20 km tether) followed by a 50 degree swing upward to the nadir that is completed at 5800 seconds. Since the tether is not cut at this time as in the SEDS 1 mission, the tether and AMSEP will oscillate in a pendulum fashion for an undetermined amount of time until finally stabilized into a vertical gravity gradient mode. The student experiments will operate until the tether is broken by natural forces. If this has not occurred in six months the tether can be severed at the AMSEP end by embedded resistive heaters. Six months is considered the maximum duration of the Long Duration Tether Dynamics Experiment (LDTDE). At tether separation, the AMSEP will gain altitude equal to seven times the length of the tether. This gain in altitude will constitute the apogee of the final satellite orbit.

The SEDS Data System onboard the second stage will be the primary downlink for information desired by NASA. The system will record, store, and continuously downlink over the Delta II S-Band telemetry data channel to the ground. It will count the turns as the tether unwinds from the core and control the tether brake. It also

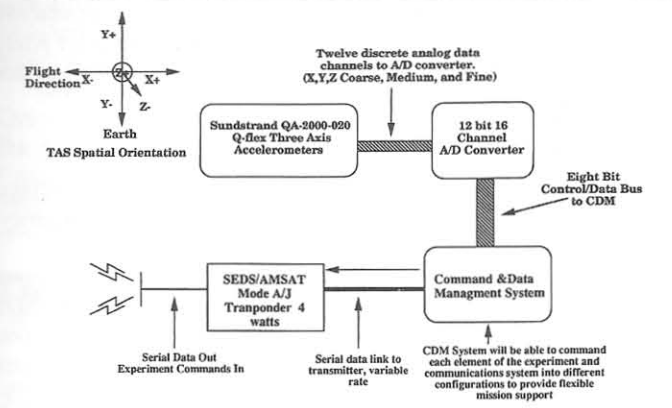

Fig. 2 — Functional block diagram for TAS.

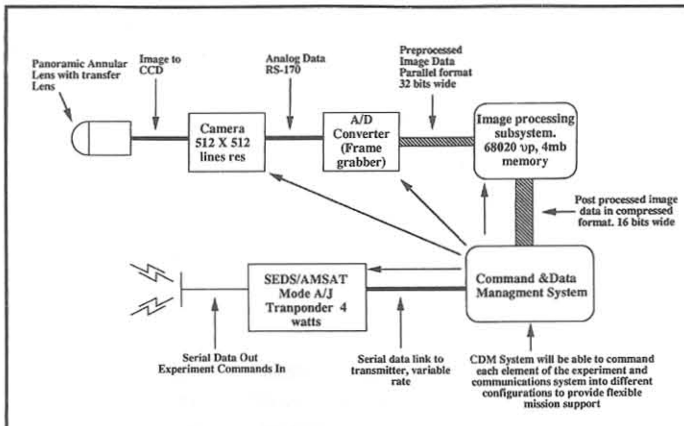

Fig. 3 —Functional block diagram for SEASIS.

serves as an event timer and responds to sequencer commands from the Delta II telemetry system. Other data stored will include tether tension, temperature, and supply voltage. The Delta II downlink capacity ranges from 1kbit/sec to 115 kbit/sec. This telemetry is completely separate from the amateur radio portion of the mission and will be supported by NASA and Air Force ground stations.

Student Experiment Package

The student experiment package consists of two co-operating experiments designed to support the gathering of tether dynamics information. A third student experiment will be mounted on the second stage itself.

Three-Axis Accelerometer System (TAS)

The objective of TAS is to obtain angular and linear acceleration data in three levels of g, (10-1, 10-2, and 10-4)[4] Each accelerometer also has a temperature output for determining temperature compensation for the accelerometer outputs. This totals twelve analog outputs that will be fed into a dedicated high accuracy 12 bit A/D converter. Figure 2 is the functional block diagram for TAS. The experiment requires +/- 15 VDC at 150 mA and weighs 1.5 pounds. The hardware design has already flown on sounding rockets and is a mature design. The accelerometers are QA 2000-020 from Sundstrand Corp, Redmond, Washington. This same unit is used for the inertial guidance of the NASA Mars Observer spacecraft.

SEDS Earth Atmospheric and Space Imaging System (SEASIS)

The SEASIS experiment uses a unique Panoramic Annular Lens (PAL) to enable the experimenters to decouple the angular accelerations of the AMSEP due to spring deployment from the linear and angular accelerations induced by the tether as it deploys from the second stage.[5] Figure 3 illustrates how this will be accomplished. The PAL is a single element lens with spherical surfaces which forms an internal virtual image of its surroundings. The image information is mapped, using stretching methods, onto a flat surface creating a 2-D representation of the 3-D cylindrical surface, and is transferred by a collector lens to a sensor array. The depth of field of the PAL extends from the surface of the lens out to infinity.[6]

In the SEASIS experiment, a Charged Coupled Device (CCD) camera is used to electronically resolve images, and gathers and amplifies light in a 700 X 400 pixel array. An electronic automatic iris control is used to limit the lighting level when viewing bright objects. A mechanical iris may also be used to supplement the electrical one. The camera collects an image and produces an analog signal. A flash analog to digital converter/frame grabber is used to convert the camera's analog output to a digital pixel array where each element is one byte in length. The board is software and hardware agile, allowing the sample rate, data array size, analog data channel, data phase, and trigger source to be controlled by computer.[7] The hardware and software driver for this frame grabber will be provided by Weber State. A dedicated 68020 microprocessor is used as a compression engine to transfer the data from the frame grabber to image memory where the data is compressed by software into a compact form. After compression, the data is transferred via DMA through a 16 bit data port to the satellite Command Data System (CDS). Software for the display of the images will be part of the software package made available to the AMSAT community.

The power required for this experiment is about five Watts, including power for the compression engine and camera system. The weight is about seven pounds, most of which is shielding for the processor and the weight of the PAL lens. It is desired that after the LDTDE mission ends that SEASIS will continue to be used to provide a unique source of wide field imagery not available from any other system.

Free Electron Wiggler LASER

This experiment is provided by the Milwaukee School of Engineering. Its purpose is to determine if the free plasma of the E and F layers of the Ionosphere is sufficient to power a LASER of this type. This experiment is not mounted on the satellite, rather it will be mounted on the second stage and its telemetry will be captured by the deployer's data system.

AMSAT Mode A/J Transponder

The transponder pair proposed for the AMSEP is a combination Mode A/J transponder similar in frequency operation to the one flown on OSCAR 8. The proposed mode A uplink frequency is 145.820 to 145.880 MHz. The downlink frequency will be 29.300 to 29.360 MHz.

The proposed mode J uplink frequency is 145.820 to 145.880 MHz. The downlink frequency will be 430.930 to 430.990 MHz.

It is further proposed that the design and construction of the AMSAT transponder pair will be the responsibility of the DOUG, which will operate a proposed AMSAT/NA spacecraft lab in the Detroit area. The design will use advances in technology to enable the transmitters to be up to 80% efficient. Design features incorporated into the Microsats such as variable transmitter power will also be used to allow the maximum rf output from the available power of the satellite. The preliminary baseline of maximum rf power output from each transponder is four Watts. Due to the electrical power limitations of the satellite only one transponder at a time will be commanded on. This will be alleviated when the LDTDE mission is over and the accelerometer is commanded off. After that time both transponders will be capable of simultaneous operation.

Two 9600 bps telemetry channels will be provided for the SEP experiments. These will be located at the bottom of the frequency allocation of the Mode J transponder. It is desired that a slower bit rate telemetry channel be made available on the Mode A downlink side to enable image and accelerometer data capture by Mode A users during the post deployment phase of the experiments operation.

Satellite Operational Systems

The AMSEP systems necessary to complete the satellite are the Electrical Power System (EPS), Command Data System (CDS), Mechanical Support Structure (MSS), and Thermal Management System (TMS). With the exception of the EPS these systems are in the preliminary design phase. Since this will become an OSCAR at the end of the LDTDE mission we are undertaking discussions on incorporating the AMSAT Microsat technology as integral to the design of the other systems. It is in each groups best interest to retain as much as possible hardware and software compatibility with the microsats. Personnel attached to this project already have extensive experience with the 80186 compatible processor used on the Microsats. We feel that this processor is a good choice for our CDS system for the same development cost issues addressed by Jan King in his paper on the Microsats.[8] Also with our relatively short time span until launch we feel that any shortening of the development process is well met. Our designs for the systems mentioned above will be finalized by December and we are already breadboarding and testing the experiment hardware and software.

Flight Operations Planning and AMSAT Support

Amateur Ground stations will require a good knowledge of the AMSEP ground track to acquire and record the experiment data as well as operate the transponders. This information will be released as the launch date nears. It should be again noted that NASA currently plans only to fly a dead weight on the SEDS 2 mission. If we are tenacious and do our jobs right both AMSAT and UAH SEDS will have a mission that will provide a needed AMSAT satellite service to its users, all too scarce hands on engineering education for our students involved, and maybe most important develop working relationships between those interested in furthering both education and amateur radio technology. Isn't that what Hiram Percy Maxim envisioned for the amateur radio art? AMSAT support is crucial to the success of this venture. Our student organization consists of volunteers as much as AMSAT does. We as students have the same time pressures as AMSAT members do (in most cases with no job to support us!). We have the enthusiasm, dedication and drive necessary to complete this job. All we ask is advice and guidance. That is an Elmer's role. Amateur radio for 90 years has prospered because of the Elmer spirit. Together we will succeed.

I would like to express my thanks to John Champa, K8OCL, for being a receptive ear and providing leadership for the transponders. I would also like to express special thanks to MARC members Chris Rupp, W4HIY, and Ed Stluka, W4QAU. They have spent much time and effort in aiding not only this but several other amateur radio and student space flight experiment projects. These are unsung heros for Amateur Radio and student involvement in space flight.

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Solar Sail Update

By Emerson H. LaBombard
Solar Sail Project Director
World Space Foundation

For many years, the World Space Foundation and AMSAT have been working together on the development of a solar sail powered spacecraft. Our objective has been the launching of such a vehicle to determine such characteristics as ability to deploy the sail, the controllability, and other things leading to the development of the technology for ultimate application in space transport and exploration.

In 1989, The Quincentenary Commission, chartered by Congress to organize the celebration of the 500th aniversary of the discovery of America, circulated an RFP requesting proposals for a group of solar sail vehicles to be launched on October 12, 1992. These spacecraft, representing Europe, the Orient, and the Americas, would race each other to the Moon and on to Mars. The Foundation/AMSAT team, joined by many other organizations, submitted a proposal. Other teams also submitted proposals, all of which were evaluated by the AIAA, and four "finalists," including ours, were selected and recommended to the Commission.

Due to funding problems, the inability to provide a suitable launch program, as well as other things, the Commission was not able to select the "America's" spacecraft in January 1990, as planned. The Foundation, therefore, continued to look elsewhere for support. A very promising program, supported by European interests, is for the spacecraft, proposed by our team, by a French/Spanish team and a Japanese entry, to be launched simultaneously as a single payload on ARIANE. This group of three vehicles, would reach high Earth orbit, separate, and deploy their sails. They would then proceed to higher orbits, ultimately escaping from Earth on their way to the Moon and beyond.

On September 12, 1990, the Quincentenary Commission decided that the ARIANE program, developed by the Foundation and the others, was exactly what the Columbus 500 Space Sail Race was supposed to look like. An announcement was made by Senator John Glenn, who is one of the advisors on the Solar Sail Race for the Commission, that the solar sail vehicle proposed by the World Space Foundation team, for inclusion on the ARIANE launch, was selected to be the America's entry in the Columbus 500 Space Sail Race.

WEBERSAT Operations and Experiment Results

WEBERSAT, a 27 pound LEO satellite launched by the Ariane 40 on January 21, 1990 into an 800 Km polar orbit, carries several inexpensive payload experiments that were developed as a learning experience for engineering students at Weber State College. The experiments include a color CCD camera, a CCD light spectrometer, video flash digitizer, 1.26 GHz NTSC video uplink, micro-impact sensor, and optical horizon sensors.

Operational command and control of the spacecraft and its payloads is performed by students in the School of Technology, from a ground station located on the WSC campus. Here, the students and their advisors monitor on-board systems, plan and execute experiments, and observe test results.

This paper describes the satellite experiments, ground station requirements, and experiment results as of this date.

By Charles Bonsall,
Keith Christensen,
Stephen Jackson,
Spencer Poff,
Jeff Raetzke,
Claude Smith,
and Dr. Robert Summers

Introduction

WEBERSAT is a small, yet sophisticated satellite now available for experimental and educational use by interested groups and individuals. It is one of four "Microsats" developed by the Radio Amateur Satellite Corporation (AMSAT), in cooperation with the Center for AeroSpace Technology (CAST) at Weber State College. WEBERSAT was launched from Kourou, French Guyana aboard ESA's Ariane 40 vehicle on January 21, 1990. It is WSC's second major satellite project, and involves undergraduate students, faculty, and industry advisors from many disciplines.

The 27 pound, 9" x 9" x 12.5" satellite is in an 800 Km, sun-synchronous, polar orbit with a period of 100.7 minutes. Four to six passes per day are visible from the ground station at WSC.

Like the other Microsats, WEBERSAT is an amateur radio satellite capable of store-and-forward message handling, and uses the amateur packet (AX.25) protocol for all data transmissions. WEBERSAT differs from its three cousins in that it contains a number of experiments in an extra "attic" module. (See Figure 1.)

Experiments

As shown in Figure 2, the satellite has six sections vertically stacked, which communicate through an onboard local area network. The top, or "Attic" modules contain various experiments, including:

Micro Meteor Impact Sensor
L-Band Video Uplink Receiver
Horizon Sensor
CCD Color Camera
CCD Light Spectrometer
Video Flash Digitizer

Impact Sensor

The impact sensor was designed and built by students at Brighton High School in Sandy, Utah, with assistance from the Zevex Corporation of Murray, Utah. It can detect small vibrations caused by micro-meteor impacts, or on-board events such as opening and closing of the camera iris, and thermal stress.

The detector is a 6 x 1.25 inch piezoelectric strain gauge, mounted on the +Y surface of the satellite. When acceleration of the sensor occurs, voltage pulses are generated and summed. The resulting voltage is sampled by an analog to digital converter, and translated into a digital value ranging from 0 to 255 (0 to FFh). This value is reported in the telemetry data.

A second, identical sensor is mounted inside the attic module, perpendicular to the external sensor. This detector feeds the count circuit in such a way as to inhibit a count from being recorded if the whole frame flexes, as it might during a thermal event. Strikes of moderate intensity may cause a portion of the structure to ring (produce a damped oscillation). This results in a greater pulse count if the impact was not large enough to trigger the second sensor.

This configuration does not provide quantity or magnitude data directly, but when sample period, rate of change, and environment factors are accounted for, inferences about relative magnitude or quantity can be made.

L-Band Video Uplink

WEBERSAT's 1.26 GHz NTSC video receiver permits ground stations to uplink, store, and re-transmit a single frame video picture.

The uplink signal is received by one or both of the quarter wavelength antennas mounted on the + & - X surfaces of the spacecraft. The 1.26 GHz amplitude modulated signal is converted down to 45.75 MHz, amplified, and detected. The resulting composite video signal is directed to an Analog Data Multiplexer, where it can be selected for digitization and storage. The latter process is also used in handling camera and spectrometer signals.

Users of this feature will need to generate a signal with a high effective radiated power (ERP). Pre-launch testing indicated the following system sensitivity:

-127 dBm: Some effects seen on CRT.
-112 dBm: Recognizable image on CRT.
-97 dBm: Readable fine print images on CRT.
-87 dBm: Fully quieted picture on CRT.

Assuming no antenna gain on the satellite, and free space attenuation of 153 to 164 dB, it would require 500 to 1000 watts ERP to produce recognizable images. Over 2.5 kW ERP would be required to produce high quality pictures.

This system can also be used to experiment with other signals in addition to composite video, such as radar, or to measure antenna radiation patterns and atmospheric attenuation effects.

Horizon Sensor

The horizon sensor is composed of two photodiodes aimed through holes in the wall of the attic module. The holes limit the

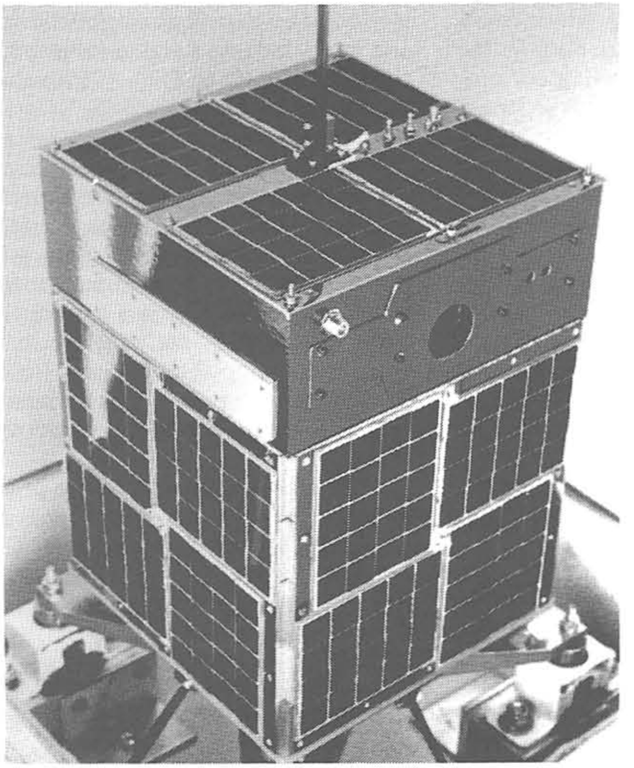


Fig. 1 — WEBERSAT.

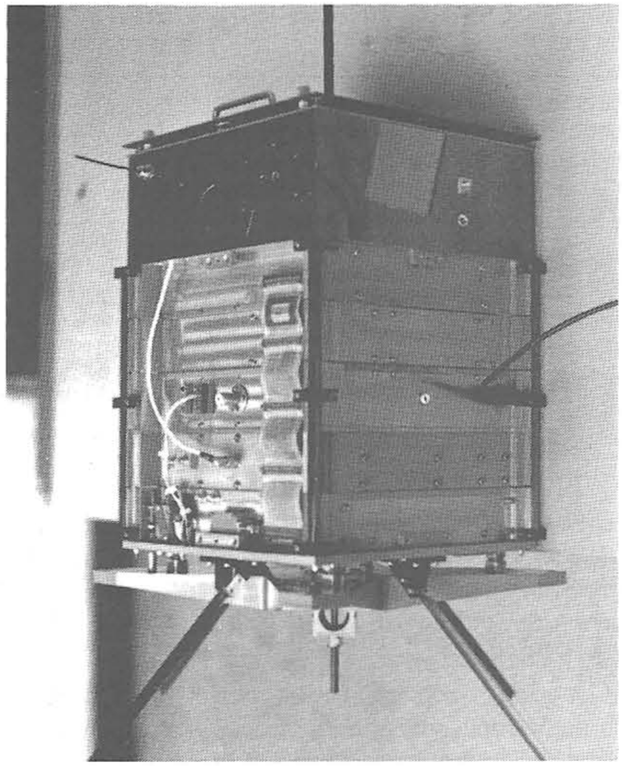


Fig. 2 — WEBERSAT's Modular Construction.

field of view (FOV) of each photodiode to 11 degrees, and are aligned to produce a total FOV of 22 degrees centered perpendicular to the +X axis (same as the camera). Sensor 1 is closest to the outside edge of the surface, and is adjusted inward toward the center. Sensor 2 is closest to the camera lens, and is aligned with the outside edge. The FOV's cross about 1 foot from the spacecraft, but do not overlap at infinite range. Given these characteristics and WEBERSAT's 800 kilometer orbit, only the Earth subtends an angle large enough to illuminate both sensors simultaneously.

Since WEBERSAT's attitude is uncontrolled, except for passive magnets on the Z axis, the horizon sensor is used to aid in directing the camera and spectrometer, and helps to determine the spin rate of the spacecraft. Restricting availability of the camera, spectrometer, and flash digitizer power to periods when the Earth is in view of the sensor also helps to conserve limited battery power.

CCD Color Camera

WEBERSAT's CCD color camera is a modified Canon CI-10 with a 25mm lens and automatic iris. It has 700 x 400 pixel resolution. The following changes were made to the basic design in order to make the camera spaceworthy:

1) Replaced iris range control potentiometer with a programmable potentiometer to accommodate widely varying brightness levels.

2) Added a 10.7 MHz digitization clock, phase-locked with the 3.579545 MHz color reference.

3) Replaced focusing mechanism with a fixed focus support.

4) Replaced aluminum electrolytic capacitors with solid tantalum capacitors.

Camera output signals, composite video, red, green, blue, and the 10.7 MHz digitization clock are fed to the flash digitizer, where they are processed for storage in the spacecraft computer RAM.

Camera control commands are stored and executed via the on board computer. The command information includes desired shoot time, horizon sensor constraints, and iris settle-in delay. The on board software also controls the iris potentiometer setting, and the time-out delay for the horizon search. Uploaded command information can be routinely varied for each picture as desired. However, actual software changes are more complex due to the extensive simulations required to insure safe operation.

On power-up, the camera draws a surge current of three amperes. This quickly drops off to the nominal value of 360 mA at 10 volts. As this is normally the power budget for the entire spacecraft, the camera remains on only as long as necessary to complete the programmed photo sequence. This is insured by software and firmware safeguards.

WEBERSAT's camera system has received the most attention of all the experiments to date. It has provided interesting data, and a few surprises which will be discussed in the Results section of this paper.

Spectrometer

The purpose of the spectrometer is to measure the spectrum of sunlight reflected from the atmosphere in order to determine the exact composition of the atmosphere in particular places and times. This data might be used to study changes in the concentration of gasses, such as ozone or carbon dioxide.

The spectrometer measures the chromatic content of light passing through a narrow slit in the -Y surface of the satellite. The light is focused by a lens onto a diffraction grating, then onto a 5Kx1 byte CCD sensor array. The array converts the spectral data to a waveform that is flash digitized by the same circuit used by the camera. The spectrometer covers the band from 200mu to 1000mu.

Flight software is not yet available for the spectrometer.

Flash Digitizer

The flash digitizer unit is common to WEBERSAT's three video experiments. Analog signals from the camera, spectrometer, or L-band receiver are converted at 50ns per sample into an 8-bit digital format, then stored in RAM for transmission. The unit allows computer control of data array size, analog data channel, phase, and trig-

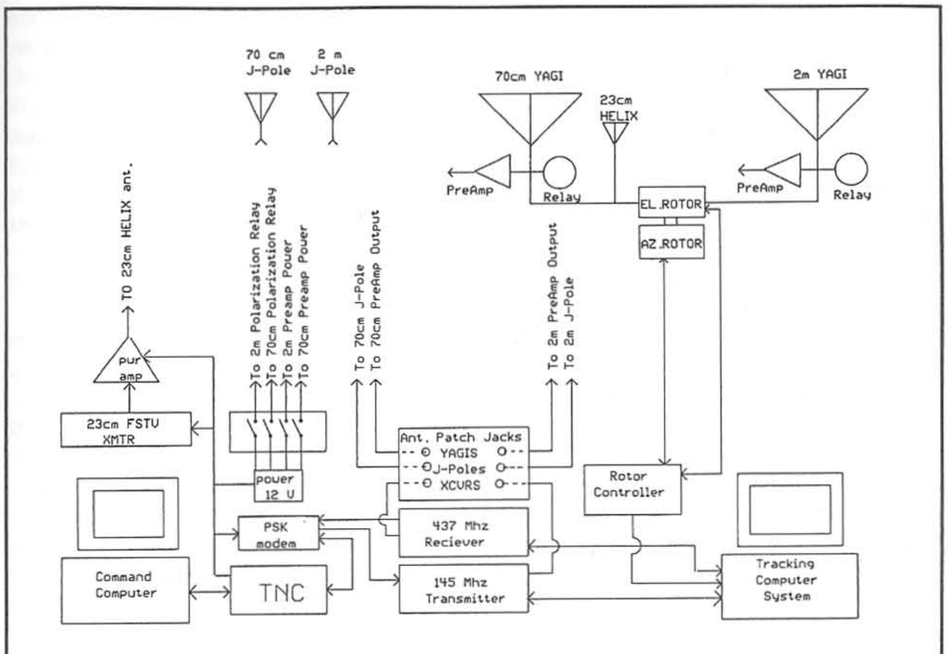


Fig. 3 — WEBERSAT ground station block diagram

ger source, making it capable of handling a multitude of data types and sources. Video compression algorithms are also available to maximize efficient use of memory, while minimizing required transmission time.

The digitizer is interfaced to the 2 Mb bank switched RAM by direct memory access (DMA), allowing up to 12 still video images of 166K pixels each to be stored for download. Pixel luminance values, represented by 8-bit binary numbers, appear as extended set ASCII characters in the serial data received by the ground station terminal.

Other Sensors

Other sensors located throughout the spacecraft provide important data about temperature, current, voltage, and power levels; information used to determine and regulate the operating conditions aboard the satellite. This data is transmitted periodically between data packets from other experiments.

Ground Station Hardware

The Weber State ground station is equipped to communicate with WEBERSAT and other amateur radio satellites. This section is a technical description of the Weber State ground station.

This system (Figure 3) has two transceivers, an L-band transmitter, two computers, a 1200 baud phase shift keyed (PSK) modem, terminal node controller (TNC), power supplies, antennas and several command, control and support software programs.

The ground station has three basic functions: tracking the satellite, receiving and transmitting data, and decoding information from the satellite.

Tracking

Tracking the satellite is one of the most important functions of the ground station. If the antennas are not pointing in the proper direction, severe difficulty in communicating with the satellite would result. The tracking system is composed of an IBM XT computer which is linked to an azimuth and elevation rotor system though two software programs: Kansas City Tracker and QuikTrak. QuikTrak calculates the position of the satellite and provides this information to Kansas City Tracker which aims the antennas at the satellite when it comes in range.

Receive System

The receive system is composed of a 435 MHz, 40 element, cross polarized yagi with a gain of 15.2 dB, connected to a 24 dB preamp. This is connected to a 70 cm all mode transceiver which receives the signal from the antenna, then passes it to the 1200 baud PSK modem which locks on to the signal and compensates for Doppler shift. The modem compensates for Doppler shift by comparing the received audio frequency to its internal clock, and sending pulses out to the receiver's frequency control circuit as needed. After frequency lock is established, the PSK modem converts the phase shift keyed signal into voltage levels. The PSK modem sends the voltage levels to the TNC which converts the level type packet format to RS-232 serial data. The signal is then fed into the serial port on the command computer, where the data is collected and saved by a WSC software package called "Capture". It is later translated into its final form by various decoding programs depending on the experiment.

Transmit System

The transmit system is composed of the command computer, TNC, PSK modem, 2m transceiver and a 22 element, cross polarized yagi with a gain of 13 dB.

When a command needs to be sent to the satellite, it is first composed and saved on the command computer until the satellite is in range. When the command is sent it is converted from RS-232 to packet level by the TNC. It is then fed into the PSK modem which converts it into phase shift keying, then on to the 2m transceiver where it is transmitted via the 2m antenna up to the satellite.

L-Band Video Uplink

The L-Band link from the ground to the satellite consists of several components. First a computer, camera, or a VCR provide the video information to be sent to the satellite. The video is sent to a transmitter, then to an amplifier and on to either a dual helix antenna or a Loop Yagi antenna via 100' of 7/8" hard line.

The dual helix design from an economic standpoint seemed to be a suitable choice for an antenna. With 20 turns each, it is feasible to obtain 17 dB of gain as well as circular polarization. Another benefit is that the existing rotor system could be used. After construction and testing, the antenna with some adjustments gave approximately 12 dBi of gain and was apparently linearly polarized. It was then clear that there must be a better choice. A Loop Yagi with 21 dBi of gain was donated to the college by Down East Microwave, and this is what is used at present.

The communications link has several gain and loss factors. There is a 47 dB gain from the amplifier, a 3.2 dB loss in the hard line, and a 21 dB gain from the Loop Yagi antenna. At 821 Km from the surface of the Earth, the atmospheric loss from the horizon to zenith is 163.6 dB to 153.5 dB respectively. Thus, the total power at the satellite with the existing system from the horizon to zenith is -104.3 dBm to -93.5 dBm. Obviously there is room for improvement on the L-Band ground station. Planned improvements include a more powerful amplifier, and a 10' parabolic dish for an antenna.

Ground Station Software

The operation of the ground station requires several command, control, and support software programs. These programs are responsible for command transmission, data collection, tracking, decoding and the execution of the on board experiments.

Tracking Software

Tracking and orbit prediction of the satellite requires several different software systems which interact with each other, and with experiments on board the satellite. The tracking portion of the ground station is one of its most important functions. The ground station uses a tracking program called QuikTrak to accomplish this task. QuikTrak uses a set of Keplerian elements to calculate the position of the satellite at any given time during its orbit. QuikTrak builds a table of the satellite's position and the Doppler shift, and stores them for use by two other programs: Kansas City Tuner and Kansas City Tracker. QuikTrak also uses these values to construct a map of the pass area, and to simulate where the satellite will be during any given time during the pass. QuikTrak also can project where the satellite will be during future passes. This function is a great asset since WEBERSAT's camera is programmable and can be commanded to take pictures at any point in its orbit. By plotting the orbit path with this program, ground station operators can pick prime locations for picture taking.

QuikTrak calculates the table for the position of the satellite and Doppler shift, but it cannot aim the antennas or compensate for Doppler by itself. Therefore, QuikTrak is mated with Kansas City Tracker and Kansas City Tuner which interface the tracking computer to the rotor system, transmitter and receiver via an add-on PC board in the XT. These programs read the calculation table for the position of the satellite and the Doppler shift from QuikTrak.

Communication Software

Receiving data from and sending information to the satellite requires several software and firmware programs. Receiving accurate data from the satellite requires the TNC's firmware to be set into KISS mode and some kind of data collection program to be present on the command computer. KISS mode is a pass all mode where all characters are passed including null and control characters. In standard packet protocol the null and special characters are stripped out. Almost any modem program will work for data collection as long as it does not strip off any of the null or control characters. For example, Procomm will act like it is properly collecting data, but in reality it is stripping out null characters and will prevent data from being decoded properly. Weber State's ground station uses a program called "Capture" which collects all the data it receives without eliminating null and control characters.

Data Decoding Software

Currently the Weber State ground station is using two different decoding programs: WEBERWARE and Decode. Both of these programs were written at Weber State by WSC students and faculty members.

Decode sorts and converts normal telemetry data, and the telemetry from the Whole Orbit Data transmissions, from ASCII files to a readable format. WEBERWARE extracts the picture information from the raw data files captured in KISS mode. It takes this information and displays it in either a gray or false color format. At this point, the operator has the option to enhance the detail of the picture by adjusting the brightness, contrast and false color pallets. WEBERWARE has the ability to generate a picture in true color if 90 percent or more of the picture information has been collected. After the picture has been fully captured and decoded it can be printed on a standard dot matrix printer.

Experiment Results

CCD Camera

The CCD color camera has successfully taken several pictures since launch. The field of view from the 800km orbit is about 150 miles on the Earth. This narrow view has made it difficult to define land masses accurately. Cloud formations, however, are clearly visible.

Efforts are still being made to take pictures over easily identifiable targets such as small island clusters.

Impact Detection

The impact sensor has been recording events that would indicate impacts from micro meteorites and dust. Thermal expansion stress has also been occasionally observed. The value given for an impact is between 0 and 255, depending on the magnitude of the hit. A magnitude of 16 is considered a minimum reading for an impact. If an impact magnitude is greater than 255, the reading may not be usable because the value will go past 255 and start from zero again. Iris movement in the camera also has been verified with corresponding impact readings at the time of the movement. Electrical noise and voltage fluctuations have been observed to cause a small change in the impact count. These effects are filtered out by comparing changes in 5 and 10 volt bus values to the variations in impact count.

Digitizer and Video Uplink

The digitizer is also capable of capturing picture data from the ground station 1.26 GHz uplink. At the present time, the WSC ground station does not have sufficient antenna gain to provide the spacecraft with a readable picture signal. The only results to date are snow with some diagonal patterns, indicating the satellite is receiving a weak signal. Efforts are progressing to erect a dish antenna capable of increasing the uplink gain.

Horizon Sensor

As previously stated, the horizon sensor was designed to detect when the +X axis is aligned with the Earth, thereby allowing the satellite to determine the proper time to take a picture. The sensor does allow detection to take place, but readings seem to indicate that the base level is higher than expected. It appears that the sensor may sometimes be fooled by reflections in the cylinders housing the photodiodes. This problem arose because the cylinder walls were not darkened to prevent such an occurrence. After initial testing, it seems that the sensor is working well enough to allow pictures to be taken in the general direction of the Earth.

Whole Orbit Data

Standard telemetry data consists of information from 66 voltage, current, temperature, and other sensors located throughout the spacecraft. Values are sampled and transmitted every 10 to 60 seconds. This real-time mode allows data to be collected only while the satellite is in range of a ground station.

Whole Orbit Data (WOD) allows up to six telemetry channels to be sampled at a rate ranging from 1 to 12 samples per minute. A maximum of 2275 data samples may be collected and stored in RAM for transmission on command. The run time of the collection is determined by dividing the maximum number of samples by the sample rate.

WOD collection has proven to be very useful in determining what actually transpires aboard the spacecraft. The first analysis performed from this data was an attempt to verify the existence of thermally induced impact events. To aid in analyzing the impact sensor data, the effect of thermal stress and other factors needed to be determined. Several solar panel current outputs, thermisters, and bus voltages were monitored along with the impact sensor. This experiment demonstrated that few sensor readings could be attributed to thermal creaking, however, erroneous readings could be induced by unusually sudden voltage changes on the 5 volt bus.

WOD has also been used to calculate WEBERSAT's spin rate and direction. This was accomplished by gathering array current data and measuring the time between peaks.

One obvious advantage of WOD collection is the ability to record events that occur outside the range of the ground station. A recent example of this is the July 22, 1990 solar eclipse over Siberia. When the satellite passed over the area, penetration of the shadow was indicated by a sudden decrease in array current.

Educational Aspects

The educational aspects of using satellites as teaching tools are numerous. Building a satellite requires the unification of many different talents and disciplines which eventually impact on each other. For example, thermal considerations affect the materials selected for the structure as well as the design itself. Size constraints affect the surface area available for the solar cells, which has impact on the power available for the spacecraft. The power available for the satellite determines how many experiments can be flown and how many can be executed at one time. This presents the students with exciting and challenging engineering problems and adds a real world dimension to their other assignments.

Students are involved in nearly all phases of the construction and operation of the satellite. This gives them hands on experience in designing systems and circuits as well as building and testing prototypes, developing software, and performing functional and environmental stress testing. Students also execute experiments, retrieve and evaluate the data from these experiments, monitor the status of the satellite and develop procedures and documentation for running the satellite.

Public School Involvement

The educational benefits of the WEBERSAT program are not strictly limited to the college level. The WEBERSAT program involves students on the Elementary, Jr. High, and High school levels in various ways. During the design and construction stages, students at Brighton High School developed the micro meteorite impact experiment for WEBERSAT. After the launch of WEBERSAT, students from Jr. High and High schools were invited to join a program that allows them to come in and participate in WEBERSAT operations during a pass. After the pass they are invited to remain for a short lecture on what went on during the pass or a related subject, given by one of the faculty or student members of the ground station team.

Educators and students are encouraged to submit proposals for experiments to be executed on board WEBERSAT. To help these experimenters, CAST has developed a WEBERSAT user's handbook which describes the on board experiments, project history and ground station requirements. This exposes students to science, engineering, astronomy, radio, computers and teamwork. To involve students on the Elementary level, CAST gives lectures, presentations and demonstrations of ground station activities. These programs will hopefully encourage students in the lower grades to become interested in science and technology.

Design of an Easy to Build, Versatile, Homebrew Satellite Ground Station

By Edward Krome, KA9LNV

The purpose of this paper is to review RF hardware requirements for satellite ground stations and show that it is possible to home construct high performance, versatile and inexpensive gear. It will also detail some construction projects that I hope will encourage non-satellite users to "get their feet wet" and experienced users to expand their capabilities. And to get everybody back into homebrew.

Before we discuss actual iron, let us review overall ground station hardware requirements. Figure 1 is a matrix of transmit and receive requirements for all current satellite frequency schemes. To proceed further requires a basic understanding of how modern transmitters and receivers operate. All use the heterodyne principle of mixing an internal oscillator with an RF signal to produce a different frequency, eventually ending up with a detector. Modern HF transceivers may have many internal conversion stages, which we can blissfully ignore. To function on frequencies outside the range of our base HF devices, we can add an additional external stage using the same principles called a converter. A typical VHF to HF converter consists of an internal signal source called a Local Oscillator, a frequency heterodyning device called a mixer and some form of filter to separate desired signals from undesired. Converters can be designed for either transmit or receive applications and can produce either a higher (up-converter) or lower (down converter) IF than RF. If similar frequency conversion devices for both the transmitted and received signals are contained in the same package, the device is termed a transverter. Transverters use a common LO for both transmit and receive functions.

Freq\mode	A	B	J-A	J-D	L	S
10M T						
10M R	X					
2M T	X		X	FM		
2M R		X				
70cm T		X				X
70cm R			X	X	X	
23cm T					X	
13cm R						X

X= SSB/CW

Fig. 1 — Satellite mode vs. frequency.

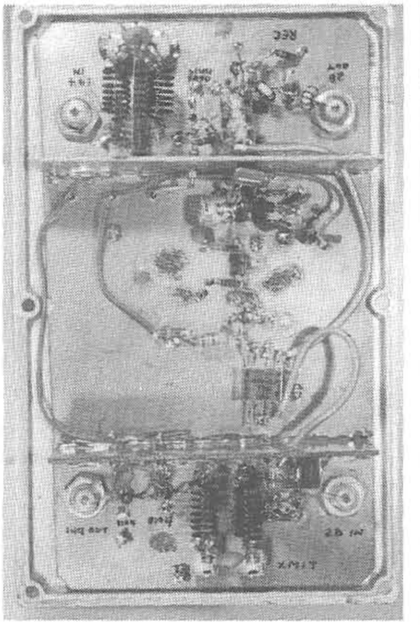
Freq\mode	A	B	J-A	J-D	L	S
10M T	T	T	T	T*	T	T
10M R	R	R	R	R	R	R
2M T	T		T	FM	T	
2M R		R				R
70cm T		T				T
70cm R			R	R	R	
23cm T					T	
13cm R						R

T or R = SSB/CW
* Only if 10M FM transmitter used into transverter otherwise, 2M FM HT

Fig. 2 — Transverter conversion schemes.

Note in Figure 1 that Mode J-Digital is treated separately, since it requires an FM uplink. The most common piece of ham gear is the 2M handheld and much HF gear does not handle FM. So why mess around with converters when you can work J-D uplink by feeding your satellite modem into the external mic input of your HT? Hang an external power amp on the back end and off you go. I have used this method for years. The major shortcoming is that it may not be possible to directly modulate the varactor in an HT for specialty modes such as UoSAT 9600 baud.

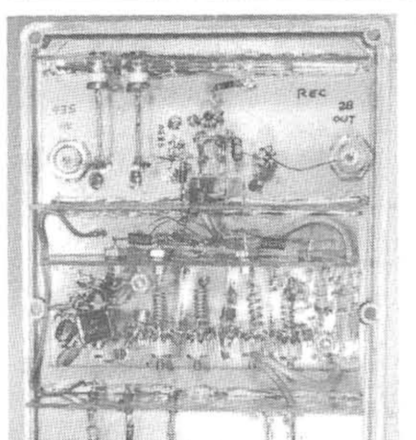
Now we will look at hardware and power level requirements to satisfy all modes. Figure 2 details possible conversion schemes. A few requirements jump out here — a good starting point is a 10M rig. Then a 2 meter converter will cover the



2 Meter transverter.

most modes, but a 70 cm transmitter is required for the most popular (Mode B). A problem becomes apparent - satellite operation is not only cross-band, but it is full duplex. In other words, you must transmit and receive simultaneously. Hard to do with a modern HF transceiver. So, face it, you need a second 10M transmitter. Anything capable of CW/SSB operation is OK, you only need one milliwatt of RF energy at 28 to 30 MHz from it. I use a 20 year old Drake and it works fine. Go to the flea markets.

A versatile ground station is now shown to require 2M and 70cm transmit and receive capabilities. Higher frequencies such as Mode L uplink on 1269 MHz and Mode S downlink on 2401 MHz are handled with the 2 Meter transverter and the marvelous "no-tune" transverters designed by KK7B and WA8NLC. These are marketed by W3HQT of Down East Microwave. With these, Mode S receive is almost simply "plug and play". I highly recommend these devices.



70 cm Transverter.

It is possible to home construct transverters for all these modes. We will detail homebrew transverters for 2M and 70 cm and assign a little homework.

Homebrewing tends to get a bad rap lately. People complain about complexity and required technical sophistication. If anything, just the opposite is true. In recent years a number of devices have appeared that make homebrewing easier than ever and greatly reduce the risk of failure. In these designs, I have used untuned devices where possible and circuits set up to only require diode probe alignment where tuning is absolutely required. Since failure is a total loss, more expensive components that work are much cheaper than less expensive stuff that doesn't.

Here are some devices that make homebrewing really neat.

1) The MMIC, or Monolithic Microwave Integrated Circuit. A 50 Ohm in and out gain block. Most are ultra linear and dead stable, with a DC to daylight frequency response. $3 to $5 each.

2) DBM or Double Balanced Mixer. Linear, good LO suppression, good port isolation and no tuning. No more dual gate mosFET mixers. $5 up.

3) Brick amplifiers, also called power modules. Lots of gain, stable and predictable and no tuning. Narrow bandwidths to not require elaborate output filters. Available up to 50 Watts out in both linear and class C. Expensive but worth every penny.

Now let's look at some actual hardware. We will start with the complete 2M transverter, first with a block diagram, then with actual circuitry. Then we will detail the 70cm version. When we get done, I expect each of you to build at least the 2M version.

Figure 3 is the block diagram of the 2M transverter. Stage gains and power levels are included to aid in understanding operation. The output from a common local oscillator is split to feed DBM's (Double Balance Mixer) in the transmit and receive converters.

The transmit section mixes a 28 MHz IF input signal with the LO. A bandpass filter selects the desired output. Two stages of MMIC gain blocks raise the output level to +13 dbm (20 mW). This is the proper level to drive the transmit converters in the KK7B/WA8NLC "no-tune" transverters. For higher power levels (Mode J), an externally mounted M57732L brick amp raises the power level to +37 dbm (7 W). This drive level is adequate for various commercial amplifiers (Mirage, Communications Concepts Inc., RF Concepts, etc.) in the 10 W in, 75W out range. The CCI model 875A in kit form ($120) is an excellent match for use with the Microsats.

The receive section looks too simple. An input bandpass filter removes the garbage, then feeds a single low noise MMIC. This drives a DBM, which outputs through a diplexer. A diplexer is a filter that passes 10M signals and terminates undesired frequencies into 50 Ohms. This receive section alone has a noise figure of approximately 3 dB and an overall conversion gain of 11 dB. Although this is adequate for local 2M use, it is really designed to be preceded by an external preamp. The inexpensive DGGaAsFET (Dual Gate GaAsFET) variety, as detailed in any recent *ARRL Handbook*, is adequate. Remember that on 2M, a noise figure of much less than 1 dB doesn't really add much, since sky noise is higher than that. Unless your following receiver is really deaf, an IF post-amplifier is not necessary and does little more than increase your S-meter reading.

The actual circuitry, shown in Figure 4, is not much more complicated than the block diagram. The Local Oscillator is an old reliable from W1JR. Use of a 116 MHz crystal eliminates the need for frequency multiplier stages, which are the single most aggravating part of any converter. Build it as shown, terminate the output with a 50 Ohm resistor and the diode probe and fire it up. It should draw about 10 mA. Tune the output trimmer for maximum output, then slightly off to the side where output drops off more slowly to insure reliable starting. If the oscillator does not start (and this is rare), vary the value of the 39 pF cap slightly and try it again. Once the LO is functioning properly, add the buffer stage and splitter. I used a commercial splitter because it was available; an alternate resistive splitter with higher insertion loss is shown. The LO alone produces about +10 dbm (10 mW) output. The splitter divides this into two +7 dbm (5mW) signals, which are at the correct level for the SBL1X mixers shown. The additional loss in the resistive splitter will probably not be noticeable.

Build the transmit and receive converter sections. Lay them out according to the circuit diagram and photos. Be careful not to break the leads off the MMIC's or pull leads out of the capacitors. The miniature capacitors shown in the photos have a maddening habit of breaking internally from lead stress when bending them. If you seem to have very low gain from a MMIC stage, look for broken capacitors. The prob-

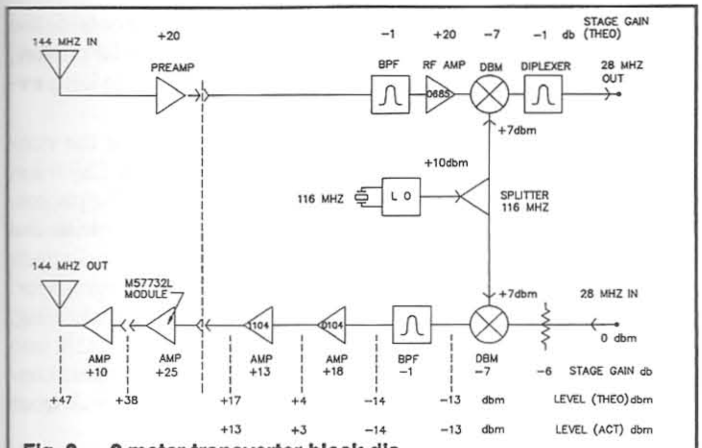


Fig. 3 — 2 meter transverter block dia.

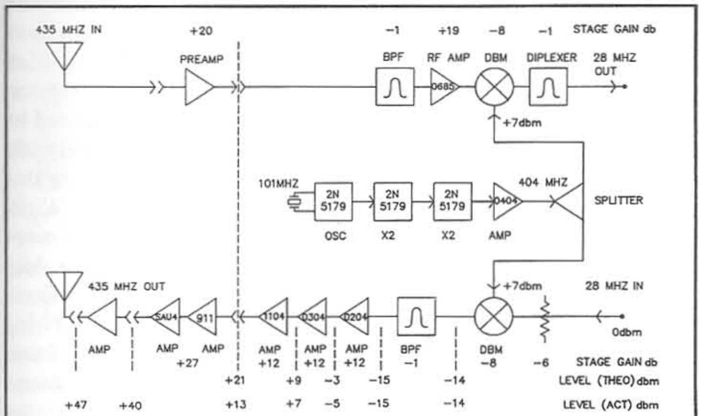


Fig. 5 — 70 cm Transverter block dia.

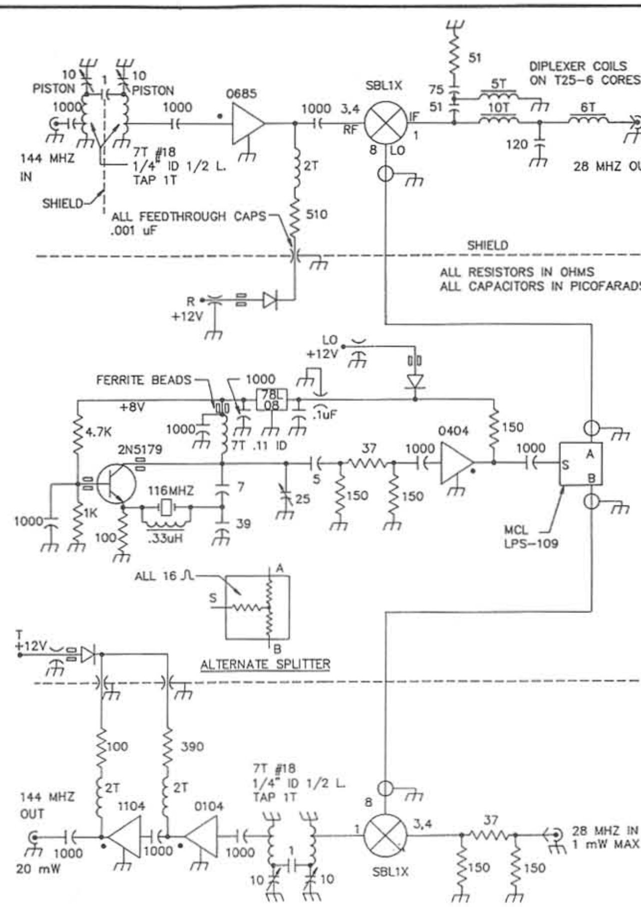


Fig. 4 — 2 meter transverter.

lem is less with silver micas or miniature ceramic discs, and they are recommended.

Piston trimmers are a must on the receive bandpass filter and recommended on the transmit end, although mica or ceramic trimmers will suffice there. The version of the transmit converter shown uses ceramic trimmers mounted on their sides and soldered to the ground plane. Lay everything out before you solder.

Receiver alignment can be either on the air or with a signal generator. Peak the piston trimmers for maximum received signal. The receive section (the 0685 MMIC) should draw about 17 mA.

For transmit section alignment, first terminate the last MMIC with a 50 Ohm resistor. Apply +12 Vdc. The 0104 should draw 17 mA, the 1104 about 60 mA. Energize the LO, then apply less than 1 mW of 10M RF to the IF input port. Since the DBM output is both the sum and the difference of the IF in and LO, the bandpass filter must be tuned to select the desired output. Since the sum, or higher, frequency is desired, start with the trimmers fully unmeshed (minimum capacitance), then tune for the first output peak from minimum.

The following M57732L ($33) brick amplifier requires no alignment. See Figure 7. Use good bypassing techniques and care in construction. Before applying voltage, recheck wiring, then terminate both input and output connectors with 50 Ohms. Apply DC voltage from 0 while monitoring current draw. At 13 VDC, the resting (quiescent) current requirement should be about 150 mA. If high current is drawn with no drive, the amp is shorted or oscillating. Shut it down immediately and determine the problem. Since this is a class AB amplifier, current will increase as drive is applied. Insure that current drawn does not exceed 1 1/2 amps. Never energize any amplifier without an antenna or suitable dummy load on the output. That's it. Not too complicated after all. Figure 5 is the block diagram for the 70 cm transverter. The biggest difference between it and the 2M unit is the complexity of the Local Oscillator, since 407 MHz crystals are hard to find.

The Local Oscillator starts out with a 101 MHz crystal oscillator similar to that in the 2M unit. It is followed by 2 stages of frequency multiplication. An MMIC amplifies the output from the last multiplier to the proper level (10mW) for the following splitter to drive both converter sections. The MMIC operates near its saturation level and maintains a fairly even output power level for a wide variation in input levels.

The receive converter is identical to that used in the 2M unit, consisting of an input bandpass filter, an MMIC amplifier, a DBM and a diplexer filter. An external GaAsFET preamplifier is required, although with a suitable antenna, it is possible to copy AO-13 Mode L barefoot. Input noise figure is around 3 dB, with overall conversion gain of 10 dB. This may appear low, but suppress the urge to add another amplifier stage (except the preamp)- all it does is increase the S-meter reading and hurt overload characteristics.

The transmit converter consists of another DBM, a bandpass filter, and a 3 stage MMIC amplifier. It produces +13 dBm (20 mW) 70 cm output for a 0 dbm (1 mW) 10M input. Can't get much simpler that this!

Two or three external power amplifiers stages are required depending on the desired output power level. The first stage is a simple bipolar linear amplifier . This raises the power to a level suitable for input to a S-AU4 brick amplifier ($50). The 40 dBm (10 W) output is usable for Mode B CW but usually not adequate for SSB, unless you have one whopper of an antenna. Another amplifier is required to get to the 75-100 W level. Be inventive — instead of spending several hundred dollars for a Mirage D1010, get a 4CX250 tube at a flea market for a few bucks and build a real cannon!

Now let's look at the actual circuitry in

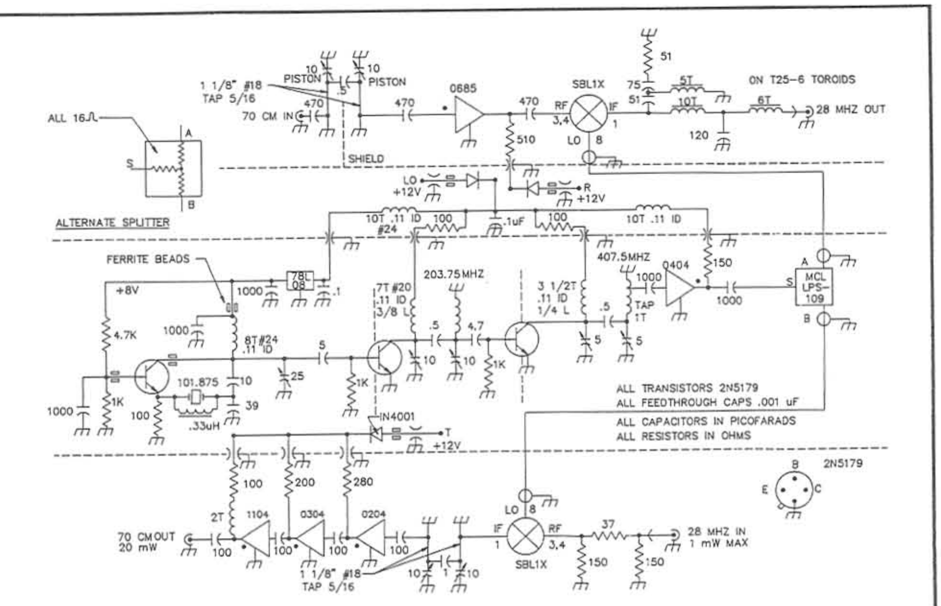


Fig. 6 — 70 cm transverter.

Figure 6. The LO should be built separately from the rest of the converter since it will be the most complicated part. The crystal oscillator is once again the W1JR type, operating at 101.875 MHz. This seemingly odd LO allows HF receivers, which won't go above 30 MHz but will go below 28 MHz, to receive all satellite 70 cm downlinks with one crystal. At the low end, UoSAT 14's 435.07 is converted to 27.57; at the high end, LUSAT at 437.15 becomes 29.55 MHz.

Good RF bypassing is essential to prevent spurious oscillation. The construction technique shown works well. The mica trimmers are mounted horizontally with their two ground legs soldered to inverted-U shaped brackets from .010 brass strip, 1/8 wide, 1/8 high and long enough to support the trimmers. Space all tank circuit inductors 1/2 inch apart.

Build the crystal oscillator first and get it working. The oscillator is followed by 2 stages of Class C doublers. Although many frequency multiplication schemes are possible, doublers are the easiest to get working without a spectrum analyzer. Class C devices have the interesting characteristic that they don't draw any current if they are not working. (Remember class A devices like the MMIC's draw the same current whether working RF-wise or not). No current, no multiplication! Double tuned tank circuits are used in each stage and are designed to be unable to tune the input frequency. Tuning is simply a matter of setting all trimmers at full mesh (maximum capacitance), then tuning each to the first peak.

Build the 2 multiplier stages and terminate the second stage with a 50 Ohm resistor. Peak the first multiplier stage with the diode probe on the output side of the coupling capacitor. Repeak the oscillator trimmer. Then peak the second with the probe on the 50 Ohm resistor. Remember that only the first peak is the one you want; frequency multipliers create lots of other higher multiples, too. When all is functioning properly, add the MMIC output stage and splitter. Shields should be placed where frequency changes occur and where unwanted signal suppression is desired. Connect all +12 V lines together outside the LO enclosure. Be sure to include RF chokes, bypass capacitors and resistors to keep everything stable.

Construction and tuning of the converter stages is straightforward. Lay them out like the circuit diagram and the photos. To align the transmit section, terminate the output with a 50 Ohm resistor and attach the diode probe to the RF end of the resistor. With the LO connected and functioning, inject a less than 1 mW signal at 28 MHz into the input. As with the 2M transmit converter, tune for the first output peak from minimum capacitance.

The first external amplifier stage uses an MRF911 to raise the 20 mW transmit converter output to 100 mW or so. The next stages are easy. An S-AU4 brick amplifier takes 100 mW to 10+ W. While its $50 price tag may seem high, it's cheap compared to the aggravation of getting to that level with discrete components. Both stages are detailed in Figure 8. A 25 W brick (M57745) is also available, but would still be only marginal for AO-13 Mode B. From there, Mirage, RF Concepts, Communications Concepts Inc. and others make nifty 10 W in, 100 W out amps. No, I don't use one; I use a homebrew 4CX250 in a cavity like I mentioned earlier.

The receive converter can either be tuned on-the-air or from a signal generator. Peak both piston trimmers. Try it — it will easily hear the Microsats with a minimum directional antenna. Then add a good GaAsFET preamp.

Before connecting a transmitter to the transmit converter, you must find a source of 1 mW RF on 10M. Most new radios have transverter outputs, although some supply pretty healthy power levels. For tube type rigs, you can disable the finals by removing the screen current, then tap (low value trimmer capacitor) off the tank circuit of the driver stage. Run that to a connector, then measure its level with the diode probe (Figure 9) as follows. A note about output readings from the diode probe — they are

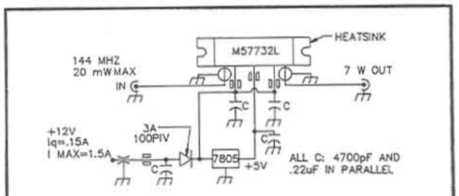


Fig. 7 — 2 meter 7 W power module amp.

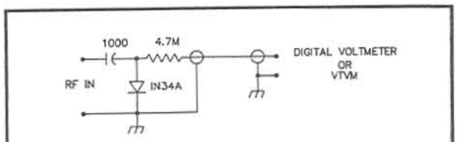


Fig. 9 — Diode RF probe.

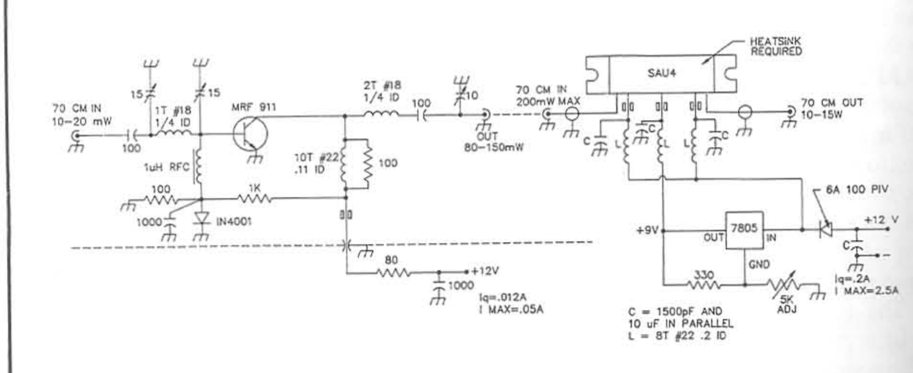
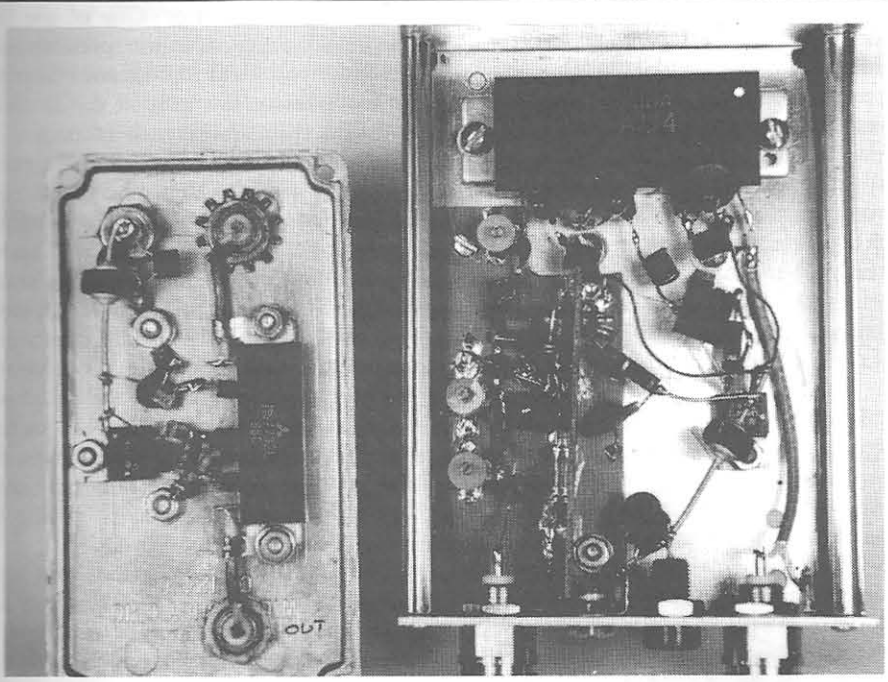


Fig. 8 — 70 cm 10 W power amp.



RF output amplifiers, 2 M on left, 70 cm or right.

inaccurate, but usable at 28 MHz. At higher frequencies they only provide relative output indication. Before connecting your transmitter to the transverter, terminate its low level output with a 50 Ohm resistor and attach the diode probe. Start at drive level control at 0 and increase it slowly. One mW is (theoretically) equal to .224 V across 50 Ohms, so don't be safe and don't exceed about .2 V. Carefully note the transmitter settings. These must never be exceeded during operation. One little bout of forgetfulness will let all the smoke out of your DBM. A much better approach to setting IF drive level is to build an attenuator of the correct value to allow the transmitter to be run at normal drive levels and still provide the required 1 mW output. See any *ARRL Handbook* for information on attenuators. Note that the output from your transmit converters must linearly follow a change in input signal. If the output level rises suddenly something may be oscillating. Fix it immediately! If the output level rises linearly then flats out, it is probably saturated. Back off the drive level until you are back in the linear range.

Now the homework. Build the diode probe first, then the 2 Meter Transverter. Use it to make local contacts on 2M, and listen to AO-13 Mode B. Add some amplifiers and head on up from there!

Homebrewing is quite possible and great fun. These designs were developed specifically to be easy to build and tune. Be patient, use good construction techniques and you will be amazed at the results.

Sources of parts:

-Microwave Components of Michigan (WA8EUU), P.O. Box 1697, Taylor, MI 48180 (MMIC, DBM, trimmers, misc. parts)

-RF Parts 1320-16 Grand Ave., San Marcos, CA 92069 (Amplifier modules, transistors)

-CCI (Communications Concepts, Inc.) 508 Millstone Dr., Xenia, OH 45385 (RF power amps and kits, DBM, parts)

-Down East Microwave (W3HQT), Box 2310, RR 1, Troy, ME 04987 (KK7B/WA8NLC "no-tune" transverters, 33cm and up antennas, amps, preamps)

AMSAT-NA Education Activities: Accomplishments, Possibilities and Prospects

By Richard C. Ensign, N8IWJ
AMSAT-NA Science Education Advisor

From 1987 to date there has been a strong effort to place the possibilities of classroom use of amateur radio satellites before the educational community. This effort has been on a global basis. Awareness has been created in local and regional school districts at the administrative as well as building level by the efforts of individual teachers active with amateur radio satellites in their classrooms. National professional organizations such as the National Science Teachers Association and Satellite Educators Association have become aware of the educational potential of amateur radio satellites. Education forums at Hamfests are becoming well attended.

This paper will take a close look with visuals from a number of locations at how amateur radio satellites are currently being used in the classroom. DOVE OSCAR 17 activities will be emphasized if the satellite is operational. Classroom printed materials, lab exercises, etc. created by teachers will be surveyed including student work.

Finally we will take a look at AMSAT EDUCATION NEWS, a monthly publication of AMSAT-NA available by subscription. Contributions to AE NEWS by educators will be highlighted.

I would like to share with you, muse if you like, on the subject of Amateur Radio Satellites in the Classroom. Being, I am told, one of the prime movers in this area, I want to take a look back at where we have been, are now and where I think we can and should go in our AMSAT educational endeavors. You are a part of this adventure because many if not most of you, just by doing the things you do for the amateur satellite program, contribute to this effort. So, together, what have we done, where have we been and where are we going? By the way, if you old time satellite enthusiasts after I'm done say, "You missed this or that educational effort" ... the reason is that you, as hams or ham-educators, knew about it, but the waves from those early efforts did not spread widely. I'll concentrate on the last few years in this paper just to show you my view looking out into the world's classrooms and the perspectives of those classrooms we have impacted. Make no mistake, this is a global effort and you could hardly keep it from being otherwise.

If I've discovered anything as your Science Education Advisor, it's that ham-educators are voraciously hungry for ways to share their hobby. Likewise, many classroom teachers actively seek out new ways to illustrate, and bring to life the concepts they teach. Once they discover and begin to explore the possibilities of amateur radio satellites in their educational setting they want to know more ... and you cannot shut them off!

The Russian-Canadian Transpolar Skitrek was really the event that turned me on to classroom possibilities and moved me from an advisory role to an active creating one. Teacher's just had to be able to share this activity with kids. The key to it all was information dissemination. First, the *Teachers Guide* was created with an afternoons library research on the geography, climate, and weather of the north polar region. Information was already on hand relative to UoSAT 2 thanks to the folks at Surrey. The Expedition information was provided by Leo Labutin and Tom Atkins. With the aid of packet radio, the availability of the guide was announced around the world. Phone calls and letters descended on me and I began to run personalized predicts for UoSAT 2 for the entire 3 months of the trek to be mailed out with the guide. Could we monitor the base stations of the expedition on HF? Yes, we could, and find out how the team was doing, the weather each day and the skiing conditions they encountered. UoSAT 2's position reports were augmented with HF reports. I can't thank Ralph Wallio, WØRPK, enough for his HF monitoring, sometimes mobile from his car, and his QSO's with the base station in Canada. Weekly Skitrek Bulletins went out over packet and on the WØRPK BBS for the entire trek.

Some 500 requesters and 3 months later we had a cadre of classroom teachers on every continent but Antarctica turned on to the possibilities of amateur radio satellites in the classroom. For a junior high librarian in Canada, preschoolers in New Zealand and students at the Arthur C. Clarke Center for Modern Technology in Sri Lanka and tens of thousands of others, the events in the far north were made real via amateur radio satellite. Those schools participated because the information was there when they needed it and the equipment necessary to participate was readily available.

"What's next!", the teachers said, ready for the next adventure, the next satellite exploration. PY2BJO's DOVE and the whole flock of Microsats provided the next stimulus. I think if Junior de Castro, PY2BJO, Doug Loughmiller, KO5I, and I added up all the DOVE info requests they would run close to 900 at this point. My collection of DOVE messages from children of many lands and languages runs close to 300. Reading and listening to them is a rewarding and illuminating experience. While I haven't been directly involved with DOVE during its post launch commissioning period ... an event filled time to say the least ... I have shared DOVE's trials and tribulations with teachers ... a fascinating story so far of the triumph of software over hardware, of power budgets and moonbouncers. I will not speak in detail of DOVE here. It is Dr. De Castro's satellite to implement as he sees fit.

In the midst of all this, the SAREX program continues with education focus the role of the ARRL. We have been supporting Rosalie White at the League in her excellent efforts by providing follow up experiences for classrooms that have prearranged contacts with WA4SIR onboard Columbia. We plan a 10 minute phone link with at least one of the schools to share the OSCARs with the assembled students, educators and press before their SAREX contact. Similar activities will no doubt follow with STS-37.

The AMSAT education information vehicle at this time is *AMSAT EDUCATION NEWS*. This monthly, at least 6 page, Xeroxed newsletter, edited by N8IWJ, is in its 13th issue. *AE NEWS* goes beyond the normal fare found in the *Journal* and the independent *OSCAR Satellite Report* to deal with subjects specific to classroom needs at many levels. Teacher's share everything from lab exercises to student experiences to computer programs to aid in telemetry reception and decoding. We distribute ideas that work in the classroom that have been developed and tested by other teachers. Right now the content is about 50% information and 50% idea sharing. This has been necessary due to the need to bring teachers up to speed on telemetry and onboard experiment format and decoding. Recently we devoted a number of pages to WEBERSAT's super summer following eclipses, cloud photos in the Pacific and micrometeoroid impacts during a meteor shower. Many AMSAT volunteers have contributed articles or collected telemetry to be shared in spreadsheet graphs.

Where are amateur radio satellite education efforts at this stage? An AMSAT education forum was held at the Dallas HAM-COM and it was very well attended and received. Presentations at the AMSAT-UK Colloquium were also well received over the last two years. Many individuals such as Marty Davidoff of *Satellite Experimenters Handbook* fame, Dave Reeves, a California physics teacher and Bob Maurais, a Maine industrial arts teacher have made presentations to educational groups outside of amateur radio. One of the first official AMSAT education presentations beyond the amateur radio scene was made by KO5I and yours truly at the Satellites and Education Conference sponsored by West Chester University in Eastern Pennsylvania. In mid-December this year, Rosalie White and I will be conducting a 90 minute workshop at the National Science Teacher Association's SOAR '90 weekend in Washington highlighting aerospace resources. There will be an AMSAT education workshop at the DARC Educators Conference in Germany this spring. That will be a fascinating one because of the first mix of East and West German ham-educators in the now one Germany. We hope to visit a former East German school following the conference.

Let's take a minute to talk about some specific educational strategies using our satellites. The Microsats are excellent "kid-sized" examples of orbiting objects. At all age levels and especially with young children 6 to 10 years old you can:

1. Use Microsat full scale models and smaller "squish-sats" (half-size foam cushion models) for a "show and tell" of what satellites are like, what they need to have onboard to work, how they work and what they do.

2. Monitor the sounds of satellites directly or on tape as a general introduction to how they talk to folks on the ground and their potential for long distance communication use.

3. Do a geography trek along the satellites ground track.

With younger gifted and talented children and junior high and high school students with appropriate math and science backgrounds you can:

1. Do a basic telemetry analysis of spacecraft health by directly monitoring in the classroom: a. DOVE's voice. b. DOVE's packet. These are easy efforts with simple antennas, scanners and existing computers in the school ... even with Apple 2e's.

2. Measure the speed of light in high school physics by monitoring the Doppler Effect on LUSAT's CW beacon signal. [Since this beacon has been turned off for a while, Microsat owners need to be made aware of the educational uses of their birds signals.] For this effort you need, at minimum: 1. An HF receiver with digital frequency readout. 2. A constant pitch sound source like a musical instrument. 3. A pre-amp and down converter from 70 cm to 10 m.

3. If your school has a big-big budget or you are a great fund raiser or you are satisfied with data gathered by supporting hams with gear at home you can gather whole orbit data from PACSAT, LUSAT and WEBERSAT analyzing spacecraft health

and motion or science experiment results from WEBERSAT or study the radiation environment around the Microsats by correlating SEU's with orbital position. Since most schools can't afford this very expensive stuff, we need to develop a cadre of helping hams around the world. Schools can help other schools too, of course and Universities can play a big role here.

I've just scratched the surface here, and we can all see the potential of inter-school sharing via transponder or store & forward capability on a satellite.

What of the future of AMSAT educational programs? We can't do much more with the small number of folks involved directly in the logistical aspects of our educational effort. Funds are limited as well. My suggestion at this point is to look for the possibility of joint, shared efforts. We can do more with the ARRL, but the focus is still inside the amateur radio community. Many organizations have teamed with the NSTA to produce materials and/or develop educational programs. As the major science education organization in the U.S., NSTA has the people and resources to bring our little birds to full educational potential through publications and promotion as well as grass-roots teacher awareness. There are lots of possibilities here including ones with smaller groups than NSTA that focus on satellites and education.

Whatever we do, we need to remember the teachers we have turned on to amateur radio satellites and not shut them off by inaction or lack of awareness. I need your help as together we look for ways to share our little treasures in the sky.

The In-Orbit Performance of Four Microsat Spacecraft

On January 22, 1990, Ariane V-35 placed four Microsat spacecraft into orbit. The orbit achieved is nearly perfectly sun-synchronous at 800 km altitude. The satellites, cubic structures measuring only 23 cm per side, were developed by the Radio Amateur Satellite Corporation of North America (AMSAT-NA). The time required to complete the project, from conception to delivery of the four satellites to Kourou, was exactly two years. Each satellite in orbit has a different mission and is performing in accordance with its intended design, although additional software is still being written to enhance the operating characteristics for each mission.

This paper reviews the design objectives of the four spacecraft and summarizes their in-orbit performance against these pre-launch technical objectives. The level of technology employed by the Microsat spacecraft is briefly discussed and the software approach taken in implementing a real-time, multitasking operating system is summarized. The paper reviews the AMSAT experience as the first payload user group of the Ariane ASAP structure. Some of the findings regarding the current technology and how it may be expanded to fulfill other mission needs has been touched upon.

By
J. A. King
R. McGwier
H. Price
J. White

Introduction

The term "Microsat" is rapidly becoming the Kleenex of the aerospace community. Everyone has a concept; the term is in wide usage and attempts have been made to define the meaning of the word. The European Space Agency (ESA), for instance, refers to any spacecraft weighing less than 50 Kg as a micro-satellite. While it is not particularly important, it's still worth noting that after creating the name, someone had to be the first to put one in orbit. As far as we are aware, the Radio Amateur Satellite Corp. of North America (AMSAT-NA), working with several other national and international groups, launched the first four true Microsats on January 22, 1990. At least, they are the first four that can be discussed in the open literature. This paper describes the design of the four spacecraft and compares the in-orbit results to the intended design. The four Microsats are all healthy and doing fine after seven months in orbit. All of the major design aspects of the satellites have been validated in-orbit, however, flight software continues to evolve for all satellites and this activity will probably continue for many years. No doubt, having created a flexible tool: It will be flexed.

True Micro-Satellites - Why?

With all due respect, a micro-satellite should not be thought of as a 50 Kg object! To those in the amateur satellite world who originally coined the term and who have been building and flying small satellites for three decades - it's just not what we had in mind at all. Rather, a micro-satellite is a spacecraft approximately one order of magnitude lighter than a GAS CAN spacecraft. If these shuttle-launched satellites are intended to be in the 100-200 lbm class, then a micro-satellite is a 10-20 lbm spacecraft. Why is such a spacecraft even interesting?

In fact, the reason is a very practical one: Cost. For AMSAT, launch costs while admittedly still subsidized, increased by a factor of four between 1985 and 1989 . The reason for this, in turn is straight-forward: Supply and demand. The lightsat era was born in this same time frame. While the international amateur satellite community was working on their 25th - 31st spacecraft, the rest of the world realized the value of the small satellite and at the same time, the shortage of launch supply for secondary payloads. It's worth noting that since 1988 and after AMSAT secured a contract with Arianespace for four launch positions on ASAP, the price has again quadrupled, making the current price to AMSAT 16 times that which we paid for launch capacity in 1985.

This set of economics, having gotten the undivided attention of the austere but industrious AMSAT organization, allowed us to conclude, without difficulty, that if the cost per kilogram was going up a lot, we had better get a lot more from every kilogram. Further, it was reasoned, if a very small spacecraft with significant capability could be created, volume and mass might be found for its inclusion on nearly any launch vehicle.

Three technology factors have significantly changed in the past decade and make micro-satellites possible. To wit:

1) Extreme micro-miniaturization of electronic components.

2) Significant improvements in photovoltaic power generation.

3) Significant improvements in the efficiency of RF power production in the VHF/UHF portion of the radio spectrum (used by our spacecraft).

To put numbers to these factors, after both trade-off studies and design & development of the Microsat system, we were able to achieve:

1) A baseline flight computer using 1.3

micron SMT device technology. The computer power consumption averages 0.45 W and contains 8,783,872 bytes of total memory. The computer is contained in a module 23 cm X 23 cm X 4 cm.

2) Solar arrays capable of 16.5% efficiency using back surface field reflector (BSFR) cell technology. GaAs cells could have been used with an efficiency of 18%, however, cost was a factor.

3) Flight transmitters at VHF with DC/RF efficiencies as high as 76% and UHF transmitters with efficiencies of 63%. Devices employed are low cost, readily available and incredibly rugged.

As can be seen, a significant capability can be packed into a true micro-satellite - a "blue cube" measuring only 23 cm (9 inches) on a side!

The AMSAT-NA Microsat Design Objectives

The intended application of our microsatellites are as digital store-and-forward communications systems. All of the first "batch" of Microsats have this capability, although only two of the four have packet data communications as their primary mission. The other two spacecraft are intended as classroom educational tools. A spacecraft of this type is necessarily a flying computer with a few other appendages. Flight software becomes the most important aspect of the mission.

An objective of the new Microsats was to correct design and human engineering difficulties that had occurred in AMSAT-NA's previous eight spacecraft fabricated and launched since 1970. Other objectives are related to the store-and-forward communications requirements of the first missions. By way of example:

1) Eliminate, to the extent possible, wiring harnesses in spacecraft. They are time consuming to fabricate, significant sources of failure and definitely not fun.

2) Create a mechanical structure that could be completely assembled and disassembled ("racked and stacked") in less than 30 minutes.

3) Create a solar array design that minimizes the possibility of damage during handling and yet can be rapidly installed on the spacecraft body.

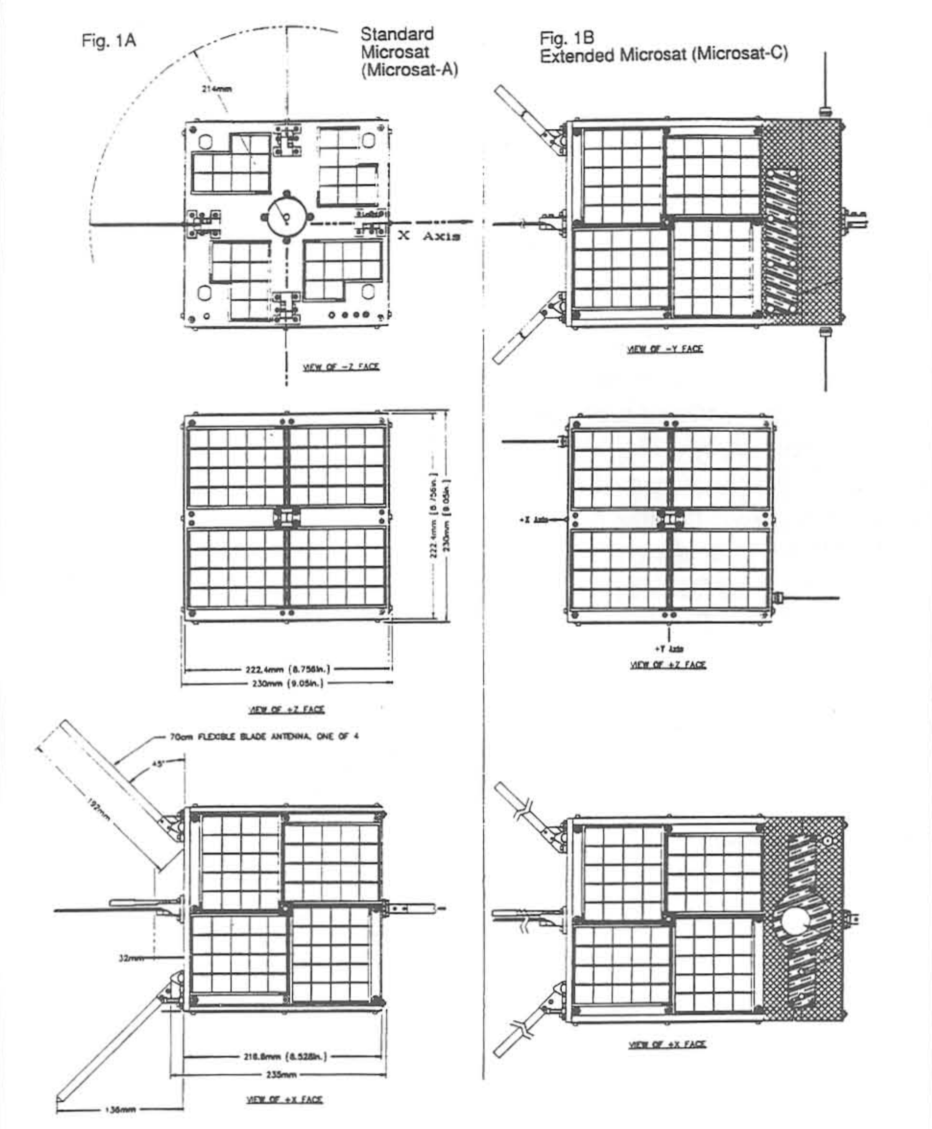
4) Use a load-side power management technique that dynamically adjusts the transmitter power output in order to maintain an orbit-average power balance. This technique should be modifiable in orbit and should deliver every possible mW of RF power to the system user downlink transmitter.

5) Create a micro-satellite design that is capable of serving data user terminals employing only omni-directional antennas.

6) Develop a suitable multi-channel serial data communications computer that has a minimum data storage capacity of 4 Megabytes and requires less than 1.0 Watts of average power.

7) Target for a total spacecraft mass of 10 Kg (22 lbs).

All of these objectives, established at the beginning of the Microsat program in late 1987, have been achieved.



Figs. 1A and 1B — Microsat configurations.

Orbit Achieved

The first four Microsat spacecraft were carried on Ariane V-35, launched January 22, 1990. The orbit achieved was in excellent agreement with the pre-launch predictions. The nominal orbital elements for the four spacecraft are:

a = 7161.2 km
e = 0.0013
i = 98.713 deg.

These Keplerian elements yield a nominal apogee height of 792.3 km and a nominal perigee height of 773.7 km. The orbital period is 100.5 minutes/orbit. The orbit is very nearly sun-synchronous with approximately a 10:30 AM ascending node. Prior to releasing the four Microsats the Ariane 40 executed a 180 degree maneuver that placed the forward end of the vehicle pointing exactly against the velocity vector of the orbit. Microsats A through D were all released within a 1 second time window, however, each with a different spring velocity in order to avoid collisions and to assure that the satellites separated from one another. Springs were selected such that each satellite (A - D), in turn had a higher separation velocity. Since the spring velocity subtracted from the orbital velocity, it was expected that Microsat-D would have the shortest period (shortest semi-major axis) and would move out ahead of the other spacecraft. Similarly, Microsat-A was expected to have the longest period and drop behind the others. This is exactly what

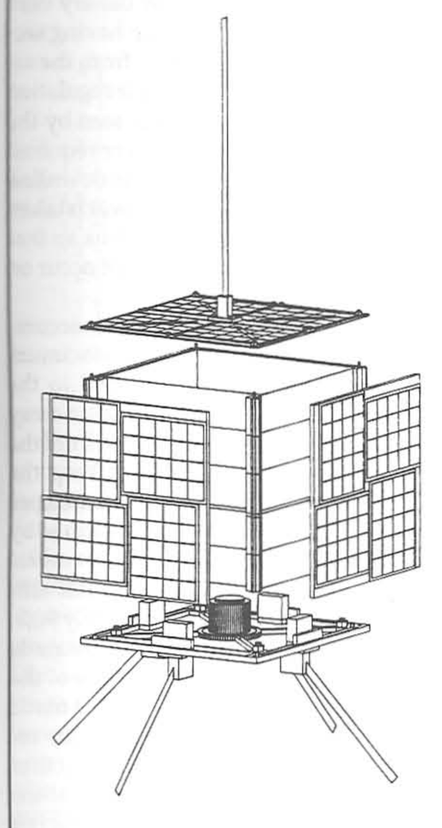


Fig. 1C — Exploded view of standard Microsat.

is observed as the four satellites pass over an individual ground station. In the sequence, Microsat-D is followed in succession by -C, -B and finally -A. The difference in periods are such that Microsat-D will "lap" Microsat-A, and be one orbit ahead, approximately one year after launch.

Structural and Thermal Design

One of the most exciting aspects of the Microsat program at AMSAT was how well the structures for the satellites worked in practice to save time during the integration and test phase of the project. This was exactly what had been hoped for, since the bolting and unbolting of modules or boxes to and from space structures had long been one of the major consumers of time. The overall structure, known as the Frame Stack Assembly is simply a stack of modules (machined boxes) each containing a major element of the spacecraft electronics. Five modules comprise the stack, however, this stack can be extended as is the case for Microsat-B (WEBERSAT). The Weber State University (WSU) stack is equivalent to seven modules. Four solar panels mount in recessed areas formed by the module stack on each side of the spacecraft. These honeycomb panels provide significant shear load support once installed on the structure. Quick and safe electrical connection is provided by a single standard electrical tip jack centered on each panel. Ground return is accomplished via the frame itself. The modules interconnect electrically via a 25 wire bus fabricated using standard printed circuit material. This constitutes the entire wiring harness for the spacecraft and can be installed or removed from a satellite in 5 minutes (including the locking hardware required for flight). The top panel contains another solar panel and the VHF receive antenna for the spacecraft. On two of the satellites a small S-Band bifilar helix antenna also shares this real estate. The most complex surface of the spacecraft is the bottom surface. It contains another four solar array segments (producing 1/2 the power of the other faces), the separation system, a microswitch for turning on the spacecraft transmitters, and the transmitting turnstile antenna. This surface is a major load carrying surface and is fabricated as a single piece of machined Aluminum. It is fastened in the corner s by four gusset plates to the bottom module frame which contains the transmitting equipment for each satellite. Figures 1A and 1B show the two different configurations of the first four Microsats. The larger configuration is for WSU who required the additional space as an experiment module. The standard configuration mass at launch was 10 Kg while the WEBERSAT version weighed in at approximately 12 Kg. Figure 1C shows an exploded view of a standard configuration.

Module Frames

Each module frame has a useful volume of 200 mm X 184 mm X 40 mm. The center module, intended for the power subsystem, has a slightly larger useful height of 42.8 mm. Each module has a recessed area in the front of the module to allow a volume in the Frame Stack Assembly for electrical interconnections. Circuit boards may be mounted within the module with small plastic Delrin blocks designed for this purpose. Other means are also possible.

Separation System

A single compression spring is used to separate the spacecraft from its launcher plate. Concentric to the compression spring is a bolt which passes through the spring and then through the launcher plate and finally through a bolt cutter. Four locator pins on the spacecraft side of the interface mate to four locator pads on the launcher plate. These devices also counteract shear loads from the spacecraft. The bolt is tensioned from the underside of the launcher plate. The spacecraft has been qualified to separate using both NASA and ESA standard initiators. Full static and dynamic testing of the separation system has been conducted using both ordnance types.

Spacecraft Resonant Modes and Vibration Performance

One of the obvious, yet very nice features of a micro-satellite structure is that the natural resonant frequencies of the tiny structure can be expected to be very high. Since launcher resonant modes are usually quite low (5 to 25 Hz) there is no resonant coupling between the spacecraft and launch vehicle. Both versions of Microsat were formally tested at qualification and acceptance levels in accordance with Arianespace documentation. The highest random level achieved during qualification level testing was 14.6 g rms for a duration of 90 seconds. It was exciting to learn that no resonances of the spacecraft exist below 100 Hz. Primary spacecraft resonances are in the 200 to 400 Hz range. The test structure was sufficiently well behaved at 14.6 g rms random that it is quite likely that at l east 20 g rms could have been sustained by the structure.

Spacecraft Thermal Design and Performance

The thermal design of small spacecraft of this type is straight-forward. To begin with, the intended orbit for the first four Microsats is sun synchronous with an ascending node time near noon. Eclipse variations over time are very minimal. For a simple rectangular solid structure with no booms or appendages a thermal model with only a few nodes is adequate to describe the performance of the system. Such a model was constructed and incorporates the two components of the rotation of the spacecraft (see section on attitude control) as well as the fluxes from the sun, Earth IR and Earth albedo. Significant spacecraft internal radiators were also included in the model although their contribution to the overall temperature balance is small.

A completely passive thermal design was implemented. The thermal balance is dominated by the external absorptivity to emissivity ratio (a / e) properties of the solar arrays. This value, which is near unity, is a given factor in the design.

There is simply no flexibility in the design to reduce the solar cell area, rather, in a micro-satellite design this quantity is to be absolutely maximized. This results in a limited remaining surface area that can be used to bias the overall temperature. Of the total spacecraft surface area of 2916 cm^2 only 591 cm^2 is available for thermal control. Taking into consideration satellite motion, eclipse and variations in solar array efficiency over the orbit (which occurs as a result of the power system control approach) the predicted bulk temperature of the spacecraft, prior to launch, was estimated to be:

	Minimum	Maximum
Temperature:	-8.4 deg. C	+2.6 deg. C

Measurements taken over a whole orbit at ten second intervals and then dumped at a single ground station show the following in-orbit results for Microsat-A:

Temperature Point:	Minimum:	Maximum:
Battery	-1.3 deg. C	+2.0 deg. C
+Z (Top) Array	-19.0 deg. C	+21.0 deg. C
Rcvr Module	-7.0 deg. C	+11.0 deg. C

The colder temperature range designed for and achieved is both good for long term battery lifetime and increases the power output from the solar arrays. It can be concluded that the thermal performance of the satellite is in good agreement with the design temperature range. The temperature differences observed between satellites, including WEBERSAT, are very small. Figure 2 shows a Microsat-A whole orbit plot of the battery temperature. Note that the total temperature swing of the particular battery cell monitored is small and that the maximum temperature actually occurs during the middle of the eclipse period (1/2 orbit thermal lag). Both of these conditions point to a high battery thermal inertia which was better than expected and is most desirable.

Power Sub-System Design

Certainly, one of the most difficult challenges in the design of a micro-satellite is the maximization of useful power and a strategy for not wasting that which is generated. The efficiencies of power regulators and RF generating equipment is critical to the design. Micro-power consumption of computers and receivers is also a major challenge.

Solar Arrays

It is quite helpful that newer solar cell technologies are becoming available with efficiencies as high as 18% (GaAs) to 23% (hybrid cells). Cost and availability, however, drove this particular design to the use of back surface field reflector (BSFR) cells. These cells have an individual cell efficiency of 15.0% at 28 degrees C and nearly 16.5% at the temperatures achieved by the Microsat spacecraft. The particular cells selected are 2 X 2 cm and are manufactured by Solarex Corp. in Rockville, MD. The fundamental unit of power selected for Microsat is referred to as a solar cell clip. A clip is a small module containing 20 series connected cells. The clips were also manufactured by Solarex to AMSAT specifications and then assembled on the honeycomb panels by AMSAT. On each of the side panels (X and Y faces) and on the top (+Z face) two clips are wired in series and two are in parallel yielding a maximum per panel current of about 0.35 Amps at a knee voltage of 20.5 volts when the panels are cold. The bottom surface (-Z face) contains four "half-clips" wired in series to produce a single 40 cell string. This surface gives less than half of the power of the other surfaces since some shadowing also results from the four canted turnstile antenna blades.

Figure 3 shows a scan of the total power generated by the arrays over one entire orbit for Microsat-A. The average power generated by the arrays over the sunlit portion of the orbit is 8.1 Watts, however, the orbit average power must consider the eclipse period as well. This particular orbit generated 5.8 Watts orbit average. Peak powers as high as 14 Watts and orbit average powers as high as 6.5 Watts have been observed.

Power Regulation

During the eclipse portion of the orbit it can be observed from Figure 3 that approximately 1.5 Watts of power is flowing through this particular current sensor. The power is provided from the battery and is fed forward via a Schottky diode to the array summing point in order to power the regulated busses of the spacecraft . Power is fed forward in this manner so that during the sunlit portion of the orbit, the regulators do not need to take power from the battery. Rather, it is taken directly from the arrays. Power arriving at the battery has already been through one stage of regulation. The battery charge regulator (BCR) down-converts the 20 V array bus to the battery voltage of approximately 11 V. By having secondary regulators take power from the arrays when it is available, a double regulation loss is avoided. The 1.5 Watts seen by the sensor is a measure of the power required for all of the spacecraft except the downlink transmitter. The transmitter power is taken directly from the main battery bus so that additional regulator losses do not occur on the main bus either.

Battery charge regulation is accomplished by a two step process. Maximum array power is always transferred to the battery by manipulation of the solar array operating point. The load impedance of the BCR is dynamically adjusted to keep the voltage point of the array always at the knee of the I vs. V curve. This is accomplished by a duty factor switch operated under control of the flight computer. The overall efficiency of this switch is approximately 90%. Corrections to the operating point are made based on the measured temperature of the array. Bias adjustments may also be made as changes in the knee voltage occur resulting from radiation damage or other effects. In principle, it could occur that the battery becomes over-charged if spacecraft loads do not demand all of the power produced by the solar arrays. While this situation is not likely to do serious damage to the batteries in such a small spacecraft, it does suggest that power is being wasted. The second step in the power regulation of Microsat is to use a load-side management scheme. The power output of the spacecraft primary transmitter is continuously variable, under computer control, from a few milliwatts to a full 4.0 Watts (as much as 5 Watts of output is achieved at the lower temperatures of the spacecraft). When excess DC power is available and the battery is fully charged, the active transmitter power increases, under software control, until a break-even power condition is obtained. If, after some time, it is determined by the computer that the power budget is slightly negative, the transmitter power can be decreased until the power is once again balanced. While this approach to power management would not be appropriate for a

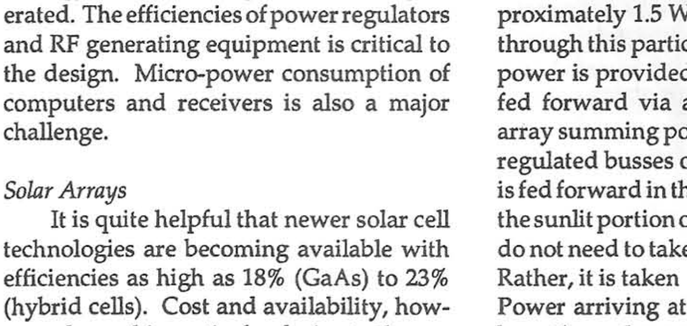


Fig. 2 — AMSAT-NA Microsat battery temperature.

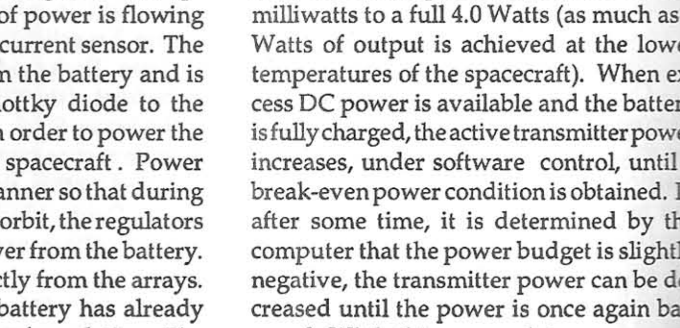


Fig. 3 — AMSAT-NA Microsat available power.

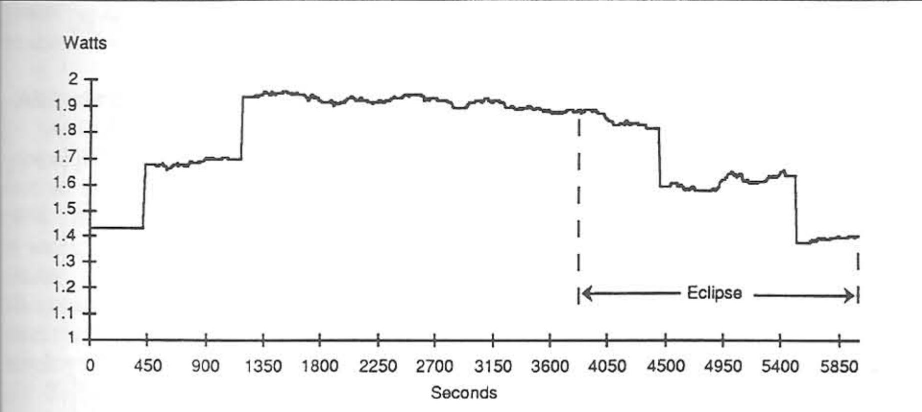


Fig. 4 — Microsat transmitter output power.

large spacecraft, in the case of the Microsat design, it assures that every single available milliwatt of RF power that can be afforded is generated for the user on the downlink. Figure 4 shows a whole orbit scan of the power output of the active transmitter of Microsat-C. Note that the power output drops during the eclipse portion of the orbit in response to the loss of array power. The average power output over the orbit is 1.75 Watts. This value is lower for Microsat-C (WEBERSAT) because other spacecraft experiments consume power continuously. The two packet communications satellites (Microsats A and D) which do not always have auxiliary experiments operating normally produce orbit average transmitter powers in excess of 2.0 watts. Microsat-B (DOVE) has VHF transmitters that are particularly efficient and as a consequence, the active transmitter averages closer to 3 Watts over the orbit.

Two regulated voltages are provided by the spacecraft power system. Both +5.0V and +8.5V are available from regulators operating at efficiencies above 90%.

All power conditioning equipment on all four spacecraft has operated flawlessly since launch.

NiCd Battery

A single 8 cell NiCd battery is used in each Microsat spacecraft. The specified capacity of the cells is 6 AH, however, the measured capacity approaches 7 AH at ambient temperature. At the operating temperature of the spacecraft, the capacity is once again back to approximately 6 AH. The cells used are standard GE goldtop series, size F and are rated to perform at temperatures as high as 70 degrees C. In order to match cells for capacity and voltage from commercial manufacturing lots and in order to select out poorly manufactured cells AMSAT has developed a proprietary cell selection and test program that has been very successful in producing flight quality cells at a fraction of the cost of cells specifically manufactured for space usage.

NiCd cells have a negative temperature coefficient of approximately 3 mV by the end of eclipse. Typical depth-of-drain for each satellite during eclipse is between 4 and 6% which, in combination with the temperature, should allow the batteries to last nearly indefinitely.

The batteries and the power regulation equipment are all contained in the third module frame of the Microsat frame stack assembly. Given the weight of the batteries (220 g per cell) a 3 mm thick Aluminum plate in the bottom of the module frame is used to mount the cells.

RF Sub-System Design

The Microsat RF sub-system consists of two redundant data transmitters and a five channel receiver system. A quarter wave linearly polarized antenna is used in conjunction with the receiver and a 45 degree canted turnstile antenna is used on the downlink. The latter is circularly polarized.

Data Receiver

The packet communications system used by the spacecraft employs data standards in current and common use in the Amateur Radio and Amateur Satellite Services. Packet communications techniques developed by these communities use the ALOHA form of Carrier Sense Multiple Access (CSMA). While the throughput of this technique is not high (18.4% maximum) it is simple to implement and ground station equipment is readily available. Each spacecraft has a single UHF downlink with a data rate selectable between 1200 and 4800 bits per second. With a maximum throughput approaching only 20% it is evident that the uplink total offered traffic should be approximately 5 times that of the downlink data rate. This has been accomplished by implementing a 5 channel VHF receiver system where each uplink channel can be adjusted by ground command between 1200 and 4800 bits per second. Uplink modulation is FSK.

A common receiver front end serves all five receiver channels. Unlike most space applications, receiver G/T performance is not important in this application. User uplink signals have EIRPs in the range from 20 to 40 dBW. At these uplink power levels and also due to the level of carriers in adjacent frequency bands, it is more important that the receiver have excellent overload characteristics than a good noise figure. In this particular design the LNA was not preceded by a high-Q filter but rather a GaAs FET transistor was used in the LNA which has a particularly high (i.e. large amplitude) front end overload characteristic. In fact, the third order intercept of the device used is above 0 dBm. Following the LNA is a helical resonator band pass filter. The input signal at 145.9 MHz is down-converted to approximately 50 MHz and is amplified and split into 5 separate channels. Each channel makes use of a Motorola 3362 FM receiver chip and the signal within each channel is down converted two more times. The final IF at 1. 8 MHz is passed to a discriminator and then to a slicer and data filter. Prior to passing raw data from the receiver to the flight computer any DC component resulting from Doppler offset or user uplink frequency error is removed. The value of the DC component, however, is measured and provided to the telemetry system so that users can choose to Doppler compensate their uplink signal. A very steep-skirted band pass filter (15 kHz wide) is placed after the second IF. This filter allows for a user transmitting 1200 bps Manchester data on the nominal uplink frequency to pass through the filter even at maximum Doppler shift without distortion. When 4800 bps data is used, however, the user must compensate for Doppler so that his modulation spectrum will properly pass through the filter. All five receiver data channels are routed to the flight computer. The receiver monitors the signal strength and frequency offset of each channel. These 10 values are available as telemetry. Receiver sensitivity varies slightly between channels and ranges from -110 dBm to -117 dBm for a 10E-5 bit error rate. The total power consumed by the receiver is less than 0.25 Watts. The receiver runs from +5V except the GaAsFET LNA stage which requires 8.5V. The receiver occupies a single module frame and is usually located in the top module position. A short coax cable connects the receiver to the top 1/4 wave VHF antenna. It should be noted that while the antenna is configured as a quarter wave antenna, in actual practice the spacecraft structure is so small that it will not properly image the active element at this VHF frequency. Instead the 1/4 wave element acts

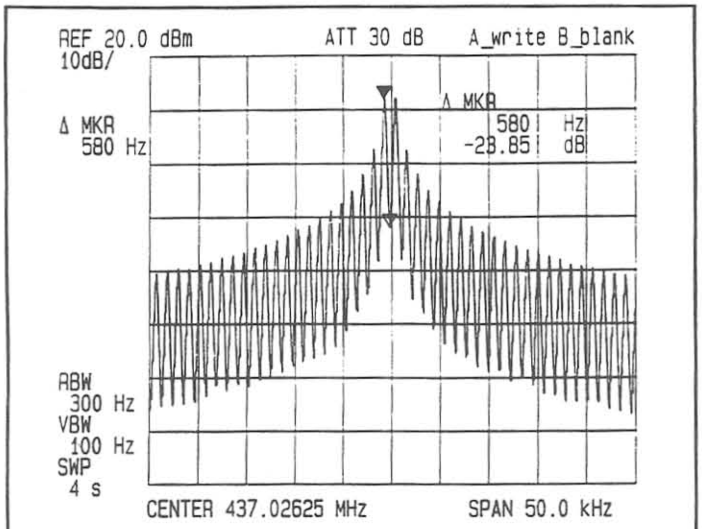


Fig. 5A — Normal PSK transmitter spectrum.

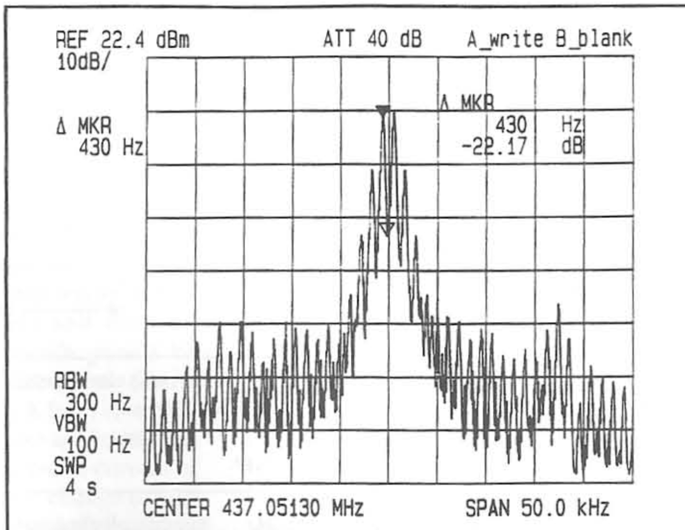


Fig. 5B — Raised COSINE transmitter spectrum.

as one half of a dipole antenna; the spacecraft structure acting as the other half (the fat half) of the dipole. In matching the antenna this fact has to be taken into consideration.

Data Transmitters

The bottom module of each spacecraft contains two transmitters. For Microsats -A, -C and -D these are UHF (437 MHz) transmitters capable of producing up to 4.0 Watts of RF power and employ PSK modulation. Microsat -B uses two identical VHF (145 MHz) transmitters also capable of 4.0 Watts of RF power output. All are power agile. Power is adjusted in 16 equal voltage steps by controlling the voltage delivered to the final two RF stages. The power output is approximately proportional to the square of the selected step. Higher power steps are larger than lower power steps. It's worth noting that the 4.0 W setting was made at a supply voltage of 10.0 volts. At the cooler spacecraft temperatures achieved the battery voltage is frequently above 11.0 V. The transmitters produce a maximum power of 5 W RF output at this higher supply voltage. As described above, the power setting is under computer control and is used in closed-loop fashion to manage the overall spacecraft power budget.

The two UHF transmitters in three of the satellites are not identical. It was important for us to experiment with variant forms of PSK. Signals from Microsat are sufficiently strong when received on standard OSCAR ground station equipment that the PSK demodulator carrier recovery loop can become confused by receiving one of the PSK sidebands instead of the carrier recovered from the center of the modulation spectrum. It was considered important to determine how difficult this situation would become in an automated ground terminal environment. For this reason, one transmitter transmits standard (+/- 90 degree phase shift) PSK while the second transmitter emits Raised Cosine PSK. This technique "shapes" the data as it is passed to the modulator in such a manner that the higher order sidebands of the signal are greatly reduced in amplitude. This technique has the added advantage that it reduces the overall occupied spectrum required to transmit a given information rate. Figure 5A shows the normal PSK spectrum measured from Microsat-A before launch while Figure 5B shows the Raised Cosine Spectrum under similar conditions. It is hard not to notice the spectral improvement. The price for this nice spectral characteristic, however, is not zero. The Raised Cosine modulator produces a non-constant envelope. That is, the signal is both amplitude and phase modulated. In order to prevent the signal from spreading out again when it is passed through the final amplifier of the transmitter (due to AM-PM conversion), that amplifier must be linear. Normally, linear amplifiers are not very efficient. Since AMSAT has been designing high efficiency linear amplifiers for space since 1972 this is simply one more application. In this case, we chose to use a variation of the technique known as Envelope Elimination and Restoration developed by L. Kahn (1). The loss of efficiency of the overall transmitter caused by using the "linear" amplifier is about 8% (from 63% for the PSK transmitters to approximately 55% for the Raised Cosine transmitters). It is also more complex than the simple PSK transmitter and consequently, somewhat less reliable.

Since they are intended for both voice and AFSK data communications, the two VHF transmitters in Microsat-B use simple NBFM modulators. The most exciting aspect of their performance is their DC/RF efficiency. The breadboard unit achieved an overall efficiency of 84% at 4.0 W output. The flight units dropped to 76% efficiency when they were installed in their modules. Some detuning necessarily occurs because of the close proximity of the box lid to the air wound coils. Note that at these efficiencies, the dissipation of the transmitters into the rest of the spacecraft can be virtually ignored. The power transistors are not even warm to the touch.

In all spacecraft the two transmitter outputs are fed to the two isolation ports of a 90 degree hybrid. The two remaining hybrid ports feed a turnstile antenna to produce circular polarization. Each antenna element contains a small "matching box" at its base to allow for the inclusion of lumped constant networks that facilitate antenna matching. When one transmitter is used, RHCP is produced. Similarly, LHCP is generated when the other transmitter is used. Users are instructed to use linear polarization so the circular polarization sense of the downlink is unimportant. Counting the 3 dB polarization loss, the link is designed so that a user at maximum slant range with an omni-directional antenna will have a 10 dB margin at 1200 bps data rate and assuming the transmitter is at 4.0 Watts output. Transmitter power output is more typically 2.0 Watts for a break-even power condition so the link margin is usually 3 dB less.

It is possible to operate both UHF transmitters simultaneously. The straight PSK transmitter contains a source multiplexer that may be switched either to the data output generated by the computer or to any one of the five receiver raw data outputs, thus bypassing the computer. This latter mode was considered for straight data relay or to allow for a ranging function. This mode has not yet been used in orbit. It would be possible to operate both transmitters simultaneously with one connected to a receiver output directly while the other is connected to the normal computer data line.

Attitude Control Sub-System Design

AMSAT has been using a particular type of passive magnetic attitude stabilization in small LEO polar spacecraft since 1974. The technique has been demonstrated to work well and there was no particular reason to increase the complexity of the Microsats by using an active system therefore, the same set of techniques was again employed.

To begin with, assuming that a particular spacecraft has good omni-directional antennas and link margins are large (both of which are valid for Microsat) the need for an attitude control system is minimal. It is, however, desirable to minimize polarization and "tip null" fades that would result in some data loss, particularly on the downlink. Also in order to avoid thermal gradients, a slow rotation of the satellite is important.

The method employed uses four ALNICO-5 bar magnets mounted to the outside of the spacecraft. They are physically located at the four edges of the cube parallel to the Z axis. Seven hysteresis rods oriented in the X-Y plane of the satellite are normal to the magnets. They are embedded in the battery support plate and run parallel to the X-axis of the spacecraft. Their location is near the center-of-gravity of the satellite. Finally, the four antenna blades that make up the transmit canted turnstile act as solar photon vanes. They are approximately 10 mm wide and are painted white on one side and black on the other. Since they are mounted in succession, the sun always "sees" at least one black surface and one white surface.

The bar magnets have a very strong dipole moment. While this value was not measured on this particular mission it is estimated to be in the vicinity of 50, 000 to 100,000 pole-cm. The effect of using permanent magnets and hysteresis rods should be to quickly align the spacecraft Z-axis with the local Earth field vector at any point around the planet. The hysteresis rods quickly damp any motion about the field lines. The spacecraft were expected to be randomly tumbling when they left the launch vehicle. This, in fact, proved to be true. The spacecraft achieved magnetic lock within 7 days and major oscillations of the Z-axis were damped within approximately 14 days. The four solar vanes impart a torque about the Z-axis and reduce the thermal gradient across the spacecraft body. The solar torque is counter-balanced by both the hysteresis rod damping and eddy current damping that cannot be eliminated in various components of the spacecraft. In order for the hysteresis rods to be effective dampers of this rotation, attitude deviations of the Z-axis from the local magnetic field vector on the order of ten degrees will be required. The two damping torques place an upper bound on the rotation rate about Z in response to solar torque. The net effect of the stabilization system is to cause a rotation of twice per orbit of the Z-axis in response to the Earth's dipole and then a rotation about Z. The target value of the rotation period about Z was set by thermal considerations to be 2.5 minutes per rotation. A large tolerance on this value is quite acceptable. Rotation rates from .25 minutes per rotation to perhaps as much as 20 minutes per rotation will still allow magnetic "lock" and acceptable thermal gradient behavior. In fact, the interior thermal time constant of the spacecraft is much longer than originally anticipated, given such a small object.

The lines of force at LEO orbit altitudes are quite nearly perpendicular to the surface of the earth, except between about plus and minus 30 degrees of the magnetic equator. Certainly, the difference angles are small enough to assure acceptable communications system performance even when a hemispherical coverage antenna is used on the spacecraft. A simplified equation for determining the tilt of the field lines with respect to a perpendicular to the Earth's surface and at approximately the altitude of the Microsat orbit is given by:

$$b = 90 - \mathrm{atan}[2*\tan(g)]$$

where:

b = angle of the field line to a line drawn from the center of the Earth through the surface at mag. latitude g.

g = the geomagnetic latitude value

Table 1 gives values of b for a number of magnetic latitudes.

TABLE 1

g (deg.):	b (deg.):
90 (pole)	0
75	7.6
60	16.1
45	26.6
30	40.9
15	61.8
0 (equator)	90.0

Figure 6A shows schematically, the attitude of the spacecraft relative to the Earth for one full rotation of the Z-axis of the spacecraft in accordance with the above equation. Figures 6B and 6C show orbit scans of the two Z-axis array currents and the +Y-axis array current during an entire sun-lit orbit segment (which is somewhat more than one full rotation of the Z-axis of the spacecraft). The data is for Microsat-A and was taken on April 14 starting at about 16:27 UTC. The graph axes are solar panel current and relative time (seconds). The sun in Figure 6A is about 11 degrees north of the geographic equator and 22.5 degrees out of the orbit plane (the plane of the paper). The pass proceeded up over the central Soviet Union in shadow and then over the northern Soviet Union, Greenland and then Canada and the United States in sunlight. In the vicinity of the descending

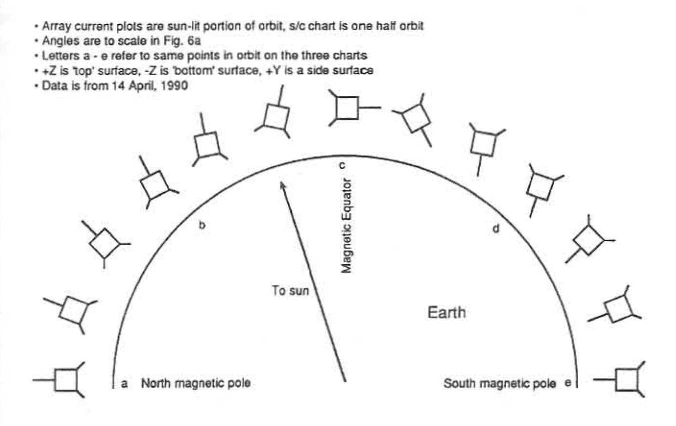


Fig. 6A — Microsat stabilization and array current examples.

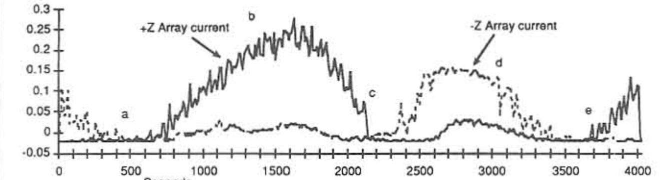


Fig. 6B

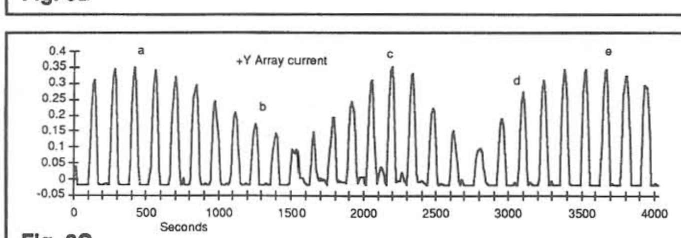


Fig. 6C

node at approximately 100 deg. W, the magnetic equator is slightly south of the geographic equator (-7 degrees). As the spacecraft first comes into sunlight, according to Figure 6A, the -Z surface should be partially illuminated. As time passes neither Z surface sees the sun and then shortly thereafter, the +Z surface current should begin to increase as the top of the satellite rotates toward the sun. As the spacecraft begins to approach the magnetic equator the rate of rotation of the Z-axis increases and the +Z array current goes past its maximum value and then falls to zero. The opposite situation occurs in the southern hemisphere as the -Z surface produces the mirror image of +Z (there is a scaling factor involved because the -Z surface has only 1/2 of the solar array area of the other panels). Just before the spacecraft goes into eclipse the +Z array begins to see sunlight again as it goes beyond the south geographic pole. Figure 6C shows the behavior of one of the side solar panels (in this case, +Y). Recall that the solar vanes should cause a rotation about the Z-axis. This effect is clearly evident and the rotation period given by the data is 2.35 minutes per rotation (in excellent agreement with the target period of 2.5 minutes per rotation). As the satellite comes out of eclipse the side panels of the spacecraft should be near maximum output current. Then as the top of the spacecraft pitches toward the sun the side panel currents should decrease. Note that the minimum +Y current corresponds exactly to the maximum current from +Z as it should. The side panel currents should not go to zero because the sun does not lie precisely in the orbit plane. This is also evident in the data. The current from the side panels then rises very quickly as the satellite approaches the magnetic equator. In the southern hemisphere the same behavior is evident in mirror image. Also visible in the data is a small contribution to the array current from Earth albedo. As much as 50 m A of current are produced near the sub-solar point by the side solar panels.

In summary, the attitude control system performance, as is evidenced by the above data, is working extremely well and very close to design expectations. Both the rotation of the Z-axis and the rotation about the Z-axis are as predicted. Further, the rotation of the Z-axis due to the Earth's magnetic field appears to be very nearly in the orbit plane. Signals received from the spacecraft are stable and attest to the usefulness of the stabilization system. Considerable fine structure of the motion of the Z-axis can be observed to take place from orbit-to-orbit. Nutation of the Z-axis is frequently observed on Microsats -A, -B, and -D, however, this motion also seems to damp out from one orbit to the next. The nutation amplitude can be as large as 20 degrees. This may be a result of perturbing effects when the spacecraft passes its northern or southern most point but is farthest from the magnetic pole. The ratio of inertias (Izz/Ixx or Izz/Iyy) are known to be very close to 1.0 and may even be slightly less than unity for some of the spacecraft. The nutations of WEBERSAT are typically larger than the other satellites and the motions of the spacecraft are quite complex. In this particular case the ratio of inertias is considerably less than 1.0. More analytical work is necessary before the details of the motion of the four spacecraft can be fully explained. It has been suggested that a 6 DOF simulation of the attitude control system be implemented. Interested volunteers are currently involved in this analysis.

Flight Computer and Data Handling Sub-System Design

Considerable reference has already been made to the flight computer. Like most other AMSAT spacecraft, the computer plays a very central role in the performance of the satellite, only in this case even more so. It is used in a multi-tasking, real time environment and, as such, it is a component of all of the other electronic subsystems of the spacecraft. Data to and from the receiver and transmitter are handled via fairly high speed serial links (designed for up to 100 kbps) using formal serial data control. Data carried between other subsystems in the spacecraft and the Flight Computer use a serial interface with a single line providing data to the subsystems from the computer and a single line return. A specialized board known as an Addressable Asynchronous Receiver/Transmitter (AART) is used within each hardware module to provide serial communications with the flight computer. Telemetry signals are also handled via the AARTs and multiplexed analog signals are routed to a single A/D Converter within the computer via the 25 pin bus. Two wires forming a differential pair are employed for this function.

Flight Computer Design

The flight computer design in Microsat is state-of-the-art in terms of its weight, size, fabrication technology and performance. Weighing in at 1025 grams and consuming an average power of 0.45 W the computer is optimized for serial communications. The clock speed is not outstanding, at 9.830 MHz, however, by making use of the computers DMA functions, the computer will support 6 simultaneous serial inputs at as high as 100 kbps each. The first four Microsat s use only a fraction of this capability, loafing along at 4800 bits per second per serial input (maximum). Three serial controller devices (NEC type 72001) handle the incoming data which is HDLC formatted and compatible with a variant of CCITT X.25. The variant, which allows for an extended address field and routing functions, is known as AX.25. The 72001s also provide up to six transmit outputs although the current design only provides for a single line to the common transmitter modulation inputs. Data from and to the 72001s is 8 bit parallel. The microprocessor used is the NEC V40 which is equivalent to an 80C186 with a slightly modified instruction set. A serial input/output pair directly from the V40 are used to communicate with four AART boards distributed on the 25 pin bus. In addition to the A/D converter mentioned above the computer provides a utility latched port and headers are provided for direct access to the address and data lines of the processor for experiments that may require maximum speed. This feature was used, for example, to facilitate the WEBERSAT Camera on Microsat-C.

Memory is, perhaps, the most impressive part of the computer. Four classes of memory are used by the Microsat Flight Computer. 2k bytes of ROM contain the boot loader. Main program memory uses 256 k bytes of error detecting and correcting (EDAC) RAM. Memory devices are the Harris HM6207. This memory is configured as 12 bits per byte and is capable of detecting two and correcting one bit error per byte (caused typically by a single event upset) anywhere in memory. If a single output data bus line were to fail out of the 12, then the memory would also carry on without a problem, however, with a degraded error protection capability. Any single event error is counted by the computer and software incorporates this value into each telemetry data packet. 2M bytes of bank switched RAM provides for high speed general purpose RAM, segmented in 512k byte blocks. Each block can be enabled or disabled as required. This memory can be used as general purpose RAM and may be accessed in 90 nS. The WEBERSAT camera experiment uses this memory as a video storage area. Bank switched RAM has no hardware error protection, however, software error protection may be employed. In addition, 6M bytes of memory are configured as RAM disk. Access to this memory is slow but, more than fast enough for packet data communications requirements. This RAM may also be switched ON or OFF in 512k blocks to save power. Bank switched RAM and RAM disk is implemented using Hitachi 62256L surface mount RAM chips. The configuration of this device is 32,768 X 8 bits. A total of 256 RAM chips make up these two classes of memory.

The computer is constructed on three multi-layer boards. The CPU board and the Mass Memory board (which contains the RAM disk) are eight layer printed circuit cards while the Bank Switched RAM board is six layer technology. The Mass Memory board is populated on both sides with surface mount components. Most integrated circuits in the Flight Computer are, in fact, surface mount ICs. RAM chips have 0.021" lead spacing while the other surface mount devices are 0.050 " between traces. Board interconnects use Kapton ribbon lead cables. All boards were conformally coated after final check-out. The total flight computer contains 453 integrated circuits. With the exception of the boot ROMs, none of the components used were high-rel. or rad-hard. The HM6617 ROMs used were qualified to MIL-STD-883B. This project was of sufficient technological complexity that it was contracted out to two surface mount technology firms who completed board layout and fabrication and then, component population of the boards. This is the first time in our history of 22 years and 12 spacecraft that AMSAT has allowed an outside organization to fabricate flight hardware. AMSAT assembled the boards into the module frames and debugged the computers as required. We are indebted to a small group of volunteers who worked tirelessly for a single week, nearly 24 hours a day to bring the four flight units to life for the first time. Given the complexity of this particular part of the project, we were very fortunate to have such a great engineering team on "hot standby" and some very good luck with the hardware.

Since the flight units have been brought on line there have been no hardware failures and computer "crashes" can all be identified with specific software errors. The computers have been amazingly reliable given their level of complexity. Their performance in space to date has been outstanding. No known failures have occurred to any of the units. There are also no known bad bits among the 281,083,904 total bits of memory distributed between the four spacecraft. Soft errors do occur regularly but, have been measured only in the 256k bytes of EDAC memory. The error rate in EDAC is approximately two per orbit when that orbit flies through the area of the South Atlantic Anomaly. Otherwise there is only an infrequent single even upset. Estimated cumulative dosage to date, referenced to outside of the computer module, is about 600 Rads Si. This data is provided from our sister UoSAT spacecraft flying in the same orbit. That spacecraft is equipped with a radiation dosimeter.

AART Design

A unique identifying feature of Microsat is its use of serial communications to handle all data flow between modules within the spacecraft. The AART board within each module of Microsat, except the Flight Computer, uses an MC14469 addressable asynchronous receiver/transmitter. The device receives 4800 bps data on a data line common to all units. Each AART has a unique single byte address that must first be recognized by that particular AART unit. The addressed AART unit then takes the next serial byte as data. Depending on the value of the data the unit will either latch as many as three data bits in a field of 24 available bits or, alternatively, will set two different analog multiplexers on the AART board to place a particular analog value on the analog bus line which is then read by the A/D converter in the Flight Computer. By changing the most significant bit of the AART address byte the AART unit can also return an 8 bit value to the flight computer on a second serial line common to all AARTs. If this feature is used, the Flight Computer software must know to poll the particular AART module periodically for the expected data. The AART unit has no means of signaling to the computer that it has data ready. Each AART board has signal conditioning for up to four thermistors and up to 32 telemetry voltages. The board also contains its own precision 2.55 V reference. This level of telemetry capability per module has proved to be more than adequate, although the power module in each of the Microsats does use most of it.

Flight Software Design

The Microsat bus is a minimal architecture design. The single CPU is required to implement all software functions in the spacecraft including:

1) Telemetry generation. This requires commanding the AARTs in each module and sampling all analog telemetry points, then generating both the real-time telemetry and the stored "whole orbit" data, which is dumped on command by the ground.

2) Ground command. Includes adjusting targets for power management, switching on and off various hardware modules, etc.

3) On-board autonomous control. Includes the load-side power management routines, experiment scheduling, over and under voltage software fuses, etc.

4) Single Event Upset cleanup. Single bit errors are purged from memory with a process called "memory wash", described in detail later in this section.

5) Data communications protocol handling. The standard amateur radio service data protocol AX.25, is a variant of LAPB, the X.25 link layer protocol. This full duplex sliding window protocol is non-trivial.

6) Applications such as the Weber State experiment package, including image capture, compression, and transmission; the DOVE digital-to-analog voice mailbox, the PACSAT and LUSAT store-and-forward message system.

The software design for the Microsat CPU had goals which were similar to the hardware design goals. We wanted something based on standard, proven, cost effective components that could be integrated in interesting ways. We could then concentrate on the actual applications rather than the nuts and bolts of operating system and compiler design. These goals and the resulting design decisions are detailed below.

The main goal was:

1) Allow AMSAT to exploit a larger group of software engineers.

Previous complex AMSAT missions used the 1802 CPU, developed before "user friendly" was first conceptualized. The 1802 was either programmed directly in assembler, or in a homegrown variant of FORTH. Implementation of all the spacecraft control, protocol handling, and several large data processing applications for a Microsat would require more software to be flown than all previous AMSAT missions combined. A Microsat would also be an ongoing experiment, requiring continuing software development over the many-year lifetime of the spacecraft. This meant a larger number of software developers would need to be brought in. Also, each sponsoring organization would be responsible for its own application software to control its mission-specific hardware module. The development system used would have to be accessible to a large number of people in several countries, and would, as always, need to be inexpensive. Most of the other goals followed from this.

Subsidiary goals:

1) Allow use of an industry standard development enviroment. This was a factor in the choice of the NEC V40 CPU for the Microsat computer. The V40 is an 80186, an Intel 808x style chip enhanced for embedded controller applications. As this chip is software compatible with the 8088 used in IBM PCs, this allows standard IBM PC development tools to be used. Additionally, since the instruction set is the "native" PC set, mainstream compilers could be used rather than cross compilers. The Microsoft C compiler was chosen.

2) Allow programs written at different times by different programmers in different locations to be brought together and run on the single Microsat computer at the same time.

Since AMSAT cannot afford either the time or money consumed by the vast amounts of procedures, meetings, documentation, CASE software, and other standard trappings to allow disparate software elements to be tightly bound, we elected to permit each major function to be a separate program running in a multitasking environment. Peaceful co-existence among tasks, enforced by an operating system which manages shared resources such as memory, the telemetry system, and the data protocols is relatively easier to obtain.

This is the software equivalent of the fast "rack and stack" mechanical structure and of the 25 wire harness, and is desirable for the same reasons.

3) A program is no different than a regular IBM PC program. Since we're allowing separate tasks, allow each to be debugged using standard programs, such as Microsoft Codeview.

4) All C functions should be available, including floating point.

5) The operating system should provide a simple intertask communication scheme.

6) The operating system should be RAM, not ROM resident, so that it can be maintained and extended once in orbit. This is in keeping with the experimental nature of all AMSAT spacecraft. Only a small (though mission critical) bootload is kept in ROM.

The operating system chosen was "qCF," developed by Quadron Service Corporation of Santa Barbara, California. This is a system designed for 80186-based communications co-processor cards. The card plugs into the IBM PC bus and acts as a communications front end, using several 8030 SCC communications chips. qCF support both the IBM ARTIC card and the Emulex DCP286i card.

qCF supports Microsoft C programs, and provides pre-emptive multi-tasking, timers, and inter-task communication. It also provides interrupt and DMA driven HDLC I/O handlers. Quadron, a company where three of the four founders are radio amateurs, ported qCF to Microsat and supplied I/O drivers for the 72001 communications chips. As the software was then compatible with the Microsat CPU and with the IBM ARCTIC card, the ARCTIC card would be used as a spacecraft simulator.

This reduced the cost of a full-up development system and spacecraft simulator to an IBM clone, a $1200 adapter card, Microsoft C, and the donated Quadron development software. The resulting off-the-shelf commercial quality components allow the software application developers to concentrate on the applications, and not on the development environment itself. The tools are widely available, including such separate locations as Argentina, Italy, and the UK.

It should be noted that the qCF system was also selected for use by the University of Surrey on one of its spacecraft launched on the V35 ASAP. Although its CPU is a very different design, the high level application programming interface is the same, allowing for some shared applications between AMSAT and UoSAT. AMSAT provided the AX.25 communications handler and the I/O driver, UoSAT in return provided the file system task and portions of the message file server system.

A short summary of the various types of programs running on a Microsat are in order.

Operating System

The kernal supplies the basic multitasking services. It manages the hardware timers, sets up memory, loads and unloads tasks.

File Support

The 8M byte data storage area is managed as a RAM-based disk. The low level C read and write subroutines in the standard C library used by applications are replaced by routines that format an I/O request and send it an inter-task message stream to the file support task. Acting much like an IBM PC RAM disk driver, the file support task provides blocking and deblocking services as well as providing error correction for single bit errors.

Message File Server

This will be the most visible program to users on the ground. The major goal of the two PACSAT Microsats is to provide a bulletin board and file service. This interface is optimized for computer to computer transfers, the user's ground station software provides the human interface. The software and procedures are being developed now to integrate the Microsats into the amateur radio service's world-wide *ad hoc* packet network. More than 100,000 interface units, called terminal node controllers, have been sold worldwide since 1983; all are potential and many are current users of this network.

AX.25 Handler

The AX.25 handler implements the LAPB-style communications protocol. It permits point-to-point connects between the various tasks running on the Microsat and the many ground stations visible in the range circle.

HDLC Driver

The HDLC driver passes frames between the AX.25 handler and the uplinks and downlink. The driver is non-trivial. The hardware design supplies several DMA channels, but even so there are more I/O channels than DMA, so the drive must do both DMA and straight interrupt driven I/O. To get the most out of the available processor power, and to enable later Microsat missions to use even higher baud rates, the HDLC driver is written in assembler code.

Housekeeping

This task implements the spacecraft power management algorithms discussed above.

Telemetry

The telemetry software module periodically gathers telemetry data by using the AART driver to collect data from sensors throughout the spacecraft. The data is both sent to the downlink for real-time monitoring, and is also stored in a virtual disk file in memory. The "whole orbit data" format, where the values for telemetry channels are stored over several hours and are later downlinked is an invaluable tool for low orbit spacecraft.

Memory Wash

Some of the memory on the spacecraft is protected with hardware Error Detection and Correction (EDAC) circuitry. When an error is induced in memory by an energetic particle normally filtered out by the atmosphere, the EDAC will correct the error when a read occurs and place the correct data on the bus. The corrected byte is not written back into memory automatically by the hardware. If an error is allowed to linger, there is a chance that a second bit in the same byte will get flipped. Since the hardware can only properly fix single bit errors, it is important to fix all single bit errors before they become multi-bit. In a process called "washing memory", a task periodically runs through the EDAC memory, reading and writing every byte, causing the corrected byte to be written back into memory over a damaged one.

Most of the memory is not protected by hardware. The reason is economics, 12 bits are used to store each 8 bit byte in hardware protected memory. Hardware EDAC is used for memory that programs run from, since a program byte in error will usually lead to no good. Software algorithms must be used to protect the remaining memory. This memory is used to store data files and messages. The RAM disk routines will use software EDAC to correct errors, but if a "disk sector" goes unread for too long, multiple bit errors may occur. To reduce this chance, the memory wash task periodically reads all "disk sectors" and writes them out.

Camera Control

In the Weber State Microsat, the primary mission is the CCD camera. Software written by WSU controls the camera, digitizes the image, compresses it, and formats it for transmission. Software is also under continuing development to run the other on-board experiments.

Software Summary

The onboard software environment has proven to be very reliable; Microsat-D (LUSAT) has gone 233 days at this writing without a reload of the qCF kernal. Applications have been reloaded several times, particularly on Microsat-C (WEBERSAT), as improved camera control algorithms are produced.

Other Microsat Experiments

Despite their very small size, it was possible to design all of the required electronics for a store-and-forward communications system into 4 of the 5 standard module frames. This leaves one frame available for experiments. All four Microsats made use of this capability, each in a somewhat different way.

Microsat-A (PACSAT): Carries a 1 Watt S-Band (2400 MHz) transmitter that can be used to test the viability of packet communications via satellite at microwave frequencies. The transmitter was exceptional in that it achieved a DC/RF efficiency of 47% despite the low absolute output power level. This is very difficult to achieve and implies that the lower level stages of the transmitter are particularly efficient. In the achieved orbit this transmitter can be received with a simple helix antenna only 8 inches long. This transmitter has been used on several occasions as an augmentation to the UHF transmitter. It is working very well.

Microsat-B (DOVE): Carries another S-Band transmitter and a voice broadcast experiment. The transmitter is identical to that on Microsat-A, however, the carrier suppression on this transmitter has been lost, apparently due to a component failure in the modulator circuitry. The voice broadcast experiment allows two forms of digital voice data to be uplinked and stored in the flight computer memory and then downlinked at a specified time or repeated multiple times. Both digitized speech and a voice synthesizer may be used to produce voice outputs.

Microsat-C (WEBERSAT): Uses its spare module plus the equivalent of two more to carry a variety of experiments that are of interest to the educational community. These experiments, developed by WSU, include:

- A visible light CCD camera
- A visible light spectrometer
- A micrometeorite detector
- A flash video image converter
- Two 2-axis flux gate magnetometers

Microsat-D (LUSAT): Uses its spare module to provide a stand-alone telemetry system. It includes a sensor package, a small microcontroller, a 437 MHz transmitter transmitting data in a modified Morse Code format and a simplified command decoder to turn the experiment on and off from the ground, thus bypassing the other command and telemetry features of the spacecraft. This unit works like a "spacecraft within a spacecraft." It has performed flawlessly since launch and has been almost continuously turned ON. It was constructed by amateurs from Argentina and represents the first space flight hardware ever flown by that country.

The ability of the spacecraft to adapt easily to other uses and to be expandable to even wider usage, as was accomplished with WEBERSAT, makes Microsat particularly valuable as a candidate spacecraft for many future small satellite missions.

Use of the Arianespace ASAP Platform

Being a secondary user of a large launcher has always had its advantages and disadvantages. There is a process, as old as space flight itself, that a "lightsater" must go through - a kind of hazing ritual. This is the process whereby the secondary payload project management convinces the primary payload management that:

1) Yes, we know what we're doing and

2) No, we won't hurt your big beautiful spacecraft.

The first time through, this process it's actually fun, particularly when you win . The tenth time through the process, it's not at all fun any more but, at least one knows the routine. There is hope that Pegasus and other launchers dedicated to small satellite services will remove this role of secondary payload/second class citizen.

To their great credit Arianespace, in creating the Ariane Structure for Auxiliary Payloads (ASAP) has almost completely buffered the secondary customer from the primary customer so as to solve these problems. Almost. There are still requirements for the secondary customer to communicate specific technical information to the primary payload project manager and there are still times when technical information delivered to said project manager is ignored and the will of said project manager is still the law of the land. Our great thanks to Arianespace for doing their best professional job to try to minimize our paperwork tasks and allow us to get our work finished at the launch site with minimum grief from the prime contractor.

The ASAP platform is a big improvement over previous means of launching small payloads on large rockets. To wit:

1) The ASAP structure is quite large and there is adequate space for all secondary users to work around its large flat mounting surface. The ASAP is placed in the integration clean room with the secondary spacecraft team(s). This allows the spacecraft workers continuous access to the ASAP hardware for quick fit checks of wiring harnesses, antennas, mounting adapters, etc. in a less formal environment then ever before. This reduces the overhead time and the length of the launch campaign.

2) The ASAP structure can be populated with small spacecraft at a pace that is more driven by the needs of the secondary user and is decoupled from the demands of the primary payload customer because they no longer share common facilities.

3) The completed ASAP structure and its secondary payloads are mated to the forward end of the launcher (VE structure) just prior to the mating of the primary payload(s). This minimizes the time from the beginning of the secondary payload launch campaign until the day of launch.

4) The Arianespace program office has now segregated the much needed daily meetings of the secondary users from those of the primary users. This was not the case in the "old days." The result is the secondary users do not have to sit through endless meeting agenda items that are of no real interest or concern to them. This reduces the staffing requirements of the secondary payload project. The Arianespace staff conducted these morning meetings in a most professional and supportive manner that helped greatly in giving "lightsaters" the feeling they're real customers.

5) The support of the Arianespace people throughout the launch campaign, and indeed throughout the entire program, was fantastic. All reasonable requests for technical support, including various specialized materials and services that we needed were quickly and accurately supplied. Problems, what few there were, were solved with a sense of team spirit. One becomes accustomed to the usual aerospace approach where, when a problem occurs a memo is never far behind. Then contractor A blames contractor B for the problem and vice-versa. During this activity, of course nothing is being accomplished. In fact, all one really cares about is for the problem to be fixed. This the Arianespace team did,

and quickly.

There are a few recommendations we would make to future secondary users of ASAP:

1) Regardless of any previous projections to the contrary, be prepared to deliver your spacecraft to Kourou approximately 2.5 to 3 months prior to the real launch date. While it may appear that the process can be completed closer to the launch, experience shows that events conspire so as to cause secondary users to come early and work at a pace slower than you would if you were working at your home facility.

2) If you intend to play in this game, be prepared to be smart enough to figure out the real launch date. It can be done. This is not a criticism of Arianespace but, a realization that all launcher schedules slip. You will be in serious trouble if you are late and you've wasted valuable time you could have been testing or improving your satellite if you are early. Life is tough!

3) Support the decisions of the primary payload when they effect you (even when painful). In the long run, the big guy will win anyway so you're wasting your time to fight it. If you fight it, they may pull you off the rocket. Remember, the primary customer paid about 200 times more than you did for your launch so he is always right.

4) Remember that the safety rules are for everyone's benefit so follow them carefully. Your life may depend upon it. We have found the CSG safety system to be sound and reasonable. The Arianespace paperwork requirements regarding safety submissions are very modest and their safety people do a great job. They are there to help you so we see no reason why safety submissions should not be done on time.

5) From the standpoint of your project's financial and schedule planning, be prepared for the real possibility of a launch slip that may likely occur even after the launch team has arrived in Kourou. This is a common occurrence in the aerospace world. It is frustrating but, even worse, it could be a disaster if you are on a very tight budget and you have not planned for this possibility. Money should actually be set aside for this eventuality.

AMSAT wishes to thank Arianespace for continuing to support the small satellite program. In turn, AMSAT has been a long supporter of the Ariane program, having been the very first of two passengers on Ariane LO2 in 1980 and one of the three passengers on Ariane 401, the first Ariane-4 launch. We have launched more satellites on Ariane today than any other user - a total of seven spacecraft on four different launches - and we are proud to have been a part of this exciting program. Our working relationship with Arianespace has been the best and we look forward to our next launch opportunity.

Conclusions

Table 2 summarizes the design values of the four Microsats and the performance obtained to date in space or the measured parameter just before launch (as appropriate).

In summary, the four spacecraft and the Microsat design exceeded, in almost every area, our expectations at the time the project was conceived. We have once again proven that sound design is more important than "high-rel." parts and that KISS is more important than redundancy. Most importantly, we have shown the way to a new wave in space technology. Microsat is the *army ant* adaptation to space as opposed to the elephant adaptation. Many Microsats in a low Earth orbiting network would provide an incredibly powerful communications network and a catastrophic failure of one satellite means very little to the rest of the swarm which continue to carry out their duties. Mass production of anything makes the product more reliable and cheaper. Microsat lends itself perfectly to this concept. Finally, a nine inch cube can do an amazing amount of work in space. They even have the communications capacity to serve omni-directional and even hand held user terminals on the ground as AMSAT has demonstrated. Spacecraft of even a smaller size than ours, carrying out specialized function are entirely possible and practical today. They will be more so in the future. AMSAT has shown that small organizations can do significant work in space and that there is room for universities and non-profit organizations to participate directly in the development of their own spacecraft.

Acknowledgments

It would be impossible here to thank individually the many volunteers who made the AMSAT Microsat program happen. These individuals know who they are and they have been recognized on other occasions. These volunteers and radio amateurs are located all over the world and the

TABLE 2 — Standard Microsat Design vs. In-Space Performance.

Parameter	Design Value	Final Value or In-Space Performance
Mass	9.5 Kg	9.7 - 10.1 Kg
MoI		
Ixx=Iyy	.075 Kg m^2	.09 Kg m^2
Izz	.070 Kg m^2	.097 Kg m^2
Orbit Avg Power (800 Km Sun Sync)	6.0 W	5.8 - 6.5 W (Max 13W)
Orbit Avg Temp (Battery)	-8.4 to +2.6 ° C	-2 ° C to +2 ° C (Average +.2 ° C)
Break even TX power	2.0 W	1.7 - 2.7 W
Rotation rate of Z axis	2/orbit	2/orbit
Rotation rate about Z axis (solar pressure)		
Sat A, C, D	2.5 min/rot	1 - 2.3 min/rot
Sat B	.3 min/rot	.3 min/rot
Nutation cone angle	0 °	0 ° - 20 ° (depending on orbit)
Soft errors per orbit (256K EDAC RAM)	3 - 5 per day	2 - 6 per day
Packet receiver sensitivity (successful packet threshold)	-110 to -117 dBm	-110 to -117 dBm

U.S. participants are from all areas of our country. Of the twelve satellites AMSAT has constructed and launched since 1970, these four were done in the shortest time and with the hardest work. None of our other projects have required so many 24 hour days and quite so much dedication on the part of our core team. The authors would particularly like to thank our sister organizations who helped finance this program: Brazil AMSAT (BRAMSAT), AMSAT Argentina and the Center for Aerospace Technology/ Weber State University. We hope that these organizations are having the time of their lives with their new satellites. We also hope we have helped each of these groups to influence the environment around themselves in a positive manner. Uniquely, the amateur radio community in Argentina can accurately state that their organization built, flew and now routinely operates the very first satellite ever from the country of Argentina. We want to thank Dr. Junior Torres de Castro of Brazil for his brief letter to us in 1987 suggesting that such a small satellite might be practical. From such simple seeds grander things sometimes grow. Finally, we wish to thank Arianespace for their significant financial investment in the ASAP platform which will greatly help the emerging small satellite world for many years to come.

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Two DSP Modems

By Bob McGwier, N4HY

At Dayton 1986, Tom Clark, W3IWI, came to me and said "I know a nifty way to do EME using brain's rather than brawn, are you interested?" It amazing how much difference in a person's life sixteen English words can make. Much has happened between then and now, including the Microsat project, the formation of the TAPR-AMSAT DSP project, the formation of Digital Signal Systems, Inc. to do a DSP project for AEA, the beginning of Phase III-D, the beginning of the death of Phase IV, the start of RUDAK-II, experimentation, and more. It is amazing how much a hand full of people can accomplish when they have good jobs (and forgiving wives and/ or bosses). This is the quick story of two of these projects.

TAPR and AMSAT Get Together

The TAPR-AMSAT DSP project has undergone quite a bit of evolution since you were last given a report. It is now a PC based plug in card. It can take advantage of the AT bus if it is available and will work in an 8 bit bus if an AT slot is not available. It is based not on the originally planned TMS320C10 (or 15) but the late second generation chip, the Texas Instruments TMS320C25. This chip is clocked with a 32 MHz crystal and will execute serial instructions at 8 million instructions per second. This is a bit deceiving of course. The TMS320C25, based on the Harvard Architecture, can pull in filter coefficients and signal samples at the same time. It has a single instruction multiply as do all 'real' DSP chips. The idea is to use this board to develop modems for amateur radio use as well has other applications. In order that HDLC does not have to be done in software (shades of certain W4's and companies in Kansas!), the designers have included the protocol engine on board. The board has an Zilog 85C30 which can be the digital data interface between the modem and the PC. With PC-100, DRSI boards, Eagle cards, and more, there is plenty of code available to use the 85C30. We need new code for RTTY, and other asynchronous modes, but that should come shortly. The stuff that will take longer is AMTOR, SSTV, WEFAX, WEFAX-APT, etc. The analog front is based on the 8 bit A/D, D/A combination, the AD7569 from analog devices with anti-aliasing and reconstruction filtering with characteristics determined by the sampling rate. This board should provide AMSAT and TAPR engineers and amateur radio packet users and experimenters stuff to do for years as well as generate revenue for our next satellite project in AMSAT. The hardware design was done entirely by the "Tucson" group led by WA7GXD, Lyle Johnson. Dan Morrison, Dan Parker, Eric Gustafson, and the ever present Chuck Green, NØADI, were all major participants in the design. You will be able to see this board in action here this weekend.

AEA is Innovating Again

The AEA DSP project, known as the DSP-2232 was done by the author N4HY, Brooks, KB2CST, of Kansas City Tracker fame, and KA2MOV, Pat Spatafore. All of us also did the DOVE speech hardware, but that is another paper! The AEA project was to produce a follow on to the PK-232 which was clearly AEA's best innovation. Imitation being the most serious form of flattery (and AEA's major competition), 'everyone' has a multimode packet controller these days and all of them are basically copycats of the original PK-232 with more bells and whistles thrown in for 'product distinction.' Mike Lamb, N7ML, president of AEA saw early on that DSP was the way of the future for audio bandwidth signal processing applications in amateur radio. He was the third participant, outside the 'inner circle' in the TAPR-AMSAT DSP project, and underwrote a lot of its early costs by purchasing several copies of a cross assembler that we used to do modem development. When Microsat took over most of the time of the TAPR-AMSAT participants, Brooks and Pat came to the author in late 1988 and said "If we do a DSP56001 board, will you write DSP software for it?" I said (with tongue in cheek) "SURE". They said it would be ready in two weeks and then I went (to myself of course) RIGHT! Well of course, they didn't make it in two weeks, they made it in four. The Motorola DSP56001 is a wonderful DSP chip and modems and applications flowed into the processor. We showed this stuff off at Dayton in 1989 and Mike Lamb and George Buxton approached us and asked us to license the design to them and we finally agreed that what we would deliver is a prototype of what is now called the DSP-2232.

The DSP-2232 is based on the Hitachi HD64180, 85C30, 85C36, and the Motorola DSP56001 as the heart of the system. It should be clear from the HD64180 that it is a 'smart modem' just as was the PK-232. The Hitachi HD64180 is a Z80 with bank switching hardware built into the IO space of the chip. This chip was chosen because of its high level on integration (the user serial interface is built in as well as bank switching) and the many man years of Z80 code development that went into the AEA PK-

232. From the reprogrammable nature of the DSP56001, it is clear that it is intended to be as multimode as we are able to make it. The DSP56001 is clocked with a 24 MHz crystal. Since its internals are different from the TMS320C25 mentioned above, this works out to be 12 million serial instructions per second. Just like the TMS320C25, it is capable of doing several things in parallel. When doing the filters, which make up most of all modems done in software, it is executing at the equivalent rate of 36 million instructions per second. When doing all the standard packet modems, RTTY modems, SSTV, WEFAX, etc., we are using less than 20% of the processor's bandwidth (measured by N4HY and an oscilloscope). It was clear that it was a shame not to introduce more capability into the box than we originally envisioned. Mike claimed that one of the places the competition had in fact managed to 'get him' was in the dual port boxes. It was immediately clear that we wanted to have the hardware capable of supporting more than one radio port. Therefore DSP-2232 supports two radios simultaneously in almost all modes. It has two D/A's two A/D's, two sets of reconstructions and antialiasing filters, and two radio jacks. It has two Morse code outputs, two RTTY driver outputs, two mike click outputs (in case you wish to support more than one Microsat at the same time for example). It will do the standard VHF-HF gateway that the Kantronics box started but it is capable of more. I am sure that much bragging will be done in the meeting corridors and this box will also be on demonstration here at the conference. Mike tells me he is now targeting January 1991 for first deliveries.

DSP is about to explode onto the amateur radio scene. The day of a house full of extremely expensive special purpose devices (like ROBOT 400C's or worse 1200C's) or thousand dollar RTTY terminal units are gone. These two units, costing well under a thousand dollars, will replace all of these devices. Start saving your sheckles or if you are Canadian, your loonies!

SAREX Hardware Development

By Lou McFadden, W5DID

The SAREX (Shuttle Amateur Radio EXperiment) is the culmination of several years of development of amateur radio equipment for use in the NASA manned space program. The first proposal for amateur gear aboard a manned spacecraft was made by Harry Helfrich (W3ZM) at Goddard. The idea was to fly a 10M radio aboard Skylab for use by Owen Garriott (W5LFL). The proposal was favorably received by NASA management but couldn't be installed since it required an outside antenna, and it was too late in the buildup flow of Skylab. When the opportunity came up for Owen to fly again on the Shuttle Spacelab mission STS-9, an all out effort was made to provide the equipment needed for him to take aboard.

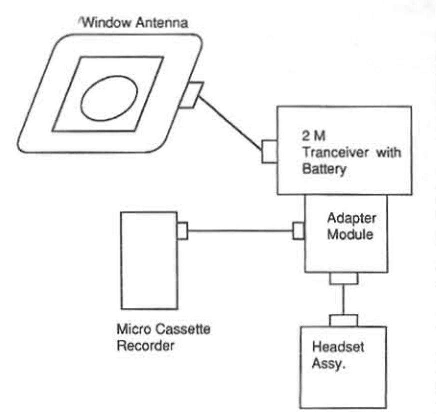

Fig. 1— STS-9 configuration.

The work needed to make the SAREX possible is provided almost entirely by volunteers. They range from retired interested hams, to employees of NASA, NASA contractors, employees of Motorola and other electronic industry companies, ARRL and AMSAT. They have contributed many hundreds of personal hours to this effort with only their personal satisfaction as reward. Without the support of these many volunteers there simply would be no SAREX.

Most people have no concept of the requirements which must be satisfied in order to get a payload onboard the Shuttle. In general, the attitude of the NASA establishment is, " Prove you are safe and ready to fly and that you have completed all your paper work, Then and only then can you get your equipment onboard". A very significant problem is determining what really is required. The documents which define that would take up an entire bookcase and then some, (needless to say it isn't for the faint of heart). There are constant new requirements cropping up. When the payload is not one of the Scientific payloads or a paying customer, the hurtles seem just that much higher. There are those that think of it as "a grown man's toy" which is taking up the space and weight which should be allocated to "real payloads". Then there are those who have the vision to see the benefit to NASA, the public and to the amateur radio community.

We have found that there are a great many people associated with NASA who are not hams but are sons, daughters, mothers, fathers, or friends of hams. There are many who want to be hams but don't ever get around to getting a license. These are the silent supporters that also make the SAREX project possible. Fortunately there are more of the friends of SAREX than those against it.

There are many documents required to be submitted to NASA in order to get approval for a payload to fly on the Shuttle. The most important of these is the PIP or Payload Implementation Plan

This is the agreement between NASA and the payload provider. This document lists all the hardware, its weights, the experiment requirements and the flight needs and who is going to provide what equipment and perform which tasks. Another very important document is the Safety and Hazard analysis. This document lists all the hazards that are identified and how these hazards are controlled. It is not sufficient to say "well, that won't happen". NASA assumes it will happen and then wants to know how we intend to control the hazard. A good example of the kinds of hazards we had to deal with was " what if the SAREX radio upsets the Shuttle flight computers". This is a real hazard which we had to deal with. We dealt with it through analyzing the RF field strength and actual tests at KSC in the bird which proved that it wouldn't happen. Most of the work is very necessary considering the consequences of a catastrophic failure.

There were several other documents which had to be completed and approved by NASA before we could get the SAREX onboard. They are too numerous to list them all here.

The equipment we assembled for

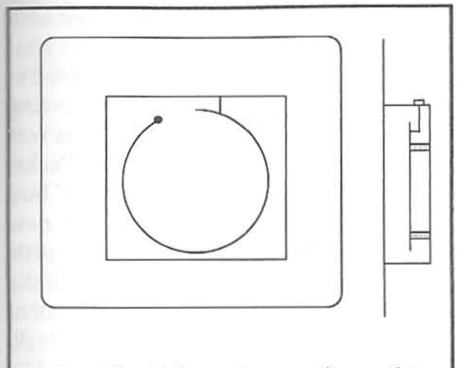

Fig. 2 — Direct discontinuous ring radiator.

Owen's flight was the simplest we could put together (Fig. 1)

There were constraints on the SAREX (Called AMRAD on this flight).

Since it was the first flight on the Shuttle we decided to keep interfaces with the orbiter at a minimum. The intent was to minimize our chances for NASA to say no. The less complicated, the better chance we had and the fewer reasons they could find to remove AMRAD from the flight. This equipment consisted of a Motorola MX360 Handie Talkie and its batteries, an Adapter module to adapt the Shuttle crew headset to the HT, and an antenna designed to fit in the aft flight deck overhead window.

The HT output was adjusted so that the six watt transmitter finals were limited to 2.5 Watts. This was necessary due to the lack of thermal convection cooling in the zero gravity flight environment.

The headset Adapter module was designed to take the low level microphone output (.5 mv) and amplify it to the level required by the Motorola HT. The Adapter module also provided the push to talk button and a mixed signal output with both sides of the conversation for the microcassette recorder this allowed recording of this historic occasion on a cassette tape recorder.

The antenna chosen for the window was a DDRR or Direct Discontinuous Ring Radiator. This antenna system is analyzed by Dome in the July 72 issue of *QST* (p27-36). The ring is located in a box shaped cavity which is mounted on a flat plate designed to fit in the overhead window. The open side of the cavity faces the window (Fig 2). This antenna had the advantage of radiating out the window and at the same time providing a method of reducing the amount of RF radiating back into the cabin. The disadvantages were that it was extremely difficult to tune and it totally blocked the window.

The flight of STS-51F on which Tony England was the operator presented new challenges. We were asked to provide something new and spectacular.

Specifically we were asked to provide a way to send pictures to the hams on the ground. The proposal included a SSTV (Slow Scan TV) system along with the voice capability. Another significant change was in the way of operating. There were more scheduled contacts, in particular those with schools and the families of the crew.

It was immediately recognized that in order to meet this requirement to send pictures to the ground, the "no electrical interfaces to the orbiter" rule would have to be abandoned. The power requirements were simply too much to allow dependence on batteries.

The initial configuration (Fig 3) also included a 10 Meter transmitter which would have required two additional batteries. The long term storage prior to flight also presents a significant shelf life problem for the batteries.

During our negotiations with the Shuttle program office prior to Tony's flight we went through several configurations. We even had a preliminary design of a 10 Meter antenna for the payload bay and a cable routing designed. An existing coaxial bulkhead feedthru was found behind the astronauts bathroom. All we needed was permission and funding for Rockwell to install the antenna and cable.

This idea was summarily disapproved. In fact, the request for the 10 M antenna and cable resulted in a disapproval letter being sent to NASA HQ which essentially tossed SAREX off the flight. After recouping from the shock of being thrown off the flight, we decided to take our SAREX proposal back with the 10 M portion deleted. Since the only reason given for the disapproval was the 10 M penetration, the program office approved the SAREX for flight.

The configuration that was finally approved included a new scan converter module, the existing Motorola transceiver and adapter module, antenna, and a new Panasonic Camera and TV / monitor (Fig 4).

The scan converter module included the necessary isolated power supplies for the scan converter board, the camera, monitor and the transceiver, and the circuits to connect the scan converter to the camera and TV monitor. There was also a requirement to be able to bring Shuttle video into the SAREX so that we could send slow scan TV pictures from the shuttle cameras to the hams on the ground. This requirements presented a significant problem since the shuttle video is 75 Ohm BALANCED video and the SAREX system was unbalanced video. The NASA Lewis Amateur Radio Club built a custom balanced to unbalanced buffer board to provide this function. This also required the blessing of the NASA TV engineers, who are very cautious. An interface verification test was conducted to satisfy their concerns.

The SSTV converter was donated by Robot Research. The SSTV system needed modifications in order to meet the flight requirements for this flight. Special software was added to the Robot which allowed it to transmit a sequence of SSTV images in formats which were not in the Robot format. This would make the signals more universal and allow reception by SSTV enthusiasts who do not possess Robot hardware. Software modifications were also needed to process the Shuttle frame sequential video into a composite color image. The Shuttle video sends video in a green, red, blue frame sequence. These frames are

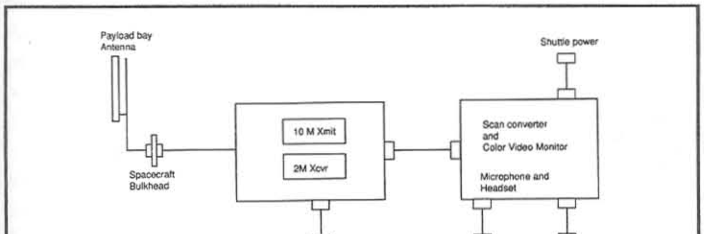

Fig. 3 — Proposed STS-51 configuration.

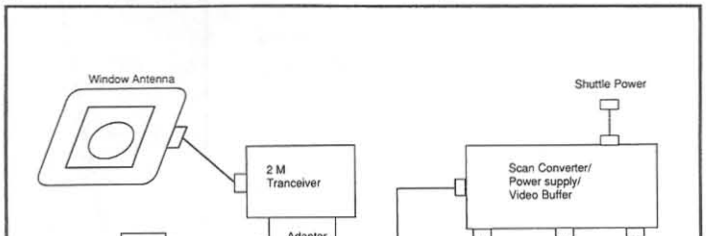

Fig. 4 — Final STS-51 configuration.

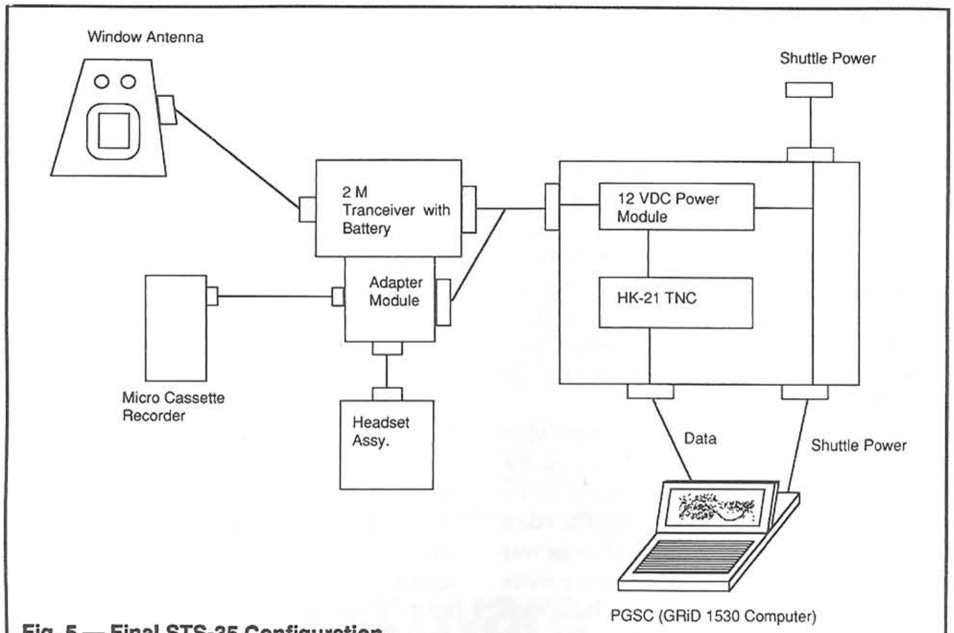

Fig. 5 — Final STS-35 Configuration.

digitized and stored in the SSTV converter memory and sent out as a composite color video signal. This was the first time the Shuttle crew had the capability to see their own video in color onboard. John Stahler (WB6DCN) of Robot Research provided the necessary software changes and the scan converter boards to include in the SAREX hardware.

Panasonic was very generous in providing the necessary cameras and TV monitors for the flight. The only changes necessary to the Panasonic hardware were conformal coating of the printed circuit boards to prevent shorts from metal particles in zero G, and shielding of the camera to protect it from the RF field from the SAREX transmitter. We all know the results of Tony's flight. There were hundreds of SSTV pictures received by hams on the ground and the first TV pictures were sent up to Tony from W5RRR as STS-51F passed over Houston. What an exciting event that was!

There were also many voice contacts with enthusiastic hams throughout the world.

Ron Parise's flight of STS-35 started out as a proposal by the NASA Goddard Amateur Radio Club to fly a Radio Shack model 100 laptop computer and the TAPR TNC2 along with the Motorola HT.

The STS-35 flight was originally planned for spring 1986. Much has transpired since then. The accident of STS- 51 L has completely changed the rules for flying hardware on the Shuttle. One of the changes is that all hardware has to be completely requalified. The Shuttle program office now provides the microcomputer used for all experiments. The configuration proposed for STS-35 called for incorporating the packet hardware into the SAREX scan converter module. In the years since the hardware for Tony's flight was built, the state of the art for power supplies has progressed greatly. This allowed us to incorporate the packet subsystem and the power supplies and scan converter into the same housing that was originally used to package the STS-51F hardware. The new power supplies are much more efficient and provide less of a heat dissipation problem. They also provide more current capability and are much smaller. They are the Lambda MLWx series power supply modules. As design was progressing on the new SAREX scan converter, we were notified by the Shuttle program office that there just wasn't enough room in the lockers for all the SAREX equipment. We were once again faced with the need to make a change or SAREX simply wouldn't be onboard. It was decided to add a new configuration to our growing inventory of SAREX hardware. Thus was born the SAREX Packet Module. The Packet Module is built into a 2.5" X 4.7" X 7.4" Bud CU-247 cast aluminum box. This new packaging and the sharing of the Shuttle provided laptop computer allowed all the unique SAREX equipment to fit into half of a stowage locker in the Shuttle mid-deck. Half a locker was all that was available. SAREX just barely made it again!

The new SAREX Packet Module includes a Heathkit HK-21 TNC which has been removed from the plastic case provided by Heathkit and mounted on the lid of the box. The power supply assembly is mounted in the bottom of the Packet Module housing. The power supply consists of a Lamda MLWS-912 power supply module, a FL461A filter module and a 7805 voltage regulator to supply the 5 Vdc for the packet assembly. A block diagram is shown in Fig. 5

The power supply converts the Shuttle 28 VDC power to 12 VDC at 2.5 amps. This power output is isolated from the shuttle power to prevent ground loops when the antenna is connected to Shuttle chassis ground.

The Packet Module also included a new circuit protection device called a polyfuse, which opens on current overload and returns to a conductive state when the power is removed. This provides protection from current overload while not requiring the replacement of fuses.

The antenna for the STS 35 mission also provided the SAREX team with new chal-

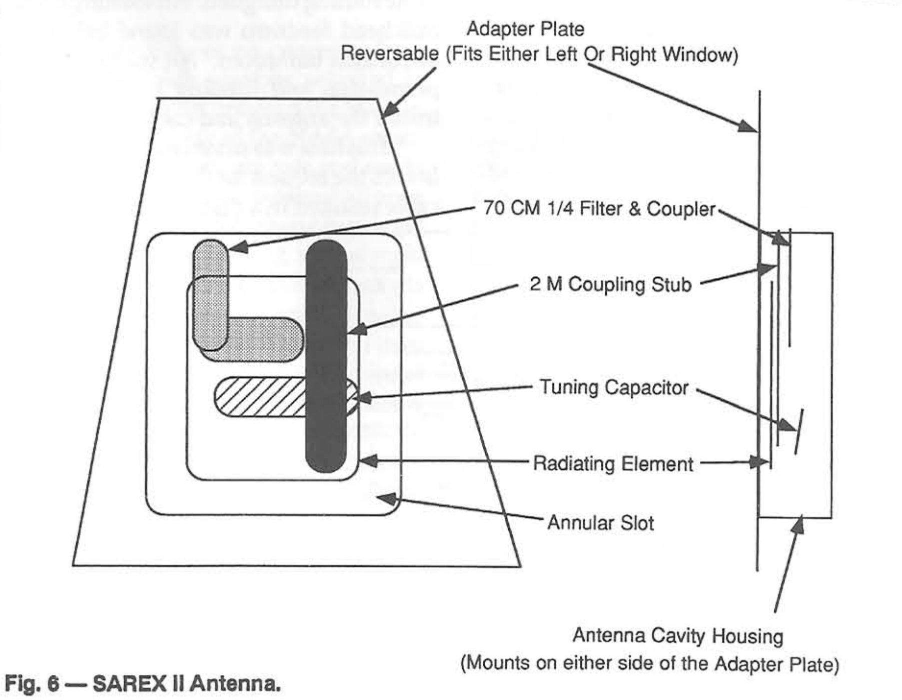

Fig. 6 — SAREX II Antenna.

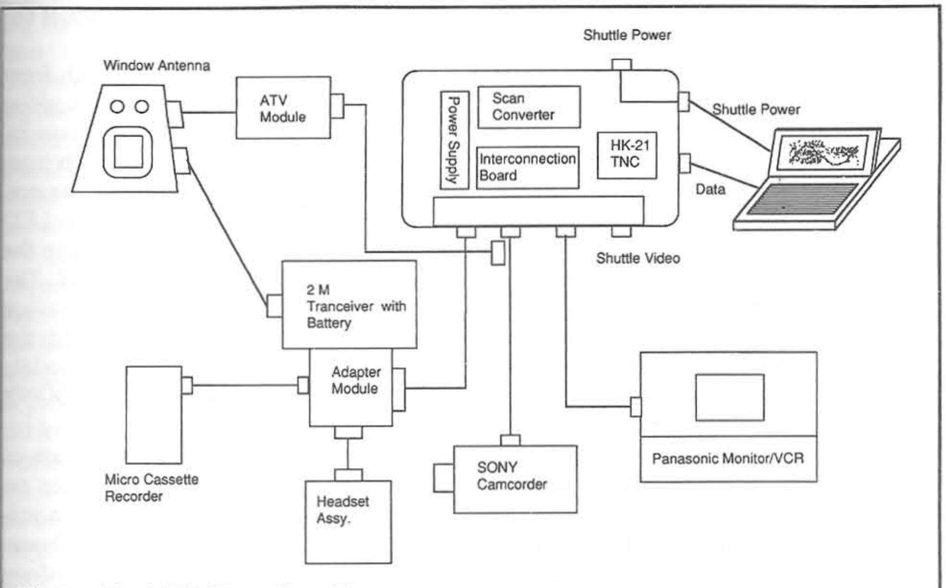

Fig. 7 — Final STS-37 configuration.

lenges. The Astro mission is primarily an astronomy mission. Astronomical observations are conducted through the aft flight deck overhead windows. The SAREX antenna used previously on STS-9 and 51F only fits in the aft flight deck window. A new antenna was required if the time for SAREX operations was not to be severely limited. The design, fabrication, and qualification of a completely new antenna was a major undertaking. The SAREX team was also very short of funds and resources.

The Motorola Amateur Radio Club at Shaumberg, Ill. was solicited to design and build the antenna. The hams at Motorola were up to the task. Their antenna design (Fig. 6) is an engineering marvel. This antenna is a variation of the annular slot antenna. The requirements for this antenna included: must not touch the glass, and must provide for transmitting on the 2 M band while at the same receiving on the 70cm band (to provide for a future ATV experiment). The prototype antenna had to be tested in the Shuttle prototype spacecraft Enterprise which is located at the Smithsonian Institute hangar at Dulles Airport in Washington, D.C.. There was no other place, except for the actual Shuttle, which had the necessary triple pane windows to simulate flight conditions. Most hams think glass has no effect on an antenna. How wrong! We found that the Shuttle windows detuned the antenna by 30 MHz.! This put the team into a panic since the required delivery date for shipment to KSC was only 2 months away when this problem was discovered. The designer at Motorola, Jim Phillips, seemed confident that the problem could be solved. There were some of us at JSC that were more than a little nervous about it. The antenna had to be redesigned, fabricated and delivered to KSC in record time. What was worse, it had to be right! There would be no second chance. Fortunately, Jim is an expert of the first caliber (perhaps it was pressure from the ONLY Ham in the family, his wife Sharon, (KA9MTB) that gave him the incentive.) The antenna was delivered just in time. When we tested the flight hardware at KSC in the Shuttle Columbia, it worked perfectly! Jim had added a large tuning plate which had the capacity to shift the center frequency by 10 MHz. The Motorola team also added a reflected power indicator so that Ron could tune the antenna in flight. What a relief that successful test was to all who participated. Jim even got to go onboard the Columbia to test it himself.

We are now eagerly awaiting the flight of STS-35. This flight has been delayed several times and is now scheduled to fly no earlier than Dec. 1. This will certainly be the "most prepared for" amateur radio flight in history. We have been through the drill four times.

While we are waiting for STS-35 to fly, preparations are in full swing to assemble the hardware for STS-37. Ken Cameron (KB5AWP), Steve Nagel (N5RAW), Linda Godwin (N5RAX), and Jay Apt (N5QWL) are the hams onboard that flight. There will be more hams onboard STS-37 than in all other Shuttle flights combined! Their equipment will have all the capabilities originally planned for in Ron's flight, with the addition of an ATV experiment (Fig. 7). The ATV experiment has also added some requirements which were new. There is a need to record the video which will be sent up to the Shuttle. The method planned will use a Panasonic donated model PV-M429 combination VCR and Color LCD monitor. This VCR has all the capabilities of a standard VCR, except for TV tuner, along with a 4" Color LCD screen. The unit uses standard VHS cassettes, measures approximately 4" X 8" X 9", and weighs 5 pounds. Another convenient feature of the VCR is that it runs off the 12 Vdc already provided by the SAREX hardware. The Shuttle Provided Sony camcorder will be used as the video source for the SSTV operations. The same balanced to unbalanced buffer will be used to allow connection of the Shuttle frame sequential video to the SAREX.

The new SAREX scan converter module has been totally redesigned internally so that the packet feature could be added. The system consists of 5 major assemblies (Fig. 8). The Packet sub assembly is very similar to the one used in the Packet Module. In fact it is "plug compatible " except for the LED cable. A Heathkit HK-21 is

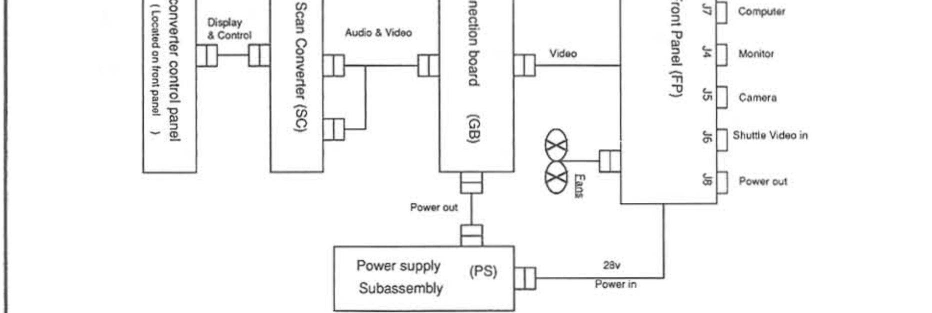

Fig. 8 — SAREX scan converter internal subassemblies.

mounted on a cover plate which is then mounted on a box shaped sheet metal housing. The whole packet sub assembly is designed to mount on the left heat sink that formerly held two of the power supplies on the STS-51 F scan converter. The mounting holes match those of the original power supplies.

These additions were made possible because of the advances that have been made in both power supply technology, and the progress in miniaturizing computer circuits, since 1984 when the first SAREX was designed.

The new SAREX power supply assembly consists of two 12 VDC 2.5 amp power supplies, one 5 VDC 3.0 amp supply, one +and - 12 VDC .6 amp power supply and an EMI filter assembly. All of these fit in a .75" X 3.3" X 6.6" assembly. This assembly is also designed to match existing mounting holes on the right heat sink from the STS-51 F scan converter.

The interconnection board, which provides all the interconnections between the various sub assemblies in the scan converter, was also redesigned. The new assembly provides the necessary switching to accommodate the addition of the packet sub assembly and provides a mounting platform for the balanced to unbalanced video buffer. All connections from the interconnection board are now made through connectors versus hard-wired on the earlier SAREX design. This will allow future modifications to be made more easily.

The Robot scan converter boards are virtually the same as they were on the earlier SAREX mission. The only changes required are in the CW Morse identification. It seemed appropriate to remove the Challenger WØORE ID. The new ID will be Atlantis KB5AWP.

The housing has been split into an upper and a lower housing to accommodate assembly. The old design was a nightmare to assemble and was very difficult to trouble shoot.

The front panel has also been extensively redesigned to accommodate the new tasks required of it by the addition of the packet and ATV functions.

Switches were added to switch from Packet to SSTV mode and to select video sources. The video source switch was required because of the need to switch from the camera to the VCR as a video source. Since the VCR also houses the color LCD monitor it had to be left connected to the monitor connector on the front panel. The camera and monitor connectors were changed to 13 pin connectors to provide the additional functions and to accommodate the 6 VDC power required for the SONY camcorder.

As can be seen by this description of the SAREX hardware, there has been no shortage of work for the SAREX team volunteers. They have all provided many hours of tireless work on this project and continue to do so.

There is still much work to be done.

The STS -37 SAREX flight should prove to be very exciting.

We will be ready!

DOVE

By Bob McGwier, N4HY

It is amazing how much just a few words, or just a sentence can change peoples lives. Junior Torres de Castro, PY2BJO, president of BRAMSAT, and long time AMSAT friend came to Jan King in 1987 and said "I believe that we could take an HT and fly it inside a package and make a very interesting educational experiment." This was enough to begin the gears and machines cranking in Jan's head. He began investigating current solar array technology and came to the Detroit Michigan AMSAT annual meeting all enthusiastic and passed this enthusiasm along to the rest of us. PACSAT and DOVE were born. As you know, others joined the contest of nerves known as the Microsat project, but these two ideas were the beginning. Junior provided most (but not all) of the funding for DOVE (the ARRL paid for the BCR's for example) and has been most patient while we sort out all of the software needs for all the spacecraft (at the same time we earn a living and get SOME sleep!). This is the written saga of DOVE since its launch as seen by my eyes, and what we have planned for it.

DOVE, like the other spacecraft in the Microsat branch of last January's launch, carried the basic loader software, telemetry collection, and command system running under the Quadron Service Corp, Inc. kernal known as qCF. This was written by NK6K with the device drivers for HDLC and asynchronous I/O written by Skip Hansen, WB6YMH. The author wrote the command, control, and telemetry software and is primary experimenter on the voice module. The voice module itself was a joint effort of N4HY, KB2CST, Brooks Van Pelt (Kansas City Tracker fame), and Pat Spatafore, KA2MOV. The onboard software at launch did little more than accept commands and tell us what the telemetry values were in the modules. No facility for sending the digitized voice files to the DOVE voice module was flown. There just was not time to get it together for flight. There is some disagreement as to what followed. I will give my personal interpretation of events. You the reader will be aware that this is in dispute. There was a bug in the way the DMA (direct memory access) handling of packets was turned on and off for memory wash in the spacecraft. DMA is a means of off-loading the task of moving the bytes received from a packet from the serial controller chip to memory from the main computer chip to a peripheral chip, known as a DMA controller.

The on board program memory is protected against single event upsets (SEU's), which are bits being changed by radiation, by Error Detection And Correction memory (EDAC). Each byte of program memory is hamming (8,4) encoded. The likelihood of a double bit error (uncorrectable in most cases) occurring in the same byte, is very small.

The way the first bit error is corrected is that periodically, each location in program memory is read (the bit is then corrected) and then rewritten to memory where the entire 12 bit coded version of the byte is corrected. This is called WASH. During the wash cycle, the DMA must be turned off. There was a conflict in the way DMA was being turned off by two different processes in memory at the time and this occurred during the WASH process. This resulted in extremely long packets being cued.

It is possible that this caused more memory to be requested from dynamic memory than was available, causing the housekeeping task to fail. Or it is possible that the unlikely double bit error occurred. At any rate, the housekeeping task failed. When this task failed, the only communications with the outside world through regular processes failed. Because of some kind of fault, the kernal continued to bang the watchdog timer (hardware) which forced the computer to continue running the kernal without a housekeeping task. Because the HDLC chip makes flags all on its own, this was the flag signal which was heard for days. In many ways, we lucked out.

If the transmitter power had been set at a low enough value, we could have had this condition last essentially forever. The transmitter power was locked on nearly its highest value. In fact, it was so high we had a negative power budget. This means we were requesting more power from the system than we were replacing with the solar generators. Several days after this situation arose, Alberto Zagni, I2KBD, called and said that he heard DOVE's transmitter going off the air and returning a short time later. I quickly guessed that what was happening was that the batteries were going flat at the end of eclipse. I ran QuikTrak and ran the satellite in fast forward and saw that at the moment Alberto said the satellite transmitter came back on, it was passing out of eclipse. We then had a plan.

The problem was that we were unable to get a reset into the receiver. We had placed the receiver and the transmitter in the same band and did not place sufficient safeguards in hardware to prevent the kind of problem we were seeing. We solicited aid from Dave Blaschke, W5UN. Dave is a world famous 2 meter EME'er and owns the world's largest privately owned two meter antenna. He was capable of radiating megawatts EIRP. I gave him the reset program for DOVE and told him about the right time and place to send the reset signal on two different orbits. It worked. Harold, NK6K, sent the correct charging values to the battery charge regulator and the next morning I commanded on the S band transmitter. Much to my chagrin, it soon became apparent that all was not right with the S band modulator. For some reason, we were not getting anywhere near full deflection during data value changes. We had a very small total phase change when we should have had 180 degrees of phase change from one bit center to another. It took us two months to think of a way to work around this. The problem was the on board bootloader and ground software was packet based. In the end, this was both our nemesis and savior.

The protocol on board was an ack/nak protocol. This meant I had to copy both acks and naks to be able to tell the difference. I spent weeks with high powered DSP solutions on the brain and missed the easy way around the problem. All that was needed in the end, was to load a small subset of the original bootloader. This was put together with the help of VE3FLL, Hugh Pett, the author of the original loader. We removed all the command functions in the old loader with the exception load to memory ONLY ACKING correct packets and remaining silent on all others. And also, begin execution so that we could start what we had just loaded! It was then possible to load by ear. You could just hear enough modulation to tell when an ack was sent.

We modified the ground software so that it would advance to the next packet in the file being sent if (1) it received an ack or (2) the enter key was struck. Number 2 and the ear were how the spacecraft was reloaded. With the aid of KØRZ, Bill McCaa's excellent S band station and the equipment PY2BJO bought for my QTH, the spacecraft was reloaded. It continues to successfully run the software we loaded and we have confirmed that this load by ear process works.

At the time of the writing, the software to make the spacecraft do the talking works in the DOVE board in my QTH. There is only one piece of software missing and this is a file system for the DOVE spacecraft and Harold and I are making a big push to get it all on board before the meeting where you will be reading this article. We also need to thank Harold for taking his computer with him on vacation and helping me to debug what was going on in the DOVE spacecraft that continually crashed the system after restart. There were times when I thought Terry (Harold's XYL) was going to take one or both of us and stick bamboo under our fingernails.

To prevent the occurrence of the previous problem in the future, the kernal now has a software watchdog timer. This timer must be stroked by at least one task or the spacecraft will be sent back to the ROM after turning off the 2 meter transmitter. Harold put other safeguards into the kernal and it does indeed appear that this all functions correctly since the bugs in the system we detected during the several times we reloaded caused this to be exercised nicely in space. In the end, all's well that ends well and let's hope that all ends well.

How do we intend to use the speech experiment? We included two speech facilities in the spacecraft. We include a Votrax SC-02 which is now known as a Artic-260. This is a 'Robot Voice' phoneme speech generator. To put it bluntly, I am less than satisfied with this chip. I wish I had more time before this selection was forced. I am not sure we could have done better, but I would have liked the opportunity. We also put on board Analog Devices AD558JD. This is a digital-to-analog converter. This is followed by reconstruction filtering and pre-emphasis. It works quite well. The latter is the system we will use. We will use 4 bits per sample. This way we can get 7280 samples per second and the fidelity is quite good. I have several facilities for doing conversion of audio sources to digital samples. The other digitizing stations, WA4ONG and N5BF, command stations for DOVE, also have this facility as they were part of the original DSP project and have the necessary hardware. Though the sound is much better out of the D/A chip, you really pay the penalty for this.

It will take about 200 seconds to send 30 seconds of speech to the spacecraft in uncompressed form. Given that this is speech, there are many ways to compress it with less than perfect reproduction of the actual contents of the bytes and all these things will be considered. It is also the case that bulletins can and will be stored in the files on board the DOVE spacecraft. You can expect the weekly AMSAT blast and elements to be put on board as well as ARRL bulletins. The plan we have discussed with Junior, is to have all speech during AM passes (primarily intended for schools) and to have bulletins with speech announcements at night along with telemetry. After we build a library of the right kinds of speech files, we will speak telemetry during the day. This only takes time not more engineering at this point.

Many of you continue to beat on us, err uhh, I mean ask about the progress on DOVE. It is being worked on by our very highly paid professional staff of super robot programmers who never need any sleep. That is, Harold and I continue to do our best in our spare time to get the job done. 'Nuff said?

Introduction to Amateur Radio Satellites

By Keith Pugh, W5IU

Welcome to the "Wonderful World of Amateur Radio Satellites!" This program will provide a brief history of Amateur Radio Satellites followed by current status of active "Birds." Definitions of common terminology will be covered to get everyone talking on the same wavelength. Tracking methods, common satellite operating practices, and elements of a typical ground station will be discussed with emphasis on the "Ford" and "Cadillac" approaches to station acquisition.

Acquisition and construction of a typical OSCAR 13 class station will be discussed in some detail to emphasize the differences between common HF practices and what it takes to optimize a station for the "weak signal" VHF, UHF, and Microwave operation required for successful operation on the high altitude "Birds." All modes of operation on OSCAR 13 will be covered.

Last but not least, sources of information about Amateur Radio Satellites will be discussed. Join AMSAT today and expand your Amateur Radio horizons to include operation on the Amateur Radio Satellites.

Decoding Telemetry from the Amateur Satellites

By G. Gould Smith, WA4SXM

The word TELEMETRY is derived from the Greek words 'tele' and 'meter', together they mean to measure from afar. Telemetry data from amateur satellites has been available since 1961. OSCAR I repetitively sent the CW message 'HI' at a speed related to the internal temperature of the spacecraft. The information gathered from this simple telemetry resulted in changes to the thermal coating and a lowering of the transmitter power for OSCAR II. The primary purpose of telemetry is to monitor, encode, transmit, and decode data concerning the vital systems of the satellite. The telemetry information gleaned from all the earlier satellites has contributed to a more reliable, longer lasting and fuller featured satellite.

Telemetry has two definitions. The most common usage is to refer to the 3 step process of: 1) converting analog data to digital data; 2) transmission of the digital data; and 3) conversion of the received signal into a displayable form. The other definition refers to the actual data itself. This dual definition often causes confusion when discussing telemetry. Telemetry generally measures four quantities: temperature, current, voltage and status. The first three can suitably describe the analog portion of the major systems. The fourth is needed to know the state of a device. Is it ON or OFF? The major components of the satellite offer an abundant amount of analog information available to be measured. It is the difficult job of the system designers to choose: 1) which values are to be monitored; 2) what mode of transmission is to be used; 3) how the data is to be encoded; 4) how much error detection to use; 5) how often to send the telemetry; 6) how much power to allocate to the transmission; 7) how fast to send the data; 8) how much memory can be allocated; and 9) how complex a ground station is needed. The major components of a satellite system are: 1) the power system; 2) the On Board Computer (OBC); 3) the Attitude control system; 4) the Transmitter; 5) the Receiver; 6) the Telemetry system; 7) and any on board experiments or transponders. Telemetry is used to monitor all the major systems. When any component is not functioning correctly it is important to quickly correct the problem. A satellite is an 'ecosystem', a system that must generate what it uses. The system must be kept in equilibrium or it will quickly fail. Determining the proper points to monitor, analyzing the telemetry, and using this analysis to keep the system in harmony will give the satellite its full controllable lifetime.

Basic Telemetry Description

A telemetry frame is the unit used to describe the collection of all the sampled points. The ideal frame is comprised of a group of attention characters, the header, all the data channels, the checksum and possibly a frame termination sequence. Most of the telemetry from amateur satellites contain all of these features. An individual data point is referred to as a channel. These data points are a measure of either the temperature at that point, the current passing through that point or the voltage present at that point. An analog to digital converter (ADC) is used to convert the temperature, current or voltage to a digital value that the On Board Computer (OBC) can store. Each ADC reads the analog value of a sensor a little differently, so it is necessary to calibrate each sensor/ADC connection. Figures 1 - 11 contain examples of many of the amateur satellite telemetry formats. First we will look at the major sections of a telemetry frame, then discuss the decoding of each of the formats of amateur satellite telemetry.

Attention characters

Attention characters are a sequence of characters used to signal the beginning of a new frame. When a receiving station begins to acquire satellite telemetry it has no way of knowing where in the data stream it is. Odds are it is in the middle of a frame. The attention characters tell the receiving system to start anew, to clear its buffer and begin a new frame sequence. AO-13 in PSK mode uses the ASCII sequence 39h, 15h, EDh, 30h, and in RTTY mode the traditional RYRYRYRYRY's. Many satellites use the 'HI HI' sequence in CW and ASCII mode.

Header Line

The header line follows the attention characters. It normally identifies the satellite and contains some type of date/time group. The time that the data was sampled by the microprocessor is as important as the data itself. When analyzing the data it is necessary to know or be able to find out things like: whether the sun was shining on the satellite or not; what mode the satellite was in; or where the satellite was in its orbit. UTC is used for both the time and the date for all the amateur satellites. The DOVE header line identifies the spacecraft, tells how long the current software has been running and gives the current UTC date and time. The AO-13 header line gives the same information, but adds a block or frame type. Often the date or both the date and time is coded to save memory space. It requires less power to transmit shorter data sequences. The decoding of the encrypted date/time groups for each satellite is covered in the format descriptions of the individual satellites.

Channel Data

This is the main objective for the telemetry transmission. In about half of the amateur satellite telemetry data fields the channel number is attached to the data. This is helpful in locating specific data and as a check. It does almost double the size of the telemetry data field, thus using quite a bit of power to transmit the extra characters. The actual data is transmitted as either a decimal, hexadecimal, octal or binary value. Different number bases are used by all of the amateur satellites. Often one satellite will send data in a variety of different number bases in a single frame. These are consistent and documented, so as long as you have the correct documentation, decoding should be a trivial exercise. As mentioned in the introduction to this section, each channel has a different calibration equation. These calibration equations are initially determined on the ground for each channel prior to launch. So when the data for each channel is received it must be normalized by its own calibration equation to give the true value of the channel measured. In addition to the analog data, status data is sent in the telemetry channels. Status is a binary function (ON or OFF), so the status points are usually transmitted as hexadecimal or octal values. These are then broken down by bit position. The state of each status function is then assigned by the 1 or 0 value in that bit position. Example #2 goes through the process of decoding status data.

Checksum

A checksum is used to validate the data and can be attached to each channel or encompass the entire frame. The data is useless unless it is valid. An even worse situation exists if erroneous data is considered valid and incorrect decisions are made because of this error. Some level of error checking is necessary, the difficult decision is how much to use. There are a number of different methods to assure the validity of the data. Unfortunately the better the error checking scheme the more characters the error checking requires. This can get to the point where there are more bits used in the error check than in the data it is validating. Obviously there has to be some middle ground that gives a reasonable level of integrity without using a large number of characters. Basically the checksum is some type of sum or EOR of the data and a comparison of the result with a known value. The checksum either passes and the data is valid or fails and the data is invalid. Telemetry sent in AX.25 protocol have the checksum as part of the packet. Often there is a terminating sequence to signal the end of the telemetry frame. The Microsats use the WASH line for this purpose.

Telemetry Decoding

The following descriptions for the decoding of amateur satellite telemetry begins with the telemetry format that requires the simplest receiving station setup and proceeds to the most complex setup. The simple to complex station determination is based upon both the equipment needed and the skills necessary to operate the equipment. Currently there are 8 distinct telemetry receiving station systems necessary to get data from all the active satellites. Many of the components are usable in more than one of the different systems. I have prepared a *Handbook of Amateur Satellite Telemetry* that contains: a thorough description of the telemetry from all of the active amateur satellites; calibration equations for each satellite; actual data decoded from each of the satellites; output examples from available telemetry decoding software; construction hints for most of the amateur satellite telemetry decoding units; large amateur satellite telemetry glossary and extensive amateur satellite telemetry bibliography. The handbook is available from the author. Table 2 lists the station equipment necessary to receive telemetry from each of the amateur satellites. Table 3 lists the telemetry beacon frequencies and telemetry transmission modes for all of the active amateur satellites. The eight current amateur satellite telemetry formats are:

Fig. 1 — Sample RS-10 CW telemetry.

RS10	IS80 NR25 ID19 NG45 IW00 IK00 IO00
	AS35 AR23 AD38 MG31 AU00 AW46 AO89 RS10

1) Digitized speech UO-11, DO-17
2) CW RS-10/11, AO-13, FO-20, LO-19
3) RTTY AO-13
4) 1200 bps AFSK packet DO-17
5) 1200 bps AFSK ASCII UO-11
6) 400 bps PSK ASCII AO-13
7) 1200 bps PSK 8 bit packet AO-16, WO-18, LO-19, FO-20
8) 9600 bps AFSK ASCII UO-14

1. Digitized Speech Telemetry

Digitized speech telemetry has the simplest requirements for both equipment and operator skill of all amateur satellite telemetry. It also is the least efficient, has the least resolution and is the most prone to error. It is transmitted as an educational tool and to interest people in satellite activities. Data values from each channel are already calibrated when spoken, so writing down the data for each channel is all that is required. Digitized speech offers a fun, simple way to pursue an interest or to interest others in satellite operation. UO-11 does not transmit this form of telemetry very often.

2. CW telemetry

Reception equipment requirements for CW telemetry are minimal, but require more operator skill to receive the telemetry than the digitized speech telemetry. The data resolution is not as high as the other telemetry forms and no error checking is used. Most of the CW telemetry transmissions don't transmit the date/time group or label each channel. It is up to the operator to add the date/time group to any CW telemetry received. Data values for each channel must be calibrated using a specific calibration equation. Each satellite has its own set of calibrations equations for each channel. An example of how to use the calibration equations is found following section 4 in Example #1. The CW calibration equations and complete decoding of the CW data are available in the *Handbook of Amateur Satellite Telemetry*. CW telemetry on the later satellites is transmitted more in deference to tradition than as a efficient method of satellite monitoring. The RS-10/11 telemetry beacon is most often found on one of the mode A beacon frequencies. Station equipment requires no more than a standard HF station for Mode A. The beacon for all modes is also used as the ROBOT CQ beacon and any QSO's interrupt the telemetry. The CW speed of 20 wpm and the fact that most ham receivers are not as sensitive at 29 MHz makes the RS-10/11 data a little more difficult to copy. Many stations use an inexpensive 10 M preamp to aid in data reception. RS-10/11 sends data for 16 analog values and 16 status points. Figure 1 has a sample of RS-10/11 CW telemetry.

FO-20 CW telemetry is also sent at 20 wpm, but there is less noise on 435 MHz than on 29 MHz, so the signal is easier to receive. The equipment needed for reception is slightly more than the standard UHF station. I have and still use inexpensive receive converts to capture data with a great deal of success. FO-20 CW telemetry is sent one frame/minute while the satellite is in Mode JA. The data consists of 12 analog items and 38 status items. Notice that FO-20 data does not contain either a satellite identification header or date/time group. The operator must record this data himself. Figure 2 has sample FO-20 telemetry data.

Figure 2. Sample FO-20 CW telemetry June 6, 1990.

HI HI	155 148 168 168
	285 284 242 262
	348 350 350 350
	407 437 410 437
	520 536 500 500

AO-13 CW telemetry is only transmitted during Mode B and at only 10 wpm. The equipment necessary to receive the telemetry is the most complex of all the CW telemetry receive stations. AO-13 tends to send more information bulletins/schedules than CW telemetry. LO-19 sent CW telemetry for the first few months after launch. The data values were sent in compressed Morse. This mode may or may not be reactivated.

3. RTTY Telemetry

AO-13 currently is the only amateur satellite that routinely transmits telemetry in RTTY. The transmissions occur during both Mode B and Mode J operation. These transmissions begin at 15 and 45 minutes past the hour for both Modes B and J. During Mode J operation, RTTY replaces the CW transmissions on the hour and half

```
RYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRY
RYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRY
RYRYRYRYRYRYRYRYRYRYRYRYRYRYRYRY
Z  HI. THIS IS AMSAT OSCAR 13
      20.45.29  4568
.0026    .0000    .0171

64  14   0   1   13  229 0

235 7    155 135 193 7   150 82   200 7
137 7    116 7   151 31  7   7    156 7
12  7    138 62  18  7   141 69   118 7

138 7    169 136 139 57  134 141 141 7
137 147 140 18   227 133 127 7   179 137
134 7    76  140 139,141 14  130 130 207
HI THIS IS AMSAT OSCAR 13 04JUL90
AO13 TRANSPONDER SCHEDULE
MODE B  MA 003 TO 165
MODE JL MA 165 TO 190
MODE LS MA 190 TO 195
MODE S  MA 195 TO 200
MODE BS MA 200 TO 205
MODE B  MA 205 TO 240
OFF     MA 240 TO 003
OMNIS   MA 240 TO 060
```

Fig. 3 — Sample AO-13 RTTY telemetry from July 4, 1990.

hour. These transmissions last for approximately 5 minutes, then the telemetry returns to PSK mode. Both telemetry and bulletins are transmitted, usually alternating. RTTY requires a more complex receiving station than digitized voice or CW, but provides more data in the same amount of time. The AO-13 telemetry is sent at 50 baud, standard 170 Hz shift, UnShift ON Space OFF or disabled, USB on 70cm and LSB on 2m. The AO-13 RTTY telemetry contains the first 60 of 128 available channels plus the Safety Information Word, transponder status byte and the command count. Unless the satellite is very close to the Earth a fairly sophisticated station is necessary. Publications that contain the calibration equations for all 128 channels are available from AMSAT-NA or AMSAT-UK. Project OSCAR has IBM software available that takes an ASCII file of the RTTY data and decodes it. Figure 3 has sample AO-13 RTTY telemetry. This telemetry is very similar to the AO-13 PSK telemetry and is decoded the same way (See section 6). The Z block designation says this is RTTY data. Notice that a message immediately follows the telemetry.

4. 1200 BPS AFSK Packet Telemetry

DOVE (Digital Orbiting Voice Encoder) or DO-17 is once again transmitting AX.25 telemetry data on 145.825 MHz FM. The data can be collected with a standard 2M FM receiver and 1200 bps AFSK packet TNC. A good terminal program can be used to store the received data to disk for later analysis. Dove uses 59 (3A hexadecimal) telemetry channels to report the current condition of the satellite. Each telemetry frame/block begins with the DOVE telemetry frame collection time line. This line contains the satellite identifier, uptime and date/time group.

Example. #1

```
channel 1Bh has a value of 7Fh (127 base 10),  solving using the general Dove
formula:
Y = 1.8381 + 127( -0.003845 + (127*0)) -> 1.8381 + ( -0.488315) -> 1.35 V
On Mon Jul 23 1990 03:52:18 UTC, the voltage of DOVE Battery #6 was 1.35 volts.

DOVE channel 35h has data value of AAh.
AAh -> Ah = 10 decimal, so 10 x 16 = 160   +  (Ah or 10) = 170 data value

channel  description       A            B           C             unit
35       +Y Array Temp   +101.05      -0.6051      0.000          Deg. C

Y = A + X( B + (X*C))
Y = 101.05 + 170( -.6051 + (170*0))
Y = 101.05 + 170( -.06051 + 0)
Y = 101.05 + ( -102.867 )
Y = -1.10 degrees C
The temperature of the +Y side panel was  -1.10 degrees C.

            ===========================================

Channel      Calibration equations

6       10.427 + 111( -0.09274 + (X * 0)) --> 0.1328 kHz receiver A DISC
7       0.0 + 73( 1.0 + X(0)) --> 73 counts on receiver A S meter
A       0.0 + 162(0.0305 + X(0)) --> +4.941 V on the +5 V Bus
B       0.0 + 220(0.000100 + X(0)) --> .022 A or 22 mA +5V receiver
13      0.0 + 1(0.1023 + X(0)) --> +0.1023 V on +Z array

16      1.7932 + 155( -0.0034084 + (X * 0)) --> 1.264 V on Battery #1
17      1.7978 + 154( -0.0035316 + (X * 0)) --> 1.253 V on Battery #2
18      1.8046 + 156( -0.0035723 + (X * 0)) --> 1.247 V on Battery #3
19      1.7782 + 155( -0.0034590 + (X * 0)) --> 1.242 V on Battery #4
1A      1.8410 + 152( -0.0038355 + (X * 0)) --> 1.258 V on Battery #5
1B      1.8381 + 148( -0.0038450 + (X * 0)) --> 1.269 V on Battery #6
1C      1.8568 + 160( -0.0037757 + (X * 0)) --> 1.252 V on Battery #7
1D      1.7868 + 156( -0.0034068 + (X * 0)) --> 1.255 V on Battery #8

26      -0.01075 + 0( +0.00215 + (X * 0)) --> -0.01075 mA from -X array
27      -0.01349 + 0( +0.00270 + (X * 0)) --> -0.01349 mA from +X array
28      -0.01196 + 0( +0.00239 + (X * 0)) --> -0.01196 mA from -Y array
29      -0.01141 + 0( +0.00228 + (X * 0)) --> -0.01141 mA from +Y array
2A      -0.01693 + 0( +0.00245 + (X * 0)) --> -0.01693 mA from -Z array
2B      -0.01137 + 0( +0.00228 + (X * 0)) --> -0.01137 mA from +Z array
no current from any of the solar panels, so the satellite is in eclipse

14      101.05 + 181( -0.6051 + (X * 0)) --> -8.473 Deg C receiver temperature
15      101.05 + 163( -0.6051 + (X * 0)) --> +2.418 Deg C (+X) receiver temperature
2F      101.05 + 164( -0.6051 + (X * 0)) --> -1.81  Deg C battery #1 temperature
34      101.05 + 202( -0.6051 + (X * 0)) --> -21.18 Deg C PSK TX HPA temperature
35      101.05 + 170( -0.6051 + (X * 0)) --> -1.81 Deg C +Y array temperature
38      101.05 + 191( -0.6051 + (X * 0)) --> -14.5 Deg C +Z array temperature
```

The uptime is the length of time the current software has been running. The date/time group is the current UTC time. The 59 data channels follow. Note that the channel numbers and the channel data are hexadecimal numbers (hex or base 16). This is because the onboard microprocessor operates in hexadecimal and it is more efficient to transmit than base 10.

Dove breaks the 59 telemetry channels up into 2 groups. The first group is composed of channels 00 - 20h and the second group is 21h - 3Ah. These are followed by the status channel data and the termination line labeled WASH. The wash label was coined because of its function, to clean out the buffer. The termination line lists both the current address and the number of error detections and corrections performed. These transmissions occur every 10 to 20 seconds, so on a good pass you could receive about 90 sets of data. I have chosen the DOVE telemetry on which to do extensive decoding because it offers: 1) a good, generalized telemetry format; 2) the data is easily captured; and 3) it provides quite a bit of interesting data. Figure 4 contains a current frame of DOVE telemetry. Example #1 decodes the data in Figure 4 using the calibration equations in

```
DOVE-1>TIME-1:PHT: uptime is 001/01:10:22.  Time is Mon Jul 23 03:52:18 1990


DOVE-1>TLM:00:59 01:58 02:88 03:30 04:56 05:56 06:6F 07:49 08:6C 09:6A 0A:A2
0B:DC 0C:E8 0D:D6 0E:00 0F:24 10:C8 11:88 12:00 13:01 14:B5 15:A3
16:9B 17:9A 18:9C 19:9B 1A:98 1B:94 1C:A0 1D:9C 1E:21 1F:5D 20:BC


DOVE-1>TLM:21:8E 22:78 23:1C 24:1C 25:35 26:00 27:00 28:00 29:00 2A:00 2B:00
2C:00 2D:30 2E:00 2F:A4 30:D2 31:A4 32:06 33:28 34:CA 35:AA 36:B1
37:B0 38:BF 39:85 3A:87


DOVE-1>STATUS: 80 00 00 85 B0 18 55 02 00 30 00 00 09 0B 3C 05 29 5A 03 04
DOVE-1>LSTAT:I P:0x3000 o:0 1:13081 f:13081, d:0

DOVE-1>WASH:wash addr:3640:0000, edac=0x3f
```

Fig. 4— Sample DOVE telemetry.

TABLE 1 — DOVE telemetry decoding formulae.

Channel	Label	A	B	C	units
0	Rx E/F Audio(W)	+0.000	+0.0246	0.000	V(p-p)
1	Rx E/F Audio(N)	+0.000	+0.0246	0.000	V(p-p)
2	Mixer Bias V:	+0.000	+0.0102	0.000	Volts
3	Osc. Bias V:	+0.000	+0.0102	0.000	Volts
4	Rx A Audio (W):	+0.000	+0.0246	0.000	V(p-p)
5	Rx A Audio (N):	+0.000	+0.0246	0.000	V(p-p)
6	Rx A DISC:	+10.427	-0.09274	0.000	kHz
7	Rx A S meter:	+0.000	+1.000	0.000	Counts
8	Rx E/F DISC:	+9.6234	-0.09911	0.000	kHz
9	Rx E/F S meter:	+0.000	+1.000	0.000	Counts
A	+5 Volt Bus:	+0.000	+0.0305	0.000	Volts
B	+5V Rx Current:	+0.000	+0.000100	0.000	Amps
C	+2.5V VREF:	+0.000	+0.0108	0.000	Volts
D	8.5V BUS:	+0.000	+0.0391	0.000	Volts
E	IR Detector:	+0.000	+1.000	0.000	Counts
F	LO Monitor I:	+0.000	+0.000037	0.000	Amps
10	+10V Bus:	+0.000	+0.05075	0.000	Volts
11	GASFET Bias I:	+0.000	+0.000026	0.000	Amps
12	Ground REF:	+0.000	+0.0100	0.000	Volts
13	+Z Array V:	+0.000	+0.1023	0.000	Volts
14	Rx Temp:	+101.05	-0.6051	0.000	Deg. C
15	+X (RX) temp:	+101.05	-0.6051	0.000	Deg. C
16	Bat 1 V:	+1.7932	-0.0034084	0.000	Volts
17	Bat 2 V:	+1.7978	-0.0035316	0.000	Volts
18	Bat 3 V:	+1.8046	-0.0035723	0.000	Volts
19	Bat 4 V:	+1.7782	-0.0034590	0.000	Volts
1A	Bat 5 V:	+1.8410	-0.0038355	0.000	Volts
1B	Bat 6 V:	+1.8381	-0.0038450	0.000	Volts
1C	Bat 7 V:	+1.8568	-0.0037757	0.000	Volts
1D	Bat 8 V:	+1.7868	-0.0034068	0.000	Volts
1E	Array V:	+7.205	+0.07200	0.000	Volts
1F	+5V Bus:	+1.932	+0.0312	0.000	Volts
20	+8.5V Bus:	+5.265	+0.0173	0.000	Volts
21	+10V Bus:	+7.469	+0.021765	0.000	Volts
22	BCR Set Point:	-8.762	+1.1590	0.000	Counts
23	BCR Load Cur:	-0.0871	+0.00698	0.000	Amps
24	+8.5V Bus Cur:	-0.00920	+0.001899	0.000	Amps
25	+5V Bus Cur:	+0.00502	+0.00431	0.000	Amps
26	-X Array Cur:	-0.01075	+0.00215	0.000	Amps
27	+X Array Cur:	-0.01349	+0.00270	0.000	Amps
28	-Y Array Cur:	-0.01196	+0.00239	0.000	Amps
29	+Y Array Cur:	-0.01141	+0.00228	0.000	Amps
2A	-Z Array Cur:	-0.01653	+0.00245	0.000	Amps
2B	+Z Array Cur:	-0.01137	+0.00228	0.000	Amps
2C	Ext Power Cur:	-0.02000	+0.00250	0.000	Amps
2D	BCR Input Cur:	+0.06122	+0.00317	0.000	Amps
2E	BCR Output Cur:	-0.01724	+0.00345	0.000	Amps
2F	Bat 1 Temp:	+101.05	-0.6051	0.000	Deg. C
30	Bat 2 Temp:	+101.05	-0.6051	0.000	Deg. C
31	Baseplt Temp:	+101.05	-0.6051	0.000	Deg. C
32	FM TX#1 RF OUT:	+0.0256	-0.000884	+0.0000836	Watts
33	FM TX#2 RF OUT:	-0.0027	+0.001257	+0.0000730	Watts
34	PSK TX HPA Temp	+101.05	-0.6051	0.000	Deg. C
35	+Y Array Temp:	+101.05	-0.6051	0.000	Deg. C
36	RC PSK HPA Temp	+101.05	-0.6051	0.000	Deg. C
37	RC PSK BP Temp:	+101.05	-0.6051	0.000	Deg. C
38	+Z Array Temp:	+101.05	-0.6051	0.000	Deg. C
39	S band HPA Temp	+101.05	-0.6051	0.000	Deg. C
3A	S band TX Out:	+0.0451	+0.00403	0.000	Watts

Table 1.

Once the data has been collected the analysis can begin. Table 1. lists the calibration equations necessary to decode the DOVE telemetry. The DOVE-1>TLM: address identifies this as telemetry. The line contains first the channel followed by the data value for that channel. Note that both the hex channel number and the hex data are separated by a colon. Channel 00h has a data value of 59h, which we need to convert to decimal for substitution into the calibration equation to compute the true value of the channel.

Using Table 1 the general formula used to convert DOVE telemetry is:

Y = Cx**2 + Bx + A or Y = A + X(B + (X*C)),

where A, B, & C are the calibration constants for each channel and X is the decimal data value received for that particular channel. This is a slightly different arrangement of the calibration constants than have previously been published. I changed them because a number of people I gave the equations to substituted the constants incorrectly.

This example uses the DO-17 telemetry from Figure 4. Look through the list of labels in Table 1 and select a channel that looks interesting. Find the data for the selected channel in the telemetry frame (Figure 4.), convert the hexadecimal data value for the selected channel to decimal. Then substitute the value for X, and substitute the selected channel constants for A, B, & C in the general calibration equation. Finally solve the equation and append the descriptive label to complete the decoding of the selected channel.

The general formula used to convert DOVE telemetry is : Y = A + X(B + (X*C))

5. 1200 BPS AFSK ASCII Telemetry

UO-11 (UoSat-2) is currently the *grande dame* of the active amateur satellites. It was designed by the UoSAT Spacecraft Engineering Research Unit at the University of Surrey, England. Launched on 1 March 1984, it is still alive, very well and sending quite a bit of very interesting telemetry. The more data I gather and the more I learn about the experiment aboard the satellite, the more impressed I am with this UoSAT-2. Since UO-11 is an educational/experimental amateur satellite most of its function is to gather data and transmit the experimental data. UO-11 also has a DCE (Digital Communication Experiment, digital store and forward system) aboard that was sending packet data around the world before most 'hams' had even heard of the word packet. Also aboard is a CCD camera that has been taking pictures of the Earth, converting them to digital data and sending them back to Earth for over 6 years. The Space Dust experiment logs the number and momentum of small particles hitting the spacecraft. Studies of the Earth's magnetic field are done by the Particle Detectors and Wave Correlator Experiments. All this data comes down via a simple modulation scheme of sending ASCII data by shifting between 1200 and 2400 Hz to convey the 1's and 0's. This ASCII data comes down at 1200 baud and can be copied by a Bell 202 modem, the bit sense will need to be reversed though. This is NOT the same 1200 baud modem you probably are using with your computer, you have a Bell 212 modem that uses a different modulation scheme. James Miller has published the schematic for a good demodulator in *Electronics and Wireless World* and *Ham Radio* magazines. AMSAT-UK also sells a printed circuit board for the builders among you. There are also simple modifications to the AEA PK-232 that allow it to copy UO-11 telemetry. The data is sent at 1200 bps, 7 data bits, even parity.

As important, as the UO-11 demodulator, is a good receiving station. The ability to track the satellite from horizon to horizon and a signal with a good S/N ratio are necessary to get consistent telemetry. Any investments in a receiving station are the best ones you can make. The actual satellite telemetry contains 70 channels of data. These are sent in 7 lines of 10 channels each. 59 of these channels contain analog measurements, with the remaining 11 channels reporting 96 status points. Figure 6 is an actual UO-11

Fig. 6 — UO-11 telemetry.

```
UOSAT-2                 9008046141320

00516201395E02232103572304053205037106020407052008045909040D
104984113355120003130662140702155067161868174 90B18483619524B
2051422122472266002300012400062500072609582746 9E28474D29499F
302742310367322 85E3357313400703527303632153742 8A38470839505A
40765041120642642643062344167045000146000247490E48505C49475B
50547351107252682B5368915466235500005600035749785849225949 54
6083E3615FC1625F4A633305644402651E0C661B4E67700668000E69000F
```

telemetry frame. The satellite identifier is obvious, but the date/time group may be a bit cryptic. It is in YYMMDDWHHMMSS format. (UTC year, month, day), day of the week (Sunday = 0), HHMMSS (UTC hours, minutes, seconds). So the data in Figure 6 was gathered Saturday 4 August 1990 at 14:13:20. Each channel's data is composed of 5 digits. The first two are the decimal channel number. Three decimal data values follow. The last character is the hex checksum for the channel, so the ground stations can validate the data for each channel. The data values are calibrated using the UO-11 calibration equations available from AMSAT-UK in a very informative publication named *UOSAT SPACECRAFT DATA BOOKLET* and in the *Handbook of Amateur Satellite Telemetry.* There are also a number of interesting bulletins sent as part of regular schedule of telemetry from UO-11.

One of the biggest problems with telemetry reception is that you only get data for the limited time that the 'bird' is in view. The designers of UoSAT-2 attempted to solve this with their DSR experiment (Digital Store and Readout). This experiment stores telemetry data for selected channels for an entire orbit, or a CCD picture, or particle counter experiment data and outputs them in an error encoded format. Thus WOD (Whole Orbit Data) was developed to allow the receiving stations to know what happens to particular onboard devices during an entire orbit. The WOD is usually composed of 4 - 6 channels of data that are sent in a very clever manner. The complete data set is divided into 4 sections. Each section sends data 8 time units apart. If the data takes a noise hit or the signal fades a complete area of the whole orbit data is not lost. The other 3 sections will each have 2 of the remaining 6 time units of data that were hit. This allows the entire orbit profile to be constructed from just one section (1/4 of the data), albeit with a slight lost in resolution. The time unit for UoSAT-2 (UO-11) at 1200 baud is 4.84 seconds. Figure 7 shows an abbreviated example of WOD received from UO-11. This data records the solar cell current for the (-Y, +Y, -X, +X) sides of the satellite. The complete data set will be referenced later to demonstrate telemetry analysis. The complete set of data is formed by interleaving as much of the four sections as was captured. You will rarely be able to receive the entire WOD on one pass, but you may be able to get at least 2 partial and 1 complete sections. Figure 7 is such an example. The ... sequence symbolizes that data was omitted. The line that begins with '0000' is the channel identification frame. The first 4 digits are the hex number of time units into the sample, then each group of three defines the channel and the last 2 are the checksum. From Figure 8 you can see that this WOD is for channels 000, 010, 020, 030 and 5B checksum. Figure 8 takes the data from Figure 7 and rearranges it into its three sections. Spaces have been added between channels to aid in data identification. Notice that in section 1 the data is at time intervals 1 and 9; in section 2 at time intervals 5 and D; and section 3 at time intervals 3 and B. The uncopied section must have been at time intervals 7 and F. The WOD start and stop times are sent in the telemetry bulletins. Figure 9 has a portion of a UO-11 bulletin.

Fig. 7 — partial UO-11 WOD data.

```
0479522522522522A2
048152152149852227
048925651643952158
049124251551845552
049952152152135356
    ...
0000000100200305B
0005516421181520CF
000D333514162520D7
001513551451752115
001D43351851922307
    ...
047552252252252 2A6
047D5225225225229E
0485397519392521BF
048D202515517521CA
049537151851938 4EC
    ...
0000000100200305B
000351617724852 2B$
000B455517134520E6
0013150514448520CD
001B351515518260B3
```

Example #2 — Selective decoding of UO-11 telemetry.

```
Channel 00 of UO-11 is the -Y solar array current.  The first 5 characters of
data line #1 make up the channel 0 data package.  00 is the channel number, 516
is the data, and 2 is the hex checksum. To calibrate the data, substitute the
data for N in the calibration equation for channel 0:

I = 1.9(516 - N) --> 1.9 (516 - 516) -> 0 mA
tells us that solar panel -Y is in the dark.

Channel 28 is the temperature of the -Y panel.  Data line #2 contains the
information for channel 28 - 28474D.
The data value 474 is substituted into the equation: T = (480 - N) / 5 ->
      (480 - 474) / 5 -> 1.2 deg C for panel -Y.
This says that panel is cooling or warming, by looking at the previous and post
frame we can tell which.

The Digital Status Channels (60 - 67) contain 12 status items per channel.  The
data is 3 hex digits that are broken down into binary.  Channel 60 has data 83E
which equals
(MSB) 1000 0011 1110 (LSB) binary.  The status definitions for channel 60 are:

            Function                                0      1
(MSB) 145 MHz General Beacon power                 OFF    ON
      435 MHz Engineering Beacon power             OFF    ON
      2401 MHz Engineering Beacon power            OFF    ON
      Telemetry channel mode select                Run    Dwell

      Telemetry channel dwell address load         OFF    ON
      Telemetry channel dwell address source       GND    Computer
      Primary Spacecraft Computer power            OFF    ON
      Primary Spacecraft Computer error count      bit 1

      Primary Spacecraft Computer error count      bit 2
      Primary Spacecraft Computer bootstrap        UART   PROM
      Primary Spacecraft Computer error count      bit 3
(LSB) Primary Spacecraft Computer bootstrap        A      B

Channel 60 tells us that the 145 General beacon is ON, the 435 and 2401 beacons
  are OFF.  Channel mode select is in RUN
Channel dwell address load is OFF
Channel dwell address source is Ground
Primary spacecraft power is ON
Computer error count is 111 or 7
Bootstrap is from PROM A
```

```
                                  section 2                        section 3
                           0000 000 010 020 030 5B        0000 000 010 020 030 5B
                           0005 516 421 181 520 CF        0003 516 177 248 522 B$
                           000D 333 514 162 520 D7        000B 455 517 134 520 E6
                           0015 135 514 517 521 15        0013 150 514 448 520 CD
                           001D 433 518 519 223 07        001B 351 515 518 260 B3

       section 1                      ...
0479 522 522 522 522 A2    0475 522 522 522 522 A6
0481 521 521 498 522 27    047D 522 522 522 522 9E
0489 256 516 439 521 58    0485 397 519 392 521 BF
0491 242 515 518 455 52    048D 202 515 517 521 CA
0499 521 521 521 353 56    0495 371 518 519 384 EC
```

Fig. 8 — UO-11 WOD data from Fig. 8 rearranged.

```
* UOSAT-2 OBC STATUS INFORMATION *

DIARY OPERATING SYSTEM V3.1 SMH MLJM MSH

 Today's date is 17 /8 /90  (Friday)
 Time is 1 :34 :24 UTC
 Auto Mode is selected
 Spin Period is - 226
 Z Mag firings  = 0
 + SPIN firings = 31
 - SPIN firings = 22
 SEU count      = 705
 RAM WASH pointer at 170A
 WOD commenced 17 /8 /90 at 0 :0 :8
 with channels 0 ,10 ,20 ,30 ,
 Last cmnd was 109 to 0 , 0
 Attitude control initiated, mode 1
 Data collection in progress
 Digitalker active

 **** UoSAT-OSCAR-11 BULLETIN - 218

            07 August 1990   ****
```

Fig. 9 — Portion of UO-11 bulletin.

6. 400 BPS PSK ASCII Telemetry

This is the predominant form of telemetry on AO-13, 40 minutes out of each hour. The station complexity increases a great deal here because a specialized piece of equipment is needed and a good receiving station is mandatory. The operator skills required are the ability to track the satellite and tune in the signal. Again the investment in the station's receiving capability is one of the best you can make. A 400 bps PSK demodulator interfaced to a TNC is necessary for AO-13 PSK telemetry reception. These are available in kit form or as a working unit, both need to be interfaced to a TNC though the modem disconnect header. The telemetry from AO-13 is extensive and provides quite a bit of interesting data about the satellite. Bulletins and messages (between the control stations) alternate with the telemetry. Two good programs for the IBM are available to decode and log the telemetry. The P3C.EXE program from AMSAT-Australia is geared toward realtime decoding. The channel data is organized by categories and placed in boxes on the screen. This program is available from AMSAT-UK and Project OSCAR. The W9FMW AO-13 program is designed for post-processing and makes a very nice printout or ASCII file of the telemetry. This is available from AMSAT-NA.

AO-13 sends its telemetry in 512 byte labeled blocks/frames. These frames are labeled as K, L, M, N, Q, Y blocks. RTTY is sent in Z blocks. Text messages are sent in the K, L, M, and N blocks. The Q blocks contain 128 analog values in hexadecimal. Y blocks are the first 64 of the 128 channels. The fact that the data is sent as 8 bit hexadecimal makes it a little tricky to store with a terminal program. I had quite a bit of trouble with ProComm Plus until I discovered that the log to file function did not log all the ASCII control characters. The ASCII download function needed to be used instead. AMSAT-UK has an excellent publication on AO-13 by RWL Limebear, *AMSAT-UK OSCAR 13 OPERATIONS AND TECHNICAL HANDBOOK*. This publication has a great deal of detailed information on AO-13 and lists the telemetry calibration equations. Figure 10 is an AO-13 Q block that has all 128 channels of data. The 128 channel data in this Q block have been converted to decimal. The 7 normally means that no data is available, but it also is the ASCII terminal BELL character. So be prepared for a great deal of beeping. The unusual number in the date/time group is the date. Here it is encoded as the number of days since 1 JAN 1978 (1 JAN 1990 = 4382). So the AO-13 frame in Figure 10 was sent on day 199 of 1990 or 18 JUL 1990. Lines 2 and 3 are status items to quickly alert the command stations to a potential problem. There are no channel identification numbers, it is done strictly by position. There is an elaborate checksum (CRC, cyclic redundancy check) sent after the block to determine the validity of the entire frame.

7. 1200 BPS PSK Packet Telemetry

The telemetry form of choice for the Microsats and FO-20 is 1200 bps PSK packet. This form has evolved to be among the most efficient and complex to decode. The range of equipment needed and the skill of the operator are also among the most advanced. This challenging aspect of the hobby is what makes it interesting for many of us. The data is sent as 8 bit hex and ASCII frames interspersed between the packet BBS or CCD picture data download. The equipment needed to receive the Microsats and FO-20 is actually the same equipment needed for FO-12. See we don't always have to re-equip the station with each new satellite.

Decoding the Microsats N4HY has written a program to decode all the Microsat telemetry, TLMDC.EXE available on CompuServe's HAMNET, DRIG BBS or from AMSAT-NA. The calibrating equations are very similar to those of DOVE and have been published a number of places. The DOVE telemetry in Figure 11a, recognizable by the TLM address, is actually sent as a stream of digits with no spaces, carriage returns or linefeeds. I altered the format to make it easier to reference and fit on the page. Both the channel identification and data are one hexadecimal byte each. Channel 0 in Figure 11a has a data value of 7A. Convert this to decimal and substitute in the appropriate calibration equation. Examples of this process are found in Example #1. WO-18 has a number of interesting experiments aboard that send their data as telemetry. The CCD camera experiment sends pictures taken of the Earth from WO-18 in AX.25 packet frames. Each frame is numbered and reassembled into a picture by WEBERWARE V1.0 software at the receiving station. Other experiments sending telemetry include:

1) The impact sensor experiment that samples the impact counter and the current readings at 5 second intervals. Each impact will increase the count by about 16.

2) The horizon intercept sensor has 2 photocells with a field of view of 10 degrees each. The photocells are angled so that they cross about a foot in front of the spacecraft. They are used to determine when the spacecraft is pointed toward the Earth and

```
Q  HI, THIS IS AMSAT OSCAR 13                             02:39:31  4581
#0026   #0020   #017A
64  9  0  1  17  230  0

 193   7 152   7 193   7 165 115 200   7 136   7 100   7 153  29
   7   7 138  54   9   7 136 136  16   7 139 151 116   7 137   7
 147 134 136   7 220 149 134   7  75 149 134 165 227 132 127  55
 179 133 139  94 146 144 138   7  13 141 125   7 208 140 132   7
  64   9   0   1  17 230   0   0  10   3 105  84   5  40  65  32
  65   0 152   0 148   0  38  55   0 205   3   5   0   0  32   0
   0 250   0 100  14 210  65   6  14  33  39   2 229  17   1   0
   0   0   1   0   0   0   1   0   0   0   1   0  38   0  17   0
```

Fig. 10 — Sample AO-13 PSK telemetry data Q block.

```
WEBER-1>TIME-1:PHT: Uptime is 089/09:25:25.  Time is Sat Aug 18 04:40:36 1990
                *
WEBER-1>STATUS:00000085B01888010093E7F507093C058E000000
WEBER-1>LSTAT:I P:0x1A9C o:0 1:193-4 f:1934
numerous photo frames sent here ...

              **
WEBER-1>TLM:007A01730271037E047C059006770786087B09370AA60BA70CD00DBE0E080F75
            10B411901206137014AD15A616891783188019851A7E1B891C801D8C1E271F60
            2094217A2278233F243B252C26002700280029002A002B002C002D302E002FA6
            30A631A73237336D34B035B036BA37AE38D539A63AA63BA13C9B3DFF3E493FD6
            40A641A542D6
                ***
WEBER-1>STATUS:00000085B01888010093E7F507093C058E000000

WEBER-1>CAST:


Current pic 5 is directly into sun.

Quite spectacular.  Will xmit it often

during the next few days.  Enjoy

73's WA3PSD

*(C5 C6 CC 26) character sequence sent between : and 0
**(E3 C6 CC 26) character sequence sent between : and 0
***(E3 C6 CC 26) character sequence sent between : and 0
```

Fig. 11a — Microsat telemetry.

not the sun. The Earth is the only object close enough to illuminate both sensors.

3) The flash D/A board experiment takes digital data from the onboard computer memory and produces an analog waveform. This waveform can modulate an FM signal, providing an experimental method of downloading a great deal of data quickly.

4) The magnetometer experiment notes changes in the Earth's magnetic field.

5) A light spectrometer to measure the spectral content of light entering through a slit in the (-Y) face. These experiments provide an excellent opportunity to investigate and learn something new.

Decoding FO-20 Packet Telemetry

During Mode JD operation of FO-20, 1200 bps PSK packet telemetry is transmitted. Telemetry from FO-20 is almost exactly like that of FO-12. This isn't unusual since they were built at the same time. FO-20 has had a few upgrades made to the FO-12 unit, especially to its power control system. Figure 11b is a sample of FO-20 telemetry. 8J1JBS is the packet address of FO-20, the RA says that the telemetry is realtime ASCII and the date/time group is obvious. The telemetry is sent interspersed between PBBS activity in 4 lines of 10 channels each. The data consists of 30 analog channels, three are not currently used. Thirty status points are sent in channels 30 - 39. The analog values are decimal values and taken straight into the calibration equations. The status channels are sent as octal values and then broken down into binary. The calibration equations for FO-20 are found on CIS HAMNET under FO20TL.ZIP and in the *Handbook of Amateur Satellite Telemetry.*

```
8J1JBS>BEACON:JAS1b RA 90/05/07 03:49:58
427 453 669 678 729 836 847 829 001 660
617 000 498 497 521 516 519 522 654 000
644 644 644 619 999 646 879 485 026 010
010 111 100 000 111 100 101 110 010 000
```

Fig. 11b — FO-20 telemetry data.

8. 9600 BPS AFSK ASCII Telemetry

Currently the UO-14 9600 bps AFSK telemetry is the most complex form of amateur satellite telemetry. Data sent at 9600 baud allows 6 times the data as a1 200 baud transmission in the same length of time. This means that 1000 characters could be sent at 9600 baud in the same amount of time as 167 characters sent at 1200 baud. Obviously this doesn't come easily. In addition to a special modem, the modem needs to be connected directly into the IF of the receiver and into the modulator of the transmitter. This mode is for the experimenter now, but before long we all will be able to utilize this technology. The crew at the University of Surrey with assistance from some of the AMSAT-NA gurus are again pushing the technology in the finest traditions of amateur radio.

Future Telemetry Formats

The variety of telemetry transmission formats and the specialized equipment required to receive satellite telemetry keep many people from exploring satellite telemetry. Technology is currently available to provide a general purpose signal conversion unit. DSP (Digital Signal Processing) will soon be widely available and will allow one piece of hardware to be able to copy nearly all digital transmissions. This includes SSTV, FAX, RTTY, PSK with Manchester encoding, even 9600 baud AFSK will be possible. The price of these units initially will be quite dear ($700 - $1000), but their versatility should make that more acceptable. The DSP units are essentially under software control and will be able to demodulate nearly anything they are programmed to do. Currently AEA, L. L. Grace Communications Products, and DRSI are working on units and plug-in boards.

Telemetry Analysis

After equipping your station, collecting the telemetry, calibrating the analog values and assigning status, it is time to begin the telemetry analysis. Analyzing the data is useful for two reasons. The first is to immediately determine when a system problem is developing. The second as a means of studying one channel, or a number of channels, and looking for patterns or interrelationships.

To perform system monitoring, a complete set of baseline values needs to be established. Each time telemetry is captured and decoded, choose a few channels to examine. Determine what the standard value or range is for each channel. The internal temperatures should remain fairly constant. The external temperatures should stay within a fixed range. The bus voltage should be fixed, and the transmit power should maintain a fixed range. Once baselines for all the channels have been determined, only a cursory examination of the telemetry is necessary to identify abnormal conditions.

System observations using telemetry requires closer examination of the data, deductive reasoning and some creative investigation. Whole Orbit Data (data from selected channels sampled and stored for an entire orbit) offers the most complete data set. The best place to begin is to take the data for a single channel and graph it verses time. Study the graph and look for trends. Then try to explain them. Using the printouts of the decoded data, a piece of graph paper, and a fair amount of time will give you a good graph. The problem is the same thing needs to be repeated each time new data is looked at or the scale changes. This kind of operation is the reason spreadsheets were designed. By inputting the data only once, you can filter only selected channels or groups of channels and instantly graph this selected data. This may require your learning to use a spreadsheet, but I guarantee you that you will spend much less time becoming familiar with the spreadsheet than doing 15 or 20 graphs by hand. Once you become comfortable with the spreadsheet you will be amazed at how creative you become. You can quickly manipulate the data and instantly graph it.

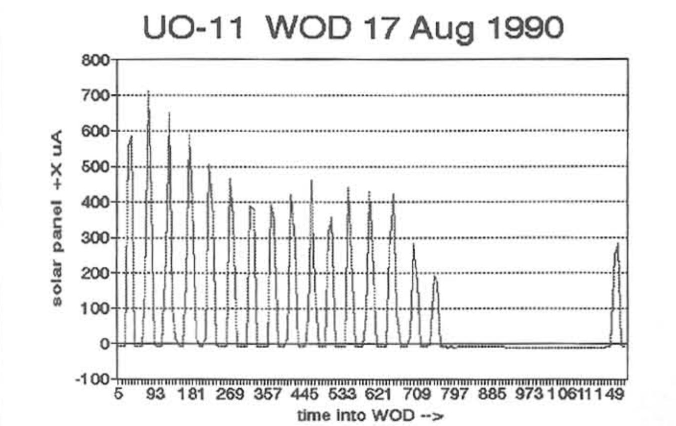

Fig. 12.

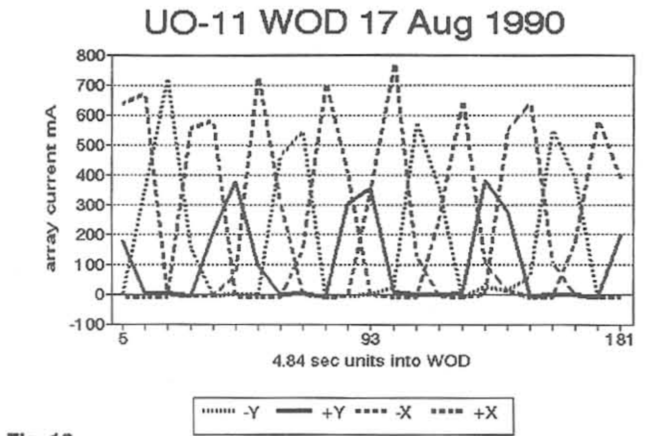

Fig. 13.

Figure 12 is a graph of channel 30h from the complete WOD (abbreviated in Figure 7). Channel 30h is the array current for side +X. Examining the graph, we see a series of current maximums. From the actual data we note that these occur every 8 samples. Using a sample rate of 4.84 seconds x 8 samples gives 38.72 seconds/ current max. We know that when the solar cells are illuminated they produce current. This is the rate that the satellite is spinning or 1.55 rpm. We can also notice a long period from 781 to 1149 in which no current is generated. The satellite must have been in eclipse. Running the N4HY QuikTrak program, setting the date/time for 17 Aug 1990 00:00 and placing the display in fast mode we can watch when the satellite goes into eclipse. Taking the start time of the WOD from the UO11 bulletin and using the 4.84 second/sample rate we calculate the beginning of the eclipse to occur at 63 minutes after data collection begins. The no current time lasts 368 time units, so we predict that the eclipse should end at 92.6 minutes after collection begins. Returning to the N4HY program we see the eclipse flag come on at 01:02:25 and goes off at 01:33:10. So the observed and calculated match very closely, and confirm our first telemetry analysis. Figure 13 is the graph of the current for all four sides simultaneously. We see the graphical representation of the power generation transfer as the satellite spins. One other observation, side +Y generates about 220 mA less current at peaks than the other three sides.

Try your hand at amateur satellite telemetry. You will find it a challenging and interesting area of satellite operation.

TABLE 2 — Compiled 8/90.

Amateur Satellite Telemetry Receiving/Decoding Equipment

1. Digitized Speech	
UO11, DO17	2M FM receiver and antenna
2. CW	
RS-10/11	HF/2M SSB receiver, stationary antenna, preamp helpful
LO19 **	435 MHz SSB receiver, stationary antenna, preamp helpful
FO20	435 MHz SSB receiver, stationary antenna, preamp helpful
AO13	2M SSB receiver, pointable antenna, preamp helpful
3. RTTY	
AO13	2M/435 MHz SSB receiver, pointable antenna, preamp, RTTY decoding unit, terminal/computer, RTTY data sent at 50 baud, 170 Hz shift, UnShift On Space OFF, USB on 70cm and LSB on 2m, software for IBM: AO13 RTTY decoding software for the IBM is available from Project OSCAR
4. 1200 bps AFSK Packet	
DO17	2M FM receiver, pointable antenna, preamp, standard TNC, terminal/computer, terminal setting: however the TNC is set - default 1200, 7, E, 1 software for IBM: TLMDC.EXE or NK6K decoding software from BBS or AMSAT-NA
5. 1200 bps AFSK ASCII	
UO11	2M FM receiver, pointable antenna, preamp, Bell type 202A modem, G3RUH demodulator, or modified PK-232, terminal/computer, terminal setting: 1200, 7, E, 1, software for IBM: by N5AHD from AMSAT-NA or G1WTW from AMSAT-UK
6. 400 bps PSK Packet	
AO13	2M/435 MHz SSB receiver, pointable antenna, preamp, 400 baud PSK demodulator to TNC, computer/terminal, terminal setting for G3RUH demodulator: 1200, N, 8, 1 software for IBM: by W9FMW AO13 telemetry decoding software from AMSAT-NA or P3C.EXE from AMSAT-UK or Project OSCAR
7. 1200 bps PSK Packet	
FO20	435 MHz SSB receiver, pointable antenna, preamp, 1200 baud PSK demodulator to TNC, computer/terminal, terminal setting - however the TNC is configured, software: none known
AO16, LO19	437 MHz SSB receiver, pointable antenna, preamp, 1200 baud PSK demodulator to TNC , computer/terminal, terminal setting - must use 8 data bits, software for IBM: TLMDC.EXE from BBS or AMSAT-NA
WO18	437 MHz SSB receiver, pointable antenna, preamp, 1200 baud PSK demodulator to TNC , computer/terminal, terminal setting - must use 8 data bits, software for IBM: TLMDC.EXE from BBS or AMSAT-NA, Weberware for picture reconstruction from AMSAT-NA
8. 9600 bps AFSK ASCII	
UO14	437 MHz FM receiver, pointable antenna, preamp, 9600 baud demodulator connected to receiver IF, computer/terminal software for IBM:

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TABLE 3 — Amateur Satellite Telemetry Beacons

SATELLITE	FREQ MHz	Mode	Transmission type
RS-10	29.360	KA, K, A	CW @ 20 wpm
	29.403	KA, K, A	CW @ 20 wpm
	145.857	T	CW @ 20 wpm
	145.903	KT	CW @ 20 wpm
RS-11	29.407	K	CW @ 20 wpm
	29.453	KA, K, A	CW @ 20 wpm
	145.907	T	CW @ 20 wpm
	145.953	T	CW @ 20 wpm
UO-11	145.825		1200 bps AFSK ASCII (FM)
	435.025		1200/4800 bps AFSK ASCII (FM)
AO-13	145.812	B	400 bps PSK ASCII(SSB)
	"	B	50 wpm RTTY (SSB)
	"	B	CW @ 10 wpm
	435.651	JL	400 bps PSK (SSB)
	"	JL	50 wpm RTTY (SSB)
UO-14	437.025	J	9600 bps AFSK ASCII (FM)
AO-16	437.025	J	1200 bps PSK ASCII (SSB)
	437.050	J	1200 bps PSK ASCII (SSB) (primary)
DO-17	145.825		1200 bps AFSK AX.25 packet (FM)
WO-18	437.075	J	1200 bps PSK HEX ASCII (SSB)
	437.100	J	1200 bps PSK HEX ASCII (SSB) (primary)
LO-19	437.125		CW (** not currently active **)
	437.150	J	1200 bps PSK HEX ASCII (SSB) (primary)
FO-20	435.795	JA	CW @ 20 wpm
	"	JA	1200 bps PSK ASCII (SSB)
	435.910	JD	1200 bps PSK ASCII (SSB)
BADR-1	144.028		
	145.825		

Poor Boy Satellite Station

By Allan J. Fox IV, N5LKJ

History

I am not one of those hams that has been chasing satellites for eons. Just the opposite, with less than one year's experience I am only a neophyte satellite chaser. However, I have the satisfaction of having helped several hams become avid satellite enthusiasts on a limited budget.

It all started about a year ago when a neighbor of mine Carl Kotila, WD5JRD, asked me to attend the Houston Com-Vention '87 with him.

That is where I met Jack Douglas, KA5DNP, and Andy MacAllister, WA5ZIB, who were giving a talk on Amateur satellites. Jack explained that the Russian satellites RS-10/11 (Radio 10/11) were in a low Earth orbit that was near circular and did not require extensive equipment or elaborate antennas to operate.

Station

My station at the time consisted of a 25 Watt two-meter all-mode transceiver. The antenna was a homebrewed ground-plane in the attic similar to one mentioned in the *ARRL Handbook*. However, my antenna was fabricated from five (5) old coat hangers and a used SO-239 chassis connector as follows.

Two-Meter Ground-Plane

First I cut the hooks off five (5) old coat hangers and straightened them out. This formed five (5) straight pieces of coated steel wire. The next procedure was to remove the paint from one end of each wire, so that a good electrical connection could be made. To accomplish this I put one end of each wire into the hot coals in our fireplace and burned the paint off.

The next step was to solder the bare end of one of these wires into the center conductor of an SO-239 chassis connector to form a vertical radiator. Now, with the aid of needle-nose pliers I bent a loop in the bare end of the other four (4) wires. This allowed me to attach them to the mounting holes in the SO-239 with four (4) #6-32 by 1/2 inch machine screws and nuts. These wires were then bent down at a 45 degree angle to serve as radials.

At this point all that remained was to cut all the wires to the proper length. With a tape, I measured each radial 20 3/16 inches and cut them. Then I measured the vertical radiator 19 5/16 inches and cut it. Since my intention was to hang this antenna in the attic it became necessary to cut an extra 1/2 inch from the vertical and install a ring lug to use as a hanger. However, you could just as easily bend an eye in it.

Now, it was time to connect the feedline and check the standing wave ratio (SWR). Without any adjustments the SWR stayed below 2:1 throughout the band.

Total cost of this antenna was less than $1.00 and about fifteen minutes construction time.

According to Jack and Andy's presentation my existing station contained half the requirements to work RS-10/11 and could serve for uplink on Mode A. Since Mode A consists of two meters upper side band or CW uplink with a ten-meter downlink the only thing needed would be a ten-meter receiver and antenna.

I bought an old SWAN 350B transceiver for $50. Now for a ten-meter antenna and my satellite station would be ready to go on the air. Since the SWAN was a transceiver it made sense that the antenna should be capable of not only receiving but also transmitting. Because of the simplicity and ease of construction I decided to build a dipole for my ten-meter antenna.

In searching the garage for antenna materials an old piece of 12/2 TYPE NM wire (more commonly called Romex) was located. The Romex was stripped back to bare copper and attached to short pieces of PVC pipe used as insulators. The resulting simple ten-meter dipole antenna was then stretched in the attic and connected to the SWAN. Now my POOR BOY SATELLITE STATION was almost ready to go on the air.

When, Where and How to Find The Birds

There are several ways to accomplish this. The first and easiest is to ask an avid satellite enthusiast when and where the next good orbit for your QTH will be. Another method is to use a computer with the appropriate software. We didn't have a computer in our household, but we did have a calculator. Therefore, my method was to tune in the beacon frequency and wait until it is heard. This can be tedious, but I have done it several times.

First, tune in 29.357 MHz for the RS-10 beacon and wait until you hear the beacon transmitting a series of dots and dashes. This indicates that you have now caught yourself a satellite. The next thing to do is note the time and tune through the downlink band 29.360 - 29.400 MHz while listening for a QSO in progress. This will let you know whether the satellite's orbit is tracking from north to south or south to north. Each orbit progresses 26.4 degrees west of the preceding orbit. Also each orbit takes 105 minutes. You have probably heard about Doppler shift but don't worry about it now!

TABLE 1 — Frequencies of RS-10/11 Mode A.

	Satellite RS-10		Satellite RS-11	
Mode	Downlink	Uplink	Downlink	Uplink
"Beacon"	29.357		29.407	
"A"	29.360-29.400	145.860-145.900	29.410-29.450	145.910-145.950

Sequence of Operation

Since tracking antennas were not in my budget, here's my sequence of operation! First tune the radios to 145.870 MHz uplink and 29.380 MHz downlink and put on a headset. With satellite operation being full duplex a headset is really a good practice because feedback can be unbearable without one.

Now begin by transmitting your call sign, then send a string of dots on CW and adjust the downlink frequency for the best copy. If your dots come down in the middle of a QSO don't worry just adjust your uplink frequency up or down and repeat the above procedure. Now you are ready to call CQ and stand by for your first satellite QSO. If you want to operate phone be sure and change to the USB mode.

Doppler shift noted above is minimal but noticeable on Mode A. You will hear some frequency shift of your signal and it will be necessary to compensate your downlink frequency slightly.

Summary

RS-10/11 are low Earth orbit satellites (only 600 miles up) and that is why they can be worked without an elaborate Earth station. On one occasion my SWAN was in for repair and while a friend was tuning it we copied a QSO on RS-11. The SWAN was only connected to a dead end piece of RG-58 coax in his attic with no antenna. Although a preamp helps for RS operation it is not necessary.

These satellites do have some drawbacks. Since they are in a low Earth orbit the average pass over any particular QTH is only about 15 to 20 minutes. Therefore, QSO's are limited, but I have made as many as four contacts on a pass. Also, their footprint only has a radius of about fifteen hundred miles. Even so, it is possible to get W.A.S. (Worked All States) via these birds for most stateside hams.

RS-10/11 have several modes of operation other than Mode A such as Mode K, Mode T, combination Modes KA and KT as well as the ROBOT (or QSO machine). However, I have no experience with them. Remember, the control on License Requirements is the uplink frequency! This makes it possible for even a Novice grade license to operate CW when RS-10 is in either Mode K or Mode T.

Good luck and don't laugh at my poor boy operation. Because at 1016Z on 25 November 1988 with only 25 Watts into the coat hangers I made contact and had a QSO with Musa Manarov, U2MIR, on 145.550 MHz FM direct while he was on board the Russian Space Station MIR. See you on RS!

Microsat Motion and Stabilization (and why we care about it)

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Introduction

Signals from the Microsats fade seemingly at random during a pass. What's more, the fades seem to be different on every pass. One likely reason is polarization changes caused by Faraday rotation of the signal as it passes through the ionosphere. Another is the motion of the spacecraft. A better understanding of the motion and its potential effects on the signals from the spacecraft may be helpful in understanding how to design the most effective ground station antennas. Additionally, since the stabilization method used is nearly unique to the Microsats and is garnering some interest from the aerospace community, it may be of some scientific or engineering interest.

This paper discussed spacecraft construction features that relate to stabilization and motion, the theory of the stabilization method, and telemetry channels and data

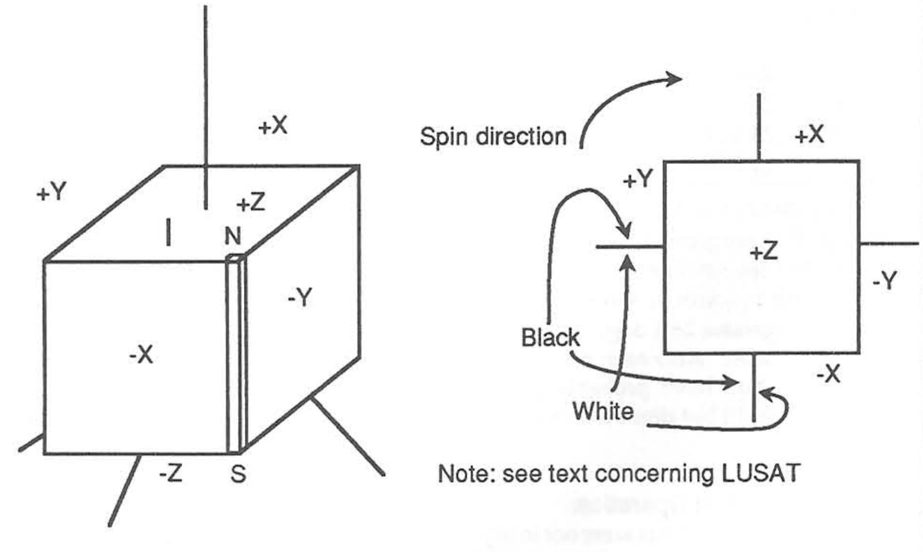

Fig. 1 — Microsat surfaces and solar propeller blades.

that can be used to determine spacecraft motion and attitude. It then reviews the initial motion after launch, including the surprise handed to us by PACSAT, and the current situation. It concludes with a summary of the effect of the motion on signals from the spacecraft and some areas that need further study to complete our understanding.

Construction Information Related to Stabilization

In order to understand the stabilization method and the motion of the Microsats, we first have to know a bit about their construction.

The "top" of the Microsats is the +Z surface (see Figure 1). This is the one with the 2 Meter antenna projecting from the center, and is normally 'up' in photographs. It is also the surface that is up when the spacecraft are mounted on the launcher (Note 1). On the opposite side of the spacecraft is the -Z surface, the one by which the spacecraft were mounted to the launcher. A line drawn vertically through the spacecraft, passing through the center of each Z surface, is called the Z axis. The sides of the spacecraft are named the +X, -X, +Y and -Y surfaces. When looking down on the top surface (+Z), and arbitrarily assuming the +X is at the top of your view, the +Y is on the left side, the -X at the bottom, and the -Y at the right. Lines drawn through the spacecraft and the centers of these surfaces are called the X axis and the Y axis.

There are four magnets mounted parallel to the Z axis, one at the corner of the spacecraft. In PACSAT, WEBER, and DOVE, they are arranged so that their -Z end is attracted to the Earth's north pole, in LUSAT they are opposite polarity.

The downlink antenna blades are painted white on one side and black on the other. These are canted turnstile antennas and are mounted around the edges of the -Z surface, centered on each side. On PACSAT, DOVE and WEBER if you are looking at the -X side, you see the white side of the blade on the left (below the +Y side) and the black side of the blade on the right (below the -Y side). The blades below the X surfaces are oriented similarly. When looking down on the +Z, this means that the white sides all point in the 'counterclockwise' direction. On LUSAT, the blade sides are oriented in the opposite direction (Note 2).

There are seven lossy iron rods (hysteresis rods) mounted in the bottom of the battery module in the XY plane and aligned with the X axis.

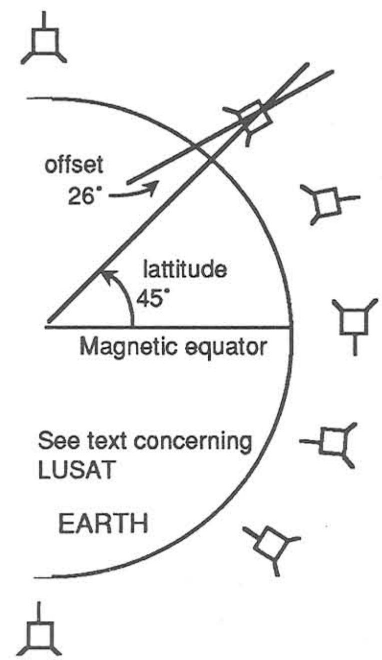

Fig. 2 — Nominal tilt within orbit plane.

Expected In-Orbit Stabilization Mode

The stabilization method used with the Microsats is quite simple compared to many sophisticated (and expensive) satellites. It has been used with previous AMSAT spacecraft, yet continues to be refined. A scientifically complete description is beyond the scope of this paper. However, this section provides an overview that should help in understanding the motion of the spacecraft. It will be related to expected signals in a later section.

The Earth's magnetic poles are not located at the geographic north and south poles. The north magnetic pole is actually located near the northwest coast of Greenland at about 78.8 degrees north and 70.9 degrees west. The south magnetic pole is near the coast of Antarctica at about 150 degrees east.

The lines of force of the earth's magnetic field are nearly perpendicular to the surface of the Earth, except between about plus and minus 30 degrees of the magnetic equator

TABLE 1 — Offset from the perpendicular at different geomagnetic latitudes.

Geomagnetic latitude (g)	Offset (b)
90 (pole)	0
75	7.6
60	16.1
45	26.6
20	53.9
0 (equator)	90

(see Figure 2). The equation for determining the slant of the field lines to a line perpendicular to the Earth's surface is:

$$b = 90 - \mathrm{atan}(2 * \tan(g)) \quad \text{(Equation 1)}$$

where

b = the angle of the magnetic force line to a line drawn from the center of the Earth through the surface at latitude g.

Note that g is the geomagnetic latitude, not (necessarily) the geographic latitude.

This is an important angle because it indicates the Z axis tilt from perpendicular. This means, for example, that at 60 degrees geomagnetic latitude, the downlink antennas will be off pointed from local vertical by about 16 degrees. Since the magnetic poles are offset from the poles of rotation, the magnetic equator is also off set from the geographic equator. At the longitude of the Americas, about 100 degrees west, the magnetic equator is about 15 degrees below the geographic equator. Hence it does not cross South America in Colombia, but about 15 degrees further south, in Brazil. Thus, the

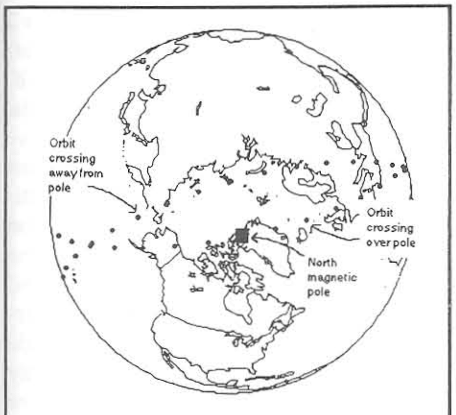

Fig. 3 — Relation of orbits to magnetic pole.

offset from perpendicular at the latitude of the northern border of the US (about 70 degrees geomagnetic latitude) is about 7 degrees, and at Florida (about 60 degrees geomagnetic latitude) it is about 16 degrees. Directly over the magnetic equator, the lines are parallel to the Earth's surface. The table on page 66 lists these angles for several latitudes.

The Microsats are in a polar orbit that is sun synchronous. To each spacecraft it is always 10:30 AM, as it stays in the same place relative to the direction of the sun, and the Earth rotates under it. To achieve this, the orbit is tilted slightly, so it doesn't pass directly over the geographic poles, but misses them by about 10 degrees or 500 miles. This means that the ground track will cross directly over the magnetic poles on some orbits and miss them by a considerable distance on others (see Figure 3).

The magnets along the Z axis of the spacecraft line themselves up with the lines of the Earth's magnetic field in a mode generally called "passive magnetic attitude stabilization". This holds the spacecraft with the Z axis nearly perpendicular to the Earth's surface, except when it is near the magnetic equator. Either the +Z or the -Z will be "up" or away from the Earth, and the

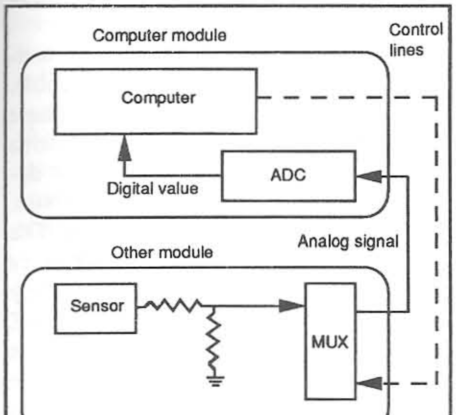

Fig. 4 — Telemetry diagram.

tilt of the Z axis to the north or south will match the angle of the Earth's magnetic field lines at that latitude. During an orbit as the spacecraft nears the magnetic equator, the top surface will be pulled toward the direction of motion until the spacecraft is flying with the Z axis parallel to the Earth's surface. After passing over the equator the leading surface will be pulled down until it is pointed at the Earth, and the spacecraft has completed a 180 degree roll. The opposite Z surface is now down and the Z axis is again about perpendicular to the surface, varying by the tilt of the force lines as described in Equation 1 and Table 1.

While the Z axis stays locked into the Earth's field lines, the spacecraft spins about the Z axis because of the pressure from solar radiation on the downlink antenna blades. Solar pressure is greater on the white sides of the blades than the black, so the spacecraft spins in a counter clockwise direction when viewed from the +Z side (except for LUSAT, which is opposite). This spin mode is officially known as 'photon assisted spin' but is commonly called the 'solar propeller' (Note 3). The spin rate was expected to be about 3 minutes per revolution for PACSAT and LUSAT, about 3 times that for DOVE, and slightly slower than that for WEBER. DOVE should be faster because it's painted antennas are for 2 meters and are about 3 times the length of the 70 cm antennas on the others. WEBER should be slower because of it's larger moment of inertia. The hysteresis rods damp forces acting on the spacecraft and prevent excessive motion. It was expected that the speed of the spin would increase until a stable rate was achieved that was a balance between the torque generated by the solar propeller and other forces acting on the spacecraft. The increase in rate would at first be quite fast and would decrease exponentially until that stable state was reached. During sun-lit parts of the orbit it was expected that the spin rate would increase slightly, then would decrease when the spacecraft is in eclipse. Some seasonal variation in spin rate should also occur as the percentage of the orbit that is in sunlight changes. This rotation provides thermal control of the spacecraft by ensuring that the sun heats each surface in turn.

All of these factors must be carefully balanced. Too much spin can introduce enough gyroscopic effect to prevent the spacecraft from rolling over at the equator. Not enough spin and the spacecraft may tumble. If there is not enough strength in the magnets the spacecraft will not lock on the field lines and will also tumble. Many factors can upset this balance and cause very complex motions, all of which are undesirable. This stabilization method is strictly passive, no adjustments can be made once in orbit.

The intent of keeping the 70 cm (2 meters for DOVE) antennas down when over favored areas is to maximize efficiency on the downlink, which is expected to be the weaker link.

Telemetry Measurements in the Microsats

The telemetry capabilities of the Microsats provide excellent means to study their motion. Samples can be taken as often as every 5 seconds and the 1200 baud downlink speed (higher speeds are possible) provides adequate bandwidth to send extensive telemetry data. Additionally, the whole orbit data (WOD) facility allows the collection of several telemetry points for up to about 5 orbits (limited by available memory). This is an invaluable tool for studying all aspects of the operation of the spacecraft. Several of the telemetry channels useful in studying motion are described in the following section.

In a Microsat, each module except for the computer, has one or more sensors (voltage, current, temperature, etc.) that is part of the telemetry system (see Figure 4). Many of the signals from the sensors are wired through a resistor voltage divider in the module before being connected to the input pin of an analog multiplexor (MUX) chip located in each module. The onboard computer selects module and the sensor to be switched through the MUX to the single analog sampling lead that is part of the spacecraft wiring bus. That lead is connected to the analog to digital converter chip (ADC) in the computer module. The digital output of the ADC is made available to the computer and can be sent in real time as a telemetry (TLM) channel, stored for later download, etc., all under onboard software control.

The voltage dividers in each module are necessary because the input range of the ADC is 0 to 2.5 volts, so all signals must be scaled down to that range. The published TLM decode equations compensate for the scaling of the voltage divider and convert the directly measured voltage to its appropriate engineering value (amps, degrees centigrade, etc.). Some channels have no units, so we refer to their values in 'counts'. The infrared (IR) sensors are a good example.

For some TLM channels a single bit change results in a larger change in the calculated (or engineering) value than you might expect. This is because the ADC is 8 bit and can only separate input voltages into 255 parts, and because of constraints in the voltage and current capabilities of the sensors. For example, a one bit change in raw value of temperature TLM channels from DOVE results in a .6 degree change in the calculated temperature.

The TLM decoding equations were derived from calibration measurement made both in the AMSAT Boulder Laboratory and at the launch site in Kourou. Those results were plotted and then software was used to fit a curve to the results and derive the TLM decode equations. In some cases few data points were available to derive the equations. In other cases a quadratic equation will not fit the calibration data. Therefore there are some built in errors. Adjustments may be made for those errors at some point in the future by either updating the equations or using completely new decoding methods such as look up tables. In the meantime, what we have is reasonably accurate and quite useful.

Telemetry Useful in Motion Studies

The primary source of motion study data to date has been the solar array currents. An additional valuable input on DOVE, PACSAT, and LUSAT is the IR sensor which looks out the +Z surface. On WEBER, there are two IR sensors mounted on the +Y surface, the same surface the camera looks out of. There are also two magnetometers in WEBER, measuring magnetic forces in the XY and YZ planes.

The +Z IR sensors are designed to show when the +Z surface is pointing at the Earth. Their scale is in units and is logarithmic: The larger the count, the more light is striking the sensor. This data is somewhat noisy. It sometimes varies from the actual value by a count or two due to slight bus voltage variations, AC on the source voltage, RFI, or other reasons yet to be determined.

WEBER has no +Z surface IR sensor (see Figure 5). It's +Y IRs look slightly to the left and right of the direction the camera points (perpendicular to the +Y surface). They form an angle between them of 22 degrees and their conical field of view is 10 degrees. They are positioned so that the only time they are illuminated simultaneously is when the +Y is facing the Earth.

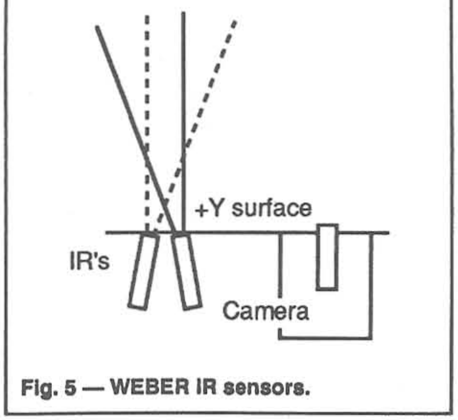

Fig. 5 — WEBER IR sensors.

The intent of this design was to allow their use to assure pictures were taken only when the camera was pointed at the Earth. Their readout is opposite the other spacecraft's IRs: Illumination decreases their count. This data is also somewhat noisy.

A temperature sensor was mounted on the inside of the +Y solar array on each spacecraft. One of the reasons for this positioning was to provide an additional point that could be used for attitude and motion determination. However, it has turned out that the solar panel is a good enough insulator that the temperatures as measured by these sensors only reflect the general warming and cooling of the spacecraft during the sunlit and shadowed portions of the orbit, and do not change noticeably as the spacecraft rotates.

The temperature sensor mounted on the top module cover (+Z side) can be used to roughly determine when the +Z is in the sun. Temperatures here will lag sun illumination by a few minutes because it takes a while for heat to be transmitted through this surface when the spacecraft comes out of eclipse.

The WEBER magnetometers were designed to allow measurements of the Earth's magnetic field. Magnetometer 1 is oriented to sense flux lines in the YZ plane of the spacecraft, and magnetometer 2 measures flux lines in the XY plane. Each of these sensors was biased with a small permanent magnet mounted near it to cancel the effect of the stronger spacecraft attitude control magnets. Proper operation of these sensors has not yet been verified. If working as designed they may be useful in motion studies.

By far the most useful telemetry channels have been the solar array currents. Since the current from the solar arrays changes essentially instantaneously as a function of the angle of sunlight on the panel, that angle can be calculated with reasonable accuracy for every surface that is in the sun every time a TLM sample is taken. This allows us to determine the angle of the sun on either two or three surfaces every x seconds, where x is the TLM sample interval. Since we know the angle of the sun to the plane of the orbit is 22.5 degrees all the time, that amount can be factored out and the angles of the surfaces to the orbit plane can be determined. The equation for calculating the sun angle from the array current is:

$$a = acos(Inow/Imax) \quad \text{(Equation 2)}$$

where a is the angle
Inow is the current measured
Imax is the maximum current the panel is capable of producing.

Imax will be 351 mA plus or minus 2 mA for every panel on every spacecraft except the -Z panels, which are exactly half, since they contain half the number of cells. The result of this calculation using many computer spread sheets will be in radians and must be converted to degrees by multiplying the result by 180/Pi. Using Equation 2, when there is no sun on the panel the calculated angle will be 90 degrees, and when the sun is directly on the panel (perpendicular to the panel surface) the angle will be 0 degrees. Since that is not the way we usually think of angles to surfaces, we can take the complement of the angle (subtract it from 90) and the result will be the angle between the direction of the sun and the panel surface. Thus the more complete equation is:

$$a = 90-(acos(Inow/Imax)*Pi/180) \quad \text{(Equation 3)}$$

See Fig. 6 for a chart of this relationship.

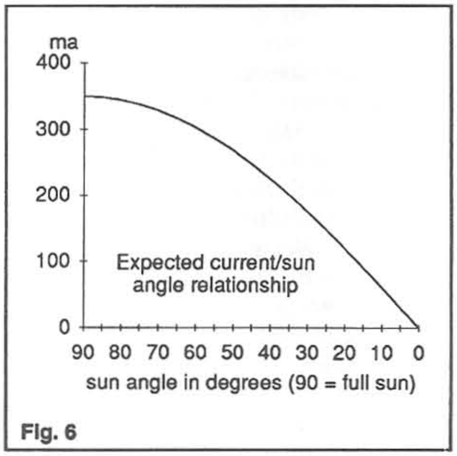

Fig. 6

This formula is not accurate at shallow sun angles because of scattering from the solar cell cover slides and array shadowing as explained below. That is why the telemetry decoding equations give negative results when there is no sun on the panel. Work needs to be done to further refine this equation, but it appears to be quite accurate above about 15 degrees of sun angle.

The effect of the shadow of the antennas falling on the solar panels is noticeable. The antennas are made of 3/8" Stanley tape measure material, therefore they will cast a 'thin' shadow and a 'thick' shadow depending on their orientation to the sun. Their long side is parallel to the X axis. The uplink antennas will shadow the +Z array all the time the +Z is in sun, since they project upward perpendicular to the +Z surface from the center of it. The downlink turnstile antennas will cast a shadow on the -Z surface at times, and on the side they are mounted below at other times. The effect on array current outputs when shadows are cast on the various panels, both for a nomi-

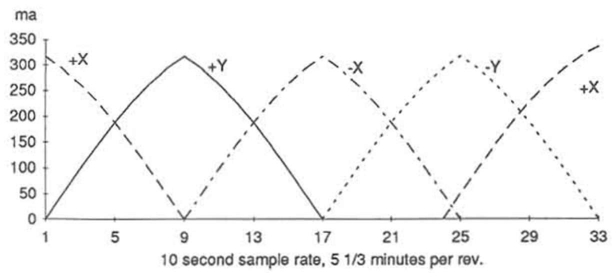

Fig. 7 — Expected X and Y array currents.

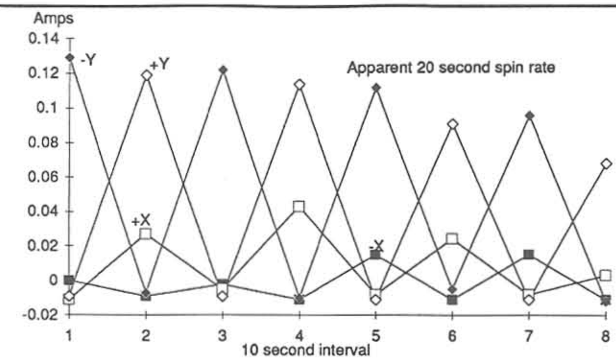

Fig. 8 — DOVE array currents on 2-17-90.

nal attitude and for situations when the spacecraft is nutating (wobbling), remains to be studied.

The spacecraft spin rate can be easily determined by examining array currents. The best way to do this is to plot them with a computer. See Figure 7 for an example of an ideal case. Note that the vertical (Y) axis of the graph is current and the horizontal (X) is time. Points on the X axis are 10 seconds apart. With nominal conditions we expect each of the side panels to rotate into the sun and out again as the spacecraft spins around the Z axis. A plot of the X and Y surface array currents will show the current from one surface start out at zero, slowly climb to a maximum, then drop to zero again, as it rotates into then out of the sun. As an example, let's assume the +X panel is fully in the sun. Its array current will be about 340 mA. This is the expected current with a sun angle of 22.5 degrees, the nominal angle of the sun to the orbit plane. No current will be generated by the other X panel because it is in full shadow on the 'back' side of the spacecraft. The Y panels also will not be generating current because they are parallel to the suns rays. As the spacecraft rotates (counter clockwise as viewed from the +Z), the current from the +X panel will slowly drop and the +Y panel will start to generate current as it comes into the sun. When the spacecraft has rotated 45 degrees the +X and +Y panels will be receiving equal sun and be generating equal current. 45 degrees later only the +Y panel will be in sun and the +X current will drop to zero because it has passed into shadow. This pattern continues as the spacecraft rotates. To calculate the spin rate, count the number of seconds between the peeks of two successive panels and multiply by four.

If there is nutation about the Z axis, and the period of the nutation is short compared to the rotation rate, the current plots from each array will be a wave superimposed over the nominal rise and fall described above. They can be pictured as a higher frequency cosine wave imposed on top of the positive half of a lower frequency cosine wave.

Initial Motion and Current Situation

The spacecraft were mounted on the launcher with a single explosive bolt extending from the center of the -Z surface through a spring to a ring (the ASAP) around the bottom of the payload section of the Ariane IV launcher (Note 1). The +Z surface was pointed straight up as the vehicle sat on the pad. Each spring was a slightly different strength. After SPOT 2 and the UoSATs were deployed, the Ariane third stage and payload section was pointed backward (top opposite the direction of flight) and the explosive bolts were fired, allowing the springs to pop the Microsats off the ASAP. Over time the spacecraft became separated because of the different spring strengths. The torque generated by the springs, which were not perfectly aligned with the center of gravity of the spacecraft, caused the spacecraft to initially tumble in orbit. After a few days the magnets had locked into the Earth's field, and some of the tumbling inertia was translated into spin about the Z axis. Initial spin rates about the Z axis were about 20 minutes per revolution, tumble rates were apparently much higher. The change from tumble into magnetic lock has not been studied in detail and is of great interest to the spacecraft builders because it provides valuable information concerning the design of spacecraft using this stabilization method.

All of the above motions happened as expected except for the spin direction of PACSAT. PACSAT's spin is discussed in more detail below.

DOVE quickly spun up to a brisk 20 seconds or so per revolution due to its longer downlink antenna blades (see Figure 8 for actual DOVE array current plots). The exact current spin rate has not been determined because the real time telemetry sample rate is too slow to assure an accurate measurement. In order to obtain an accurate picture of a wave form, it must be sampled at a rate at least twice its frequency (Nyquist rate). Since the sample rate is 10 seconds and the apparent spin rate was 20 seconds, we believe we were sampling slower than the Nyquist rate, resulting in aliasing, and the result is suspect. However, strip chart recordings of signal strength made by Junior DeCastro, PY2BJO, also indicated an apparent spin rate slightly greater than 20 seconds.

There was some concern that DOVE would spin so fast that the gyroscopic effect of the spin would overcome the magnetic lock and it would not roll over at the equator. This does not seem to be a problem as array current and IR sensor telemetry clearly indicate its +Z surface is up in the northern hemisphere and its -Z surface is up in the southern.

Nutation about the Z axis has been apparent on all spacecraft since magnetic lock was achieved. This is of interest because it affects RF links, has the potential to tell us a great deal about this stabilization method, and affects what can be done with the WEBER camera and other experiments. This nutation can be described as a line extending from the Z axis describing a cone pattern in space, and is sometimes called (reasonably) 'coning'. Initial measurements indicated PACSAT was nutating up to 20 degrees either side of the nominal Z axis alignment, or a total of 40 degrees (see Figure 9 for an early PACSAT array current plot). The nutation rate was about 56 seconds. That is, a complete circle from say, tilt in the direction of light, all the way around until tilt was again in the direction of flight, took 56 seconds. Theory holds that the nutation direction will be the same as the spin direction, but this has not been proven with data. The nutation appears to vary a great deal from orbit to orbit. The early array current wave forms were fairly complex and it now appears that we were seeing a combination of the effects of rotation, nutation and antenna shadowing. LUSAT was also nutating, but somewhat less. WEBER nutation was expected to be of greater amplitude than the others because it has less favorable moments of inertia, however WOD scans have not shown this to be the case. DOVE's nutation amount is currently unknown because the TLM sample rate has been too low. The nutation

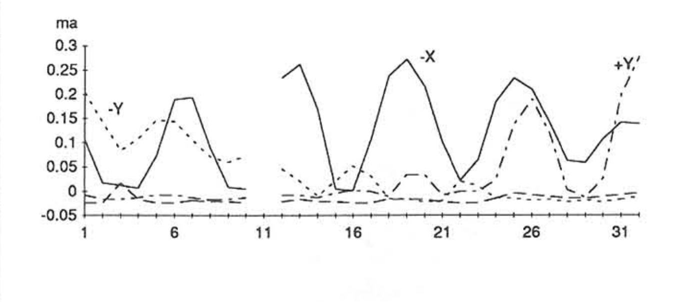

Fig. 9 — PACSAT 2-11-90 showing large nutation.

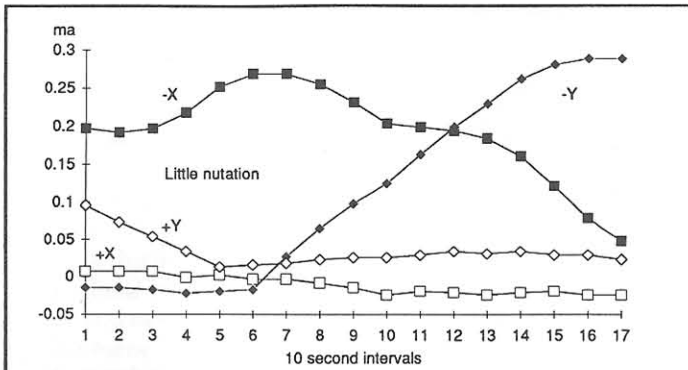

Fig. 10 — PACSAT 3-6-90.

amplitude of PACSAT appears to have reduced since it began to spin up in the correct direction. Nutation amounts of PACSAT and LUSAT now appear to vary from nearly none to about 10 degrees, 20 total. See Figure 10 for an example of PACSAT array currents showing little nutation. The pattern of this variation is not apparent, and the cause is unknown. However, one current theory is that the nutation now being seen is caused by the pull of the magnetic poles as the spacecraft passes over the top and bottom of the Earth, but at a point far away from those poles. The effect is similar to giving the top of a spinning gyroscope a push to the side with your finger: A wobble is induced that eventually damps itself out. When the spacecraft orbit passes more directly over the magnetic poles, no nutation is induced because the pull is in line with the orbit plane. At present this is speculation and confirmation will require collection and analysis of additional whole orbit data (WOD). It has also been suggested that the variations in nutation are influenced by changes in the Earth's magnetic field and that the spacecraft could be used to study those variations. The nutation amount for PACSAT has been confirmed by correlating the IR sensor data with the array current data (see Figure 11). Plots of both have shown that the Z axis leans over far enough at times that the IR sensor in the +Z sees the sun. Sun angles calculated from the +Z array current match up well with the angle necessary for the IR to be illuminated by the sun.

There was initially some confusion about the spin direction of LUSAT. However, once the opposite orientation of both the turnstile blades and the magnets is taken into account, it is clear that LUSAT spun up in the correct direction.

PACSAT Spin Reversal

Perhaps one of the most fascinating events related to motion that has occurred since launch was the reversal of the PACSAT spin direction.

Although it had never before been seen in a spacecraft using this stabilization method, there was a 50/50 chance that any one of the Microsats would start out spinning in the 'wrong' direction; that is, the direction opposite that caused by the solar propeller. As it turned out, this is exactly what happened with PACSAT. By early February it was clear it was spinning clockwise instead of counterclockwise, and was slowing down. By the tenth of February it had slowed down to about one revolution per hour, and on about February 17 it turned around and began to spin in the correct direction (see Figures 12 and 13). While enough data has been examined to assure this interpretation is correct, much additional study is necessary to determine exactly when the turn around occurred, if there was any tumbling, if magnetic lock continued even though there was no spin, how long there was little or no spin, etc. PACSAT has continued to spin up and has now reached a rate of about 2 1/2 minutes per revolution, which is well within the design parameters (see Figure 14).

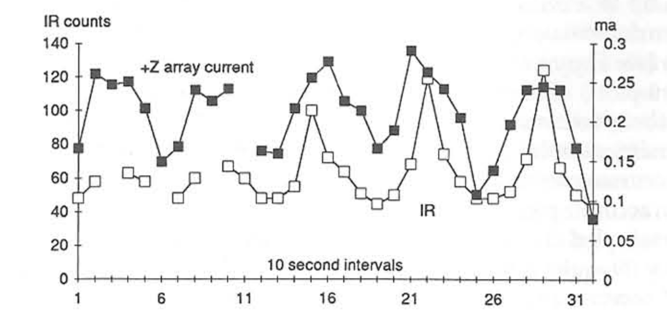

Fig. 11 — IR and +Z current correlation.

The importance of understanding nutation

Understanding nutation is important for a number of reasons. Let's first look at RF link performance. For the purposes of this discussion we will ignore the slight tilt of the Z axis caused by the tilt of the Earth's magnetic field lines. Assume for a moment the Z axis of PACSAT is stable (no nutation) and the orbit will pass directly over your station, which is in the northern hemisphere well away from the magnetic equator. As the spacecraft comes over the horizon the uplink antenna sticking out the top of the spacecraft will be pointed away from you at an angle of about 117 degrees from a line drawn between you and the satellite (see Figure 15a). The downlink turnstile will be pointed at the Earth, but away from you by about 63 degrees. We could say the pointing angle of the downlink antenna is 63 degrees. This angle will slowly decrease as the spacecraft approaches until, when it is directly overhead, the pointing angle will be essentially zero. It will then increase until at the opposite horizon it is again about 63 degrees. On the horizon the polarization of the downlink signal will be elliptical and of the proper handedness and overhead it will be nearly perfectly circular. Note that the handedness of the polarization will be left for one transmitter in each spacecraft and right for the other.

If the pass is not directly overhead the initial off pointing will be less, but it will not be zero at time of closest approach (TCA) or highest elevation. For a pass that never gets above 15 degrees elevation, the pointing angle never gets better than about 45 degrees, and the polarization is always elliptical. Of course, for stations near the magnetic equator the situation is quite different since the spacecraft is rolling over 180 degrees at that point.

Now let's assume that the spacecraft has a 40 degree nutation about the Z axis (20 degrees either side of the stable position). Remember that the nutation rate is about 1 minute per rotation. Now when on the horizon, the pointing angle will vary from

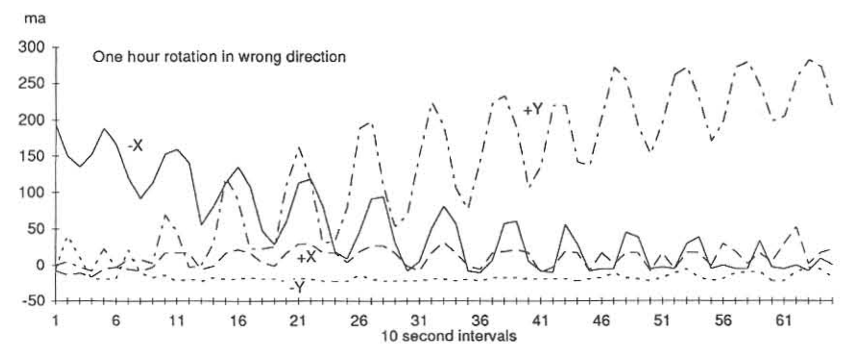

Fig. 12 — PACSAT on 2-16-90.

about 83 degrees to about 43 degrees in 30 seconds (Figure 15b). An 83 degree off pointing will cause the polarization to be nearly linear and at that point in the nutation cycle it would be horizontal. When nutation causes the spacecraft to tilt to the left or right as seen by the observer the polarization would be strongly elliptical and canted about 20 degrees from horizontal.

At this point we do not have radiation pattern measurements from the Microsat antennas, except S band. The engineering model maybe used to complete that work. However it should be obvious that nutation such as we are seeing will have some effect on RF link performance. This will be especially true when using simple omnidirectional ground stations antennas. Remember that nutation is not present on every orbit. Since one of the objectives of the Microsat effort was to demonstrate effective use with simple antennas, and the most efficient simple design is probably going to be influenced by the nutation, understanding it is important.

S band performance on DOVE and PACSAT will also be affected by nutation. The S band antenna is a bifilar helix which projects from the +Z surface and is mounted about 1 1/4" in from the edge. That surface is generally away from the Earth in the northern hemisphere, so for high elevation passes in that area the body of the spacecraft is often between the antenna and the ground station. However, when nutation is present the ground station will see a complex pattern of changes in polarization and signal strength as the short nutation period and the longer spin period interact. The design of ground station antennas could be changed to most efficiently work with this pattern once it has been characterized.

It would be advantageous to be able to include the pointing angle of the Microsats in tracking programs. This would help those experimenting with antennas or just using the spacecraft; station adjustments could be made to achieve maximum efficiency. It may turn out, for example, that one type of simple antenna works best when the spacecraft is making a low elevation pass and a different type works well for high elevation passes. It may also be true that different antennas work best for different amounts of nutation. It will be necessary to more fully understand the cause of the nutation in order to mathematically model, and to some extent predict, the spacecraft motion in tracking programs.

Since nutation is generally undesirable and magnitudes this large were not expected, it is important to know its cause and characteristics so the designs of future similar spacecraft can be modified appropriately.

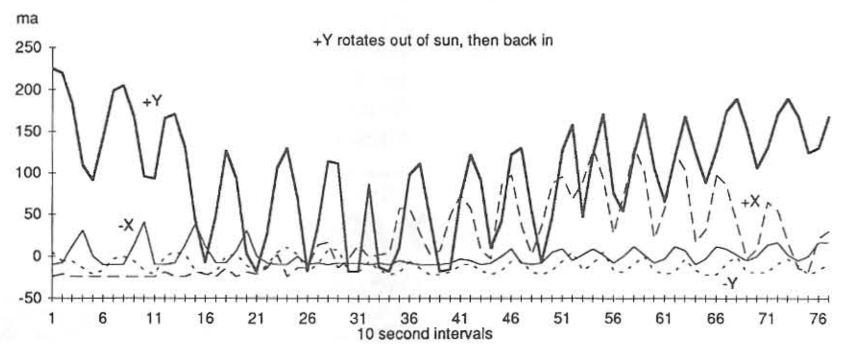

Fig. 13 — PACSAT turn around 2-17-90.

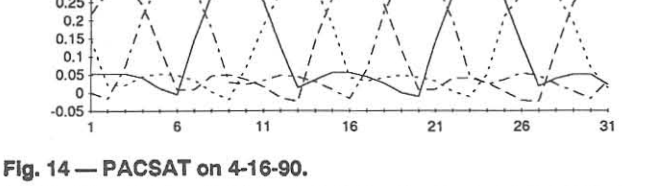

Fig. 14 — PACSAT on 4-16-90.

Areas needing further study and investigation

A number of areas of study falling into the general category of motion and stabilization are ripe for further investigation. Some will require research into fields such as antenna radiation patterns, or the application of knowledge of physics, orbital mechanics, etc. Some will also require access to sophisticated test equipment or the Microsat engineering model. Many can be undertaken with only a small amount of assistance from the engineering team. However, for most, all needed data can be obtained from Microsat telemetry and published documents. Following is a summary (in no particular order) of those study areas. It is not exhaustive, but is included here in an attempt to show the richness of further investigative opportunities, and in the hope that it will stimulate those interested in amateur satellites, or just in satellites, to participate in this fascinating field.

- Exactly when and why does a Microsat's Z axis wobble? What is the cause of the nutation? Can we understand enough about the cause to predict when it will occur and its amplitude? There is a component of precession in the roll over that occurs at the equator. Exactly how much does the Z axis deviate from the orbit plane during this event?

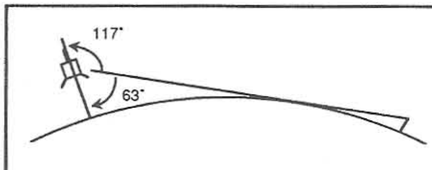

Fig. 15a — Pointing angle, no nutation.

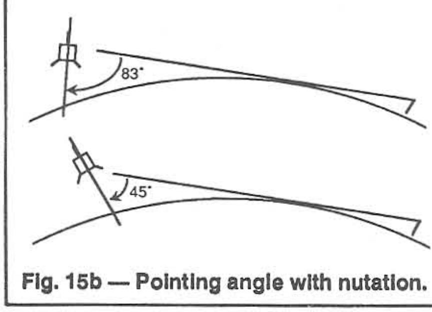

Fig. 15b — Pointing angle with nutation.

• What is the nature of WEBER wobble as compared to the others? WEBER's moments of inertia are different. How does that affect its susceptibility to nutation? Given verification of proper operation, can WEBER nutation be correlated to its magnetometer readings to validate those readings, or the other way around? Can the magnetometer readings be correlated to the array currents?

• What are the effects on the RF links of the nutation? Can predictions be correlated to measured signal strength and polarization changes? What are the radiation patterns of the antennas (70 cm downlink, 2 meter downlink, and 2 meter uplink)? What are the best simple ground station antennas to use when nutation is present and when it is not?

• Exactly how quickly did each Microsat achieve magnetic lock? What was the nature of the motion (tumble) in the first few days? How quickly did PACSAT lock as compared to the others, given that it was spinning in the wrong direction?

• Exactly when did PACSAT turn around, and how much, if any, tumble occurred at that time? After it turned around, what was its spin rate each day until it reached a stable rate? How did the temperatures in PACSAT change as its spin slowed down to zero about February 17th? How hot did the +Y surface get when it faced the sun for long periods?

• What is the DOVE spin rate currently, and how fast did it increase since it came out of tumble? A WOD collection of the array currents is planned using a 2 second sample rate. This should allow accurate determination of the spin rate, and also tell us if DOVE's roll over at the equator is delayed or affected at all by its higher spin rate.

• The conical view angle of the IR sensors in all but WEBER needs to be measured so the IR data can be more precisely correlated with other sensor data. What is a more precise method for relating sun angle to solar array current when the sun angle is low?

• What is the exact current drop from a panel when a thick and a thin 2 meter antenna shadow falls on it? What is the effect of shadowing of the S band antennas on the +Z arrays? Under what circumstances will the shadow of the 70 cm and the 2 m downlink antennas fall on the X or Y panels (with and without various amounts of nutation)? Can this be verified with telemetry?

Contact Information

Experimenters interested in pursuing any of these areas should contact the author or Bruce Rahn, WB9ANQ. Bruce is the coordinator of the Command Station Development Program (CSDP) for AMSAT-NA. Information about how to obtain Microsat telemetry from the TLM data bank can be requested from Reid Bristor, WA4UPD. When requesting information please include an SASE, and for data include a disk, mailer and return postage.

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Abbreviations

TLM - Telemetry

ADC - Analog to Digital Converter

WOD - Whole Orbit Data. Data collected for one or more entire orbit and downloaded in one package.

TCA - Time of Closest Approach. The time at which the satellite comes closest to the ground station.

ASAP - Auxiliary Secondary Payload Adaptor

MUX - Multiplexer

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WEBERSAT, Stan Sjol, WØKP, *AMSAT Journal*, V12 #3, Nov 89.

Microsat Telemetry Equations, *AMSAT Journal* V13 #1, March 90, pp 24-25.

Notes

1. For a photo illustrating the mounting of the Microsats on the ASAP see *AMSAT Journal* V13 #1, March 90, pp 28

2. For a photo illustrating the black and white painted antenna blades see *AMSAT Journal* V12 #1, May 89, pp 8.

3. Full nomenclature for the stabilization method is 'passive magnetic attitude stabilization with photon assisted spin'.

Acknowledgments

Thanks go to Jan King, W3GEY, for generously sharing his vast knowledge, Chris Williams, WA3PSD, for his patience in explaining the WEBER attic, Bob McGwier, N4HY, and Harold Price, NK6K, for their assistance with telemetry formats and WOD collection, Franklin Antonio, N6NKF, for providing the math describing the Earth's magnetic field, and Ron Cox, Stan Woods, Richard, VK7ZBK, & Graham, VK5AGR, for data collection and reporting.

Astronaut Deployable Satellite

The Astronaut Deployable Satellite (ADSAT) is an educational satellite being designed and built by faculty, local engineers, and students at Weber State University. The ADSAT is our third satellite project after the success of two others, NUSAT I (Challenger-April 85) and WEBERSAT-OSCAR 18 (Ariane-Jan 90. The ADSAT is designed to be tossed into space by an astronaut. The 16" X 16" X 4" ADSAT is self-contained and is designed to ride into space in a mid-deck stowage locker on the shuttle. When launch is desired, the astronaut removes the ADSAT from the locker and carries it outside. The astronaut then deploys the antennas and throws the ADSAT into space.

The ADSAT is designed to send to Earth voice messages concerning onboard experiments. The voice messages will be generated by an onboard speech synthesizer that verbally relays the data to low-cost scanners on the ground. ADSAT is being designed to be thrown in a couple of years if NASA will agree to the concept.

By Dr. William G. Clapp, KB7KCM
Weber State University
Ogden, Utah

Introduction

Realistic engineering training at the university level is a difficult task to accomplish successfully. There is no substitute for on-the-job training that takes place after graduation. Many universities offer senior projects courses in undergraduate programs to help the student transition into their entry-level engineering positions. The School of Technology at Weber State University has implemented a rigorous one-year senior projects program that consumes about 300 hours for each student. The students must work in teams to accomplish a significant task. A satellite is an ideal project because it can be a well defined complete system. A satellite does not take up much storage space during construction and can be put into orbit to eliminate long-term storage problems.

History

Weber State University faculty, local engineers, and students have been building satellites since 1978. The first satellite, NUSAT I, was a joint project between Weber State University and Utah State University. NUSAT I was inserted into orbit in April of 1985, from the Shuttle Challenger. Over 1500 two-way communications were completed during its 20 month life before reentry. Its mission to calibrate FAA radars throughout the world was not totally accomplished because of the unanticipated density of the radar signals from ground radars. The cash outlay for NUSAT I was less than $20,000 with more than $1 million donated in the form of labor, parts, and services. This first satellite was the catalyst to organize the Center for Aerospace Technology (CAST) at Weber State University to help facilitate similar future endeavors.

NUSAT II was being developed while NUSAT I was still in orbit. The second satellite would have enhanced capabilities to complete the FAA experiments. The structure was space qualified and the electronic systems were prototyped before the shuttle disaster occurred. Work on NUSAT II was discontinued because of the loss of low cost launch opportunities.

Weber State University joined the Radio Amateur Satellite Team (AMSAT) to help build four Microsat satellites. PACSAT (AO-16), DOVE (DO-17), WEBERSAT (WO-18), and LUSAT (LO-19) were launched into orbit in January of 1990, aboard an Ariane 4 from French Guiana. Each Microsat weighs just 20 pounds and is less than a cubic foot in size. With five receivers, two transmitters, and 8 Megabytes of RAM storage, they are powerful communications satellites. Weber State University students built most of the flight hardware for all four Microsats.

One of the four Microsats was designated as WEBERSAT and carries an additional top module designed and built by students, local engineers, and faculty. The upper three inch module adds a CCD color camera, light spectrometer, particle impact sensor, and a microwave receiver. Daily contacts with WEBERSAT are convincing us that it is working very well. The learning process to effectively use the camera has taken months and we are still trying many of its variables.

The AMSAT Phase IV Satellite is yet another satellite that Weber State University has made significant contributions. The Phase IV is a 1000 pound satellite designed for a geostationary orbit. Weber students, local engineers, and faculty have contributed about 10,000 volunteer hours in building a full-scale model using the design by Dick Jansson. This project is temporarily on hold waiting for additional funding.

Astronaut Deployable Satellite

To continue our realistic engineering training at Weber State University, we needed another satellite project. The concept of an astronaut deployable satellite came about because of the prohibitive high costs of launching satellites. To launch again on the shuttle or the Ariane is now many times higher because of the commercial interest since our launches. The shuttle launch costs to eject a satellite from a Getaway Canister (GAS) is now beyond our budget capability. To reduce the launch interface expenses, maybe NASA could simply carry the satellite in a mid-deck stowage locker to altitude and then have an astronaut toss it into space. Negotiations with NASA have begun. They may never agree to the idea, but they have not said no either.

The ADSAT is being designed to send voice messages concerning onboard experiments. The voice messages will be generated by an onboard speech synthesizer that will verbally relay the data to low-cost scanners in schools throughout the world. With a low orbit of 150 miles and the ADSAT transmitter power of 4 Watts, communications to low-cost scanners is possible. The experiments carried aboard will be high school sponsored projects that will hopefully encourage space and science education.

The electronics design is being supervised by Dr. Robert Summers and Verne Hansen, both professors at Weber State University. They are advising senior projects teams in the design and testing of the microprocessor and its payload interfaces. Three students have completed the basic hardware design and three other students have begun the task of software development. The ADSAT will have 32 channels for analog to digital conversion for sensors and experiments. A real-time clock will be used to broadcast the time and to provide a time reference for the experiments. A speech and sound synthesizer will be used to generate the required audio sounds. A voltage controlled oscillator will be used to transmit varying tones that will be tied to the experiments. A touch tone generator will be included to send down a specific sequence of tones to turn on ground stations. A CCD camera will be included to send back video images of the Earth.

A new technique to transmit video analog signals using audio signal paths is being designed by Professors Summers and Hansen. The video images taken by the satellite will be transmitted as FM modulated audio signals. The video data would then be received on the ground using a low cost scanner with the audio output going to an audio tape recorder. An interface card would allow the user to convert the tape recorded audio to video images on a standard personal computer with CGA graphics capability. The transmission of a single picture would only take a few minutes.

The signals will be transmitted to the ground using a 4 Watt FM modulated audio signal using the amateur radio 2 Meter Band. The output power will be adjustable by the onboard computer as a tool to manage the power drain on the batteries. The solar panels and power regulator system should allow the transmitter to operate near full power while prolonging battery life and turning off unused circuits.

One of the experiments being designed uses a three-axis magnetometer and a voltage controlled oscillator to verbally tell the listeners how fast the satellite is tumbling in each axis. The output of each magnetometer will be fed into a voltage controlled oscillator that will change frequency as the satellite rotates. The speech synthesizer will take turns switching on each axis and transmit that audio tone for about ten seconds. Listeners on the ground could easily determine the satellites rate of tumble in each axis.

Other experiments might include a particle impact sensor, similar to the one now flying on WEBERSAT, an eclipse detector to determine the time the satellite is in the eclipse of the sun, and maybe even a photon light motor. The 32 analog input channels will allow some flexibility to fly some fun experiments. Power budget and volume allowed for each experiment will be the biggest limiting factor.

The speech synthesizer, sound generator, voltage controlled oscillator, and video audio will be programmed so that each has a turn transmitting data. The complete cycle of data will last about ten minutes and then continually repeat as the satellite orbits the Earth. The maximum reception time by any one ground receiver will be less than 10 minutes because of the low orbit.

The ADSAT space frame is about the size of a brief case measuring 16" X 16" X 4" and will weigh less than 25 pounds. The mechanical design is complete and students in the Manufacturing Engineering Technology Dept. at Weber State University are about to begin building four ADSAT spaceframes. They will develop the processes to manufacture the frames using high technology concepts. Many parts will be machined on our five-axis Okuma Mill.

The ADSAT is designed to fit into a

mid-deck stowage locker. When the astronaut desires to launch ADSAT, he opens the locker and pulls it out by the handle. The astronaut attaches ADSAT to the side wall of the shuttle using velcro to help facilitate exiting the pressure locks. The handle provides an easy grip for the astronaut as he releases the antenna. He Squeezes the trigger and the ADSAT gently springs out into space.

Conclusion

Satellite projects have provided students with an excellent vehicle to learn valuable engineering lessons. All of our departments are working together because the program would simply not survive without everyone contributing. Even if ADSAT never flies, the experiences and lessons learned will be invaluable. Negotiations with NASA are underway and we are optimistic of flying in a couple of years.

Macromets and Microsats

By David Liberman, XE1TU
PUIDE/UNAM.
AMSAT-Mexico

and

Dr. Arcadio Poveda
Programa Universitario de Investigacion y Desarrollo Espacial - PUIDE/UNAM.

Since its beginnings, AMSAT has always had an interest in educational programs. Throughout the years we have seen how many of these activities have started. Good examples are, of course, the University of Surrey, the University of Marburg, Weber State College and others.

The National Autonomus University of Mexico (UNAM) had a space group that had been working for some time. One of the activities of this group was to build a GAS-CAN with a set of good scientific experiments on it. For reasons we all know, the GAS is still at the Cape and has not flown yet, naturally having caused a certain amount of frustration.

One of the problems in countries like Mexico is to allocate the needed money to fund a space program or project, due to the lack of confidence in the development or use of the right technology at the right price. AMSAT has played a very important part in solving this problem by showing the feasibility of space use, with a very economical but still very powerful and flexible small satellite, the result of a rational employment of limited resources and the best possible application of available technology.

Through a series of lectures and conferences, the academic staff of UNAM learned about the capabilities and limitations of the microsats. They were asked to come forward with proposals for the use of a satellite built under the guideline of the microsat philosophy. The result gave birth to a project that is now contemplating the construction and launch of a microsat with several tasks, including a scientific experiment, to be described ahead.

Dark Matter and Meteorites

The mass-energy equilibrium in the Universe called for a certain amount of dark matter on it. Not being able to observe but the light and other type of radiation emitting bodies, some astronomers have calculated the amount of dark matter that has to be in the Universe. Throughout the years, these numbers have been superseded by better estimates, but we are still a distance from really knowing the right number.

In very general terms, this type of matter receives the name of "Missing Mass Objects" or MMO's. They are arranged in the Universe in several distributions. They may manifest themselves by their gravitational perturbation on the motion of stars in the Galaxie, or in the motions of Galaxies in Clusters. It has been estimated that in the solar vicinity about 1/2 of the mass is in the form of dark matter, i.e. matter that has not been observed directly. In the scale of the Galaxie, it appears that 9/10 of its matter is in the form of dark matter, and at the scale of the Universe as a whole, it may be as much as 99%.

The nature of this matter is, at present, unknown; it may be composed of conventional matter — baryons — in unconventional form — neutron starts, black holes, etc. — but it may also be composed of exotic particles, not yet observed in the laboratory, but which the particle physicist, who have worked on the very early stages of the Big-Bang, speculate about their abundant existence, as a relic of those early days.

In the case of dark matter in the neighborhood of the Sun, it has been speculated that it could be composed of rocks, meteors, comets, etc. Depending on their size distribution, the probability that some of these mysterious bodies might hit the Earth, cannot be neglected. The orbits at which they move, some gravitational focusing effect of the Sun on Earth and their number has to lead us to think that some of them are reaching the Earth, and in doing so, they cause some effects that allow us to detect them. More specific is the case of the meteors that, upon entering the atmosphere produce a highly ionized trail, used by many of us to bounce radio waves and QSO successfully.

Many scientific surveys have been made, using the ionizing property of the trail and also different types of radar, and their velocities, energies and orbits are partially known. Unfortunately these studies have been very short. Hills (Hills 1968) has calulated that all the meteor surveys put together will only amount for 30 hours of observation over the whole Earth's atmosphere. This is also due to the fact that many of these investigations were made using high gain antennas which allow observation on a very small solid angle.

At the beginning of the space age, many satellites were flown with devices to detect meteorites, looking for those that could produce some damage to the future satellites. The result of this study established the probabilities, sizes and numbers of incoming micrometeors in relation with the safety factors for spacecraft to be launched. The mass distribution of the meteorites detected, centered itself around 10^ -3 grams. LDEF has only one bigger impact on the structure (none in the pannels), that caused a hole, certainly produced by a "larger" meteorite. It spent 6 years in space before retrieval, and it shows a "grinding effect" of the smaller mass meteorites.

Depending on their energy, meteorites can be classified in two groups. Those that upon entering the atmosphere produce more than 10^14 ions/m are called "Overdense"; below this figure they are called "Underdense".

We know that practically all the meteorites come from the solar system. Even when we don't expect a large number of extra-solar meteorites, we suspect that some of them might belong to the dark matter distribution of the solar vicinity. They will not be related to the periodical meteor-showers, as these clearly belong to the solar system distribution, and are related in many cases to the paths followed by comets that leave a big amount of debris on their passage close to the Sun. Some of them even have "radiants" (Opik 1957) associated with them, as if all of the meteorites belonging to a certain radiant, originated in the same point in space.

The mass distribution of the MMO's can be estimated from several experimental results. If we take that they have a mass of 10^-3 grams or less, the number of particles this size would be extremely large, to the point that they would attenuate the light we see from stars, by more than one magnitude. This is not observed (Hills 1986), and we have to conclude that their mass average is above this value. On the other hand, if the MMO's were massive objects, their gravitational effect would be noted, specially on binary systems of stars, and this also, has not been observed. We have to conclude that their mass distribution is centered between 10^-3 and 10^7 grams.

The rate at which they hit the Earth is affected by gravitational focusing of the Sun, and Hills calculated that 5000 tons of MMO's reach the Earth in one year. From observed meteors, most likely from the solar system, we know that a 1 gram meteor will produce 10^17 ions/m, clearly an overdense trail. The velocity at which they reach the Earth is related to their escape velocity, but when inbound to the solar system, we have to consider the rotation velocity of the Earth, the velocity of the Earth around the Sun and the velocity of the Sun within the galaxy. We can see that the main difference with the meteors from the solar system is the speed at which they approach the Earth.

At a distance of 1 AU the near-parabolic escape velocity of an object in solar orbit is:

$$a := 1\cdot AU$$

$$Vsun_{esc} := \left[2\cdot\frac{GM_{sun}}{a}\right]^{\frac{1}{2}}$$

$$Vsun_{esc} = 42.12\cdot\frac{km}{s}$$

Likewise for the earth, the escape velocity from its surface is :

$$Vearth_{esc} := \left[2\cdot\frac{GM_{earth}}{R_{earth}}\right]^{\frac{1}{2}}$$

$$Vearth_{esc} = 11.206\cdot\frac{km}{s}$$

If we consider that the pre-encounter velocity of an inbound interstellar object with respect to the sun is :

$$Vinb_{sun} := 30\cdot\frac{km}{s}$$

and that the orbital velocity of the earth with respect to the sun is :

$$Vorb_{earth} := 30\cdot\frac{km}{s}$$

we have that the maximum head-on velocity of an interstellar meteor will be :

$$Vmax_{interst} := \left[\left[\left[Vinb_{sun}^{\ 2} + Vsun_{esc}^{\ 2}\right]^{\frac{1}{2}} + Vorb_{earth}\right]^2 + Vearth_{esc}^{\ 2}\right]^{\frac{1}{2}}$$

$$Vmax_{interst} = 82.476\cdot\frac{km}{s}$$

while the maximum head-on velocity of a meteor of the solar system is :

$$Vmax_{solar} := \left[Vorb_{earth}^{\ 2} + Vearth_{esc}^{\ 2}\right]^{\frac{1}{2}}$$

$$Vmax_{solar} = 32.025\cdot\frac{km}{s}$$

The amount of ions/m of the trail is directly related to the energy of the arriving meteor, and of course the energy is proportional to the velocity. By statistical means it is possible to better describe the distribution of velocities and eventually also the energy distribution.

Microsats

We know that it is possible to bounce a radio wave on the ionized trail of a meteor. Many QSO's have been done by using this technique generically known as "Meteorscatter".

Two echoes are present; one coming from the trail and another one, called the "head-echo" coming from the meteor itself (Kaiser 1955), scattered by very short life ionization, probably produced by ultra-violet radiation from the meteor as it enters the atmosphere (Opik 1958, Lovell 1952). The head-echo due to speed of the meteor is shifted in frequency by Doppler effect that can be used to measure its relative velocity.

There are many factors altering the amplitude and phase of the reflected signal, most of them due to the geometry of the problem. One alternate method of measuring the velocity could be the Fresnel diffraction, which affects the amplitude of the head-echo (Lovell 1952).

For the purpose of calculating the required power and size of signals, let's assume a near polar orbit with 800 km of altitude in a Sun-synchronous orbit, very similar to the one at which the present microsats are flying. Let's also assume a 1 gram meteorite entering the atmosphere at a speed of 70 km/s and producing 10^17 ions/m of trajectory. From the geometry of the orbit we can immediately calculate the solid angle of coverage that the satellite will have. The meteorites start ionizing at around an altitude of 120 km. The maximum range from the satellite at this altitude will be 4200 km. We also see that the coverage is about 11 times more than what a station on the surface of the Earth. In the initial modeling of the proposed experiment we propose a frequency around 146 MHz as this will always be "transparent" in the ionosphere. For reasons related to the power budget we intend to use pulses.

The linear ionization density is:

$$q := 1\cdot 10^{17}\cdot\frac{ions}{m}$$

and the frecuency

$$f := 146\cdot 10^{6}\cdot Hz$$

corresponding to a wave-length of

$$\lambda := \frac{c}{f}$$

$$\lambda = 2.055\cdot m$$

We will consider a maximum distance from the satellite to the trail of :

$$D_{max} := 3500\cdot km$$

The effective cross section of the electron for radio waves is :

$$\sigma_{electron} := 1\cdot 10^{-28}\cdot m^2$$

The total reflecting cross section of the trail (Maanders 1965) will then be

$$\sigma_{trail} := \left[\frac{1}{2}\right]\cdot\sigma_{electron}\cdot q^2\cdot D_{max}\cdot\lambda$$

$$\sigma_{trail} = 3.596\cdot 10^{12}\cdot m^2$$

The peak power of the pulses is

$$P_{tx} := 240 \cdot W$$

The flux arriving at the trail at the distance considered is

$$\phi_1 := \frac{P_{tx}}{4 \cdot \pi \cdot D_{max}^2}$$

$$\phi_1 = 1.559 \cdot \frac{pW}{m^2}$$

and the total reflected power will be

$$P_1 := \phi_1 \cdot \sigma_{trail}$$

$$P_1 = 5.606 \cdot W$$

The flux reaching the satellite back from the trail is

$$\phi_2 := \frac{P_1}{4 \cdot \pi \cdot D_{max}^2}$$

$$\phi_2 = 0.036 \cdot \frac{pW}{m^2}$$

Assuming a unity antenna gain the capture area is

$$A_{ant} := \frac{\lambda^2}{4 \cdot \pi}$$

$$A_{ant} = 0.336 \cdot m^2$$

The received power at the satellite will then be

$$P_{rx} := \phi_2 \cdot A_{ant}$$

$$P_{rx} = 0.012 \cdot pW$$

$$Pdb_{rx} := 10 \cdot \log\left[\frac{P_{rx}}{P_{ref}}\right]$$

$$Pdb_{rx} = -139.123$$

The temperature of the system is (Jan King 1990)

$$T_{sys} := 4000 \cdot K$$

The intended passband on the receiver is

$$B_{rx} := 1000 \cdot Hz$$

So the noise power will be

$$P_{noise} := K_{boltz} \cdot T_{sys} \cdot B_{rx}$$

$$P_{noise} = 5.52 \cdot 10^{-11} \cdot \mu W$$

$$Pdb_{noise} := 10 \cdot \log\left[\frac{P_{noise}}{P_{ref}}\right]$$

$$Pdb_{noise} = -162.581$$

The signal to noise ratio in these conditions is

$$Pl_{sn} := Pdb_{rx} - Pdb_{noise}$$

$$Pl_{sn} = 23.457$$

Due to the fact that we will be always in a condition of backscatter, we have to consider a reduction on the signal. The calculated reduction for this frequency is (Keitel 1955)

$$Pdb_{back} := 4.65$$

$$P_{echo} := Pl_{sn} - Pdb_{back}$$

$$P_{echo} = 18.807$$

The power in the head echo will vary depending on several factors, like size and velocity of the meteorite. From several published papers (McKinley 1955, McKinley 1961) we have concluded that a good average figure is 1% of the total reflected power. Jan King suggested to confirm this figure by doing some experimentation from the ground. This corresponds to a 20 dB reduction from the main echo.

$$Pf_{dopp} := 10 \cdot \log(20)$$

The signal to noise ratio of the Doppler component is then

$$P_{dopp} := P_{echo} - Pf_{dopp}$$

$$P_{dopp} = 5.797$$

The Doppler shift has two components. One due to the circular speed of the satellite in orbit and the other due to the radial component of the speed of the meteorite.

$$h_{sat} := 800 \cdot km$$

$$r := R_{earth} + h_{sat}$$

$$r = 7.148 \cdot 10^3 \cdot km$$

$$V_{circ} := \sqrt{GM_{earth} \cdot \left[\frac{1}{r}\right]}$$

$$V_{circ} = 7.467 \cdot \frac{km}{s}$$

$$\delta F_{sat} := \frac{V_{circ}}{c} \cdot f$$

$\delta F_{sat} = 3.634 \cdot KHz$ due to the satellite.

In a collinear head-on encounter the doppler shift will be

$$Vcol_{antip} := \left[Vmax_{interst} + V_{circ}\right]$$

$$Vcol_{antip} = 89.944 \cdot \frac{km}{s}$$

The maximum doppler shift will then be

$$\delta F_{max} := \delta F_{sat} + \frac{Vcol_{antip}}{c} \cdot f$$

$$\delta F_{max} = 47.407 \cdot KHz$$

Satellite Power Budget Analysis

Assuming the same Sun-synchronous orbit of 800 km altitude, inclination of 98 degrees and very low eccentricity we have an orbital period of

$$Per := 100.87 \cdot min$$

the percentage of time exposed to the sun is

$$Sun_{\%} := 65.5 \cdot \%$$

so the sun exposed time is

$$Per_{sun} := Per \cdot Sun_{\%}$$

$$Per_{sun} = 66.07 \cdot min$$

The solar energy in the vicinity of the earth is

$$E_{sun} := 1.355 \cdot 10^3 \cdot \frac{W}{m^2}$$

Using BSFR silicon solar cells with an area (each cell) of

$$A_{cell} := 4 \cdot cm^2$$

and having clips made of 20 cells each the area of each clip will be

$$N_{clip} := 20$$

$$A_{clip} := N_{clip} \cdot A_{cell}$$

$$A_{clip} = 80 \cdot cm^2$$

each face containing four clips

$$A_{face} := 4 \cdot A_{clip}$$

$$A_{face} = 320 \cdot cm^2$$

the energy intercepted by this area is

$$E_{face} := A_{face} \cdot E_{sun}$$

$$E_{face} = 43.36 \cdot W$$

the efficiency of this type of solar cells at 5°C at begining of life is

$$Eff_{cell} := 16.0 \cdot \%$$

so the collected energy is

$$Etot_{face} := E_{face} \cdot Eff_{cell}$$

$Etot_{face} = 6.938 \cdot W$ at a voltage of $V := 11.4 \cdot volt$

There is an additional contribution given by the cells on each of the +Z and -Z faces, equivalent (present telemetry) to 1 clip

$$E_z := \frac{Etot_{face}}{4}$$

$$E_z = 1.734 \cdot W$$

giving a final total of

$$E_{tot} := Etot_{face} + E_z$$

$$E_{tot} = 8.672 \cdot W$$

throughout the whole orbit we have

$$P_{avail} := E_{tot} \cdot Per_{sun}$$

$$P_{avail} = 572.958 \cdot W \cdot min$$

This available power will be used by the different systems on the satellite in the following way :

$$E_{computer} := 1.5 \cdot W$$

$$P_{computer} := E_{computer} \cdot Per$$

$$P_{computer} = 151.305 \cdot W \cdot min$$

the receiver (multichannel, includes channel for spectrum analyzer)

$$E_{rx} := 1 \cdot W$$

$$P_{rx} := E_{rx} \cdot Per$$

$$P_{rx} = 100.87 \cdot W \cdot min$$

The pulsing transmiter will send pulses of a peak power of

$$E_{peak} := 240 \cdot W$$

Assuming an efficiency of 60 %

$$Eff := 60 \cdot \%$$

$$Ein_{max} := \frac{E_{peak}}{Eff}$$

$$Ein_{max} = 400 \cdot W$$

The maximum current drawn at the peak from the batteries is

$$I_{max} := \frac{Ein_{max}}{V}$$

$I_{max} = 35.088 \cdot A$ which is well bellow the manufacturer maximum current of 118 amps.

In order to have a good sampling rate of the echoes considering that the mean duration of a trail of 10^17 ions/m is only 80 s and we want to see the TCA, we propose a frequency of 12 pulses/min

$$Frec_{pulse} := 12 \cdot \frac{pulses}{min}$$

$$Rate_{pulse} := Frec_{pulse}^{-1}$$

$Rate_{pulse} = 5 \cdot s$ we send a pulse every 5 s.

The number of pulses per orbit is then

$$Num_{pulse} := Frec_{pulse} \cdot Per$$

$$Num_{pulse} = 1.21 \cdot 10^3 \cdot pulses$$

We propose a pulse duration of

$$T_{pulse} := 8 \cdot ms$$

The total time at the peak power per orbit is

$$Ttot_{pulse} := Num_{pulse} \cdot T_{pulse}$$

$$Ttot_{pulse} = 0.161 \cdot min$$

The total power per orbit for pulsing is

$$Porb_{pulse} := \frac{Ttot_{pulse} \cdot E_{peak}}{Eff}$$

$$Porb_{pulse} = 64.557 \cdot W \cdot min$$

The AART boards require an additional

$$E_{aart} := .25 \cdot W$$

$$P_{aart} := E_{aart} \cdot Per$$

$$P_{aart} = 25.218 \cdot W \cdot min$$

If we assume 1 W for the telemetry Tx

$$E_{telem} := 1 \cdot W$$

$$P_{telem} := E_{telem} \cdot Per$$

$$P_{telem} = 100.87 \cdot W \cdot min$$

So far the total power allocated is

$$P_{use} := P_{computer} + P_{rx} + Porb_{pulse} + P_{aart} + P_{telem}$$

$$P_{use} = 442.819 \cdot W \cdot min$$

leaving us with a reserve of

$$P_{remain} := P_{avail} - P_{use}$$

$$P_{remain} = 130.138 \cdot W \cdot min$$

As we can see, there are about 130W*min per orbit excess power that can be used as a reserve to avoid the total depletion of the internal batteries at the end of the eclipse period. Also there is a possibility of having a larger pulsing frequency when a valid echo is received, in such a way that a better Doppler curve can be generated and perhaps even some Fresnel diffraction measurements can be made.

Tom Clark, W3IWI, has suggested to make the spectrum analyzer using a product detector (SSB) with a A/D converter and performing a Fast Fourier Transform in the computer on board, accumulating on an open bottom buffer the data. It seems like a very elegant and efficient way of gathering the spectral information and we are thankfully accepting his suggestion.

The proposed scientific use of the Microsat technology shows clearly that the flexibility and system characteristics of this type of satellite is far from exploited or exhausted. We are absolutely certain that the results of the proposed experiment have many ramifications that we have not seen yet, mainly in the field of radiocommunications, the observation of ionization process in auroras (Ron Dunbar), the forward meteor-scatter in sub-horizon passes, etc.

This experiment will allow UNAM to enter the field of satellite technology and to perform a good scientific experiment in space. AMSAT will further show the capabilities of this technology in the field of educational and scientific applications.

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