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AMSAT

RADIO AMATEUR SATELLITE
CORPORATION

PROCEEDINGS OF THE

AMSAT-NA

Tenth Space Symposium,
AMSAT/ARRL Educational Workshop
and **AMSAT** Annual Meeting

October 9-11 **1992**
Washington, DC

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Proceedings of the

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Foreword

These papers, prepared for the 1992 AMSAT Technical Symposium and joint AMSAT/ARRL Educational Workshop, represent the state of the art in Amateur Radio space experimentation. Many readers will recognize the names of authors who have long been associated with AMSAT's and ARRL's efforts to further the amateur space program. Others are less well known, but bring an equally farsighted vision to these Proceedings.

The ARRL is pleased to have the opportunity to publish these Proceedings. We trust that it will serve to stimulate even greater interest in the amateur space program. If you're among those whose interest has, thus far, been latent, why not contact AMSAT and see where your talents and abilities might fit in?

David Sumner, K1ZZ
Executive Vice President, ARRL

October 1992

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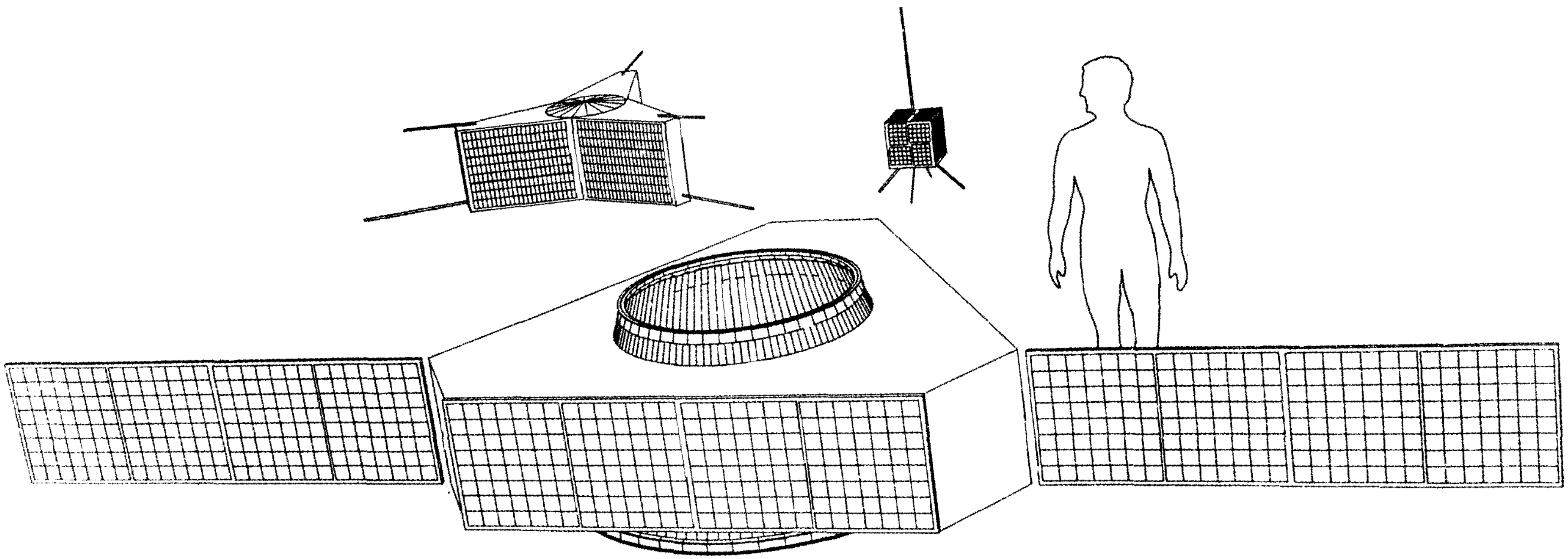

Drawing of the Phase IIID Spacecraft

Dick Jansson, WD4FAB

AMSAT-NA OPERATIONS REPORT 1992

by Keith D. Pugh, W5IU
Vice President of Operations, AMSAT-NA

It's hard to believe that nearly a year has gone bye since I took office. Within this first year, AMSAT Operations have been challenged on several fronts. This report will document these challenges as well as report on the normal operations throughout the year and the people who are responsible for the continued success of our satellites, nets, and other operations.

SATELLITE OPERATIONS -

This has been a good year for Amateur Radio Satellites. Only one new "bird" has been added to the flock, KITSAT, but operations activity has been high on all of the fourteen active "birds." I will attempt to summarize the activity on each category of satellites. Where applicable, I will describe our control activity or our input to that activity.

High Altitude - AO-13 & AO-10

Most activity continues to center on AO-13. It has been operational throughout the year; however, there have been challenges to its operation. In late 1991, the command team - G3RUH, DB2OS, and VK5AGR - solicited comments for changes in the mode schedule. The idea behind the solicitation was that the balance between modes B, J, L, and S could be improved. A number of comments and suggestions were received and in early 1992, a new mode schedule was implemented. This new schedule added day of the week variations on top of the old phase of the orbit variations and created quite a controversy amongst the user community. Some of the most vocal users were not even willing to give it a try. Unkind words were exchanged in print. The command team was within their rights making the changes as they saw fit and they did ask for comments and suggestions well in advance of the change. In the future, AMSAT-NA will attempt to formulate a position on matters such as this in hopes of avoiding some of the controversy associated with this change. By mid year, AO-13 was forced to adopt a Mode B only schedule due to Sun angle considerations and a traditional schedule will be adopted again upon return to better Sun angles. Due mostly to political pressure brought about by this controversy, AMSAT-NA, is looking for an acceptable North American volunteer to add to the AO-13 Command Team. The volunteer must be dedicated, knowledgeable about AO-13 systems and orbital characteristics, and capable of working with the current members of the team. By mid-year, due to Sun angle considerations, AO-13 has been placed in an attitude (150, 0) not used before and some adjustment of user habits has been necessary. Throughout all of this it should be remembered that Amateur Radio is a Hobby. It should be fun. Amateur Radio Satellites are experimental, and please have patience and tolerance of other viewpoints. After all, we are all volunteers.

Our old standby, AO-10, has operated throughout the year with only an occasional mode change to interrupt it's operation. So far the command stations have still been able to issue resets to the "bird" and restore it to the Mode B default. This "bird" has been with us nine years now and is performing well considering it's "brain dead" state.

Low Altitude Digital -
AO-16, DO-17, WO-18, LO-19, UO-22, KITSAT,and UO-11

New records are being set for digital operations every day. The software, PB and PG, is becoming more mature with every revision. We have Jeff, G0/K8KA, and Harold, NK6K, to thank for this. PACSAT, AO-16, recently completed over 300 days of continuous operation without a crash. It finally did go down due to a Single Event Upset (SEU), apparently in the microprocessor RAM. Nothing that software could do for that! The reload opportunity created by the crash will be used to put the latest software incorporating directory broadcast, developed on UO-22, in place on AO-16 and LO-19.

The AO-16 command team - WB9ANQ, WD0E, and KB5MU - along with the LO -19 command team from AMSAT-LU, and the WO-18 team from Weber State University have kept all of the Microsats up and running in good shape. Activity on these "birds" has peaked and started to fall off due to the popularity of the higher data rates on UO-22 and KITSAT. Bruce, WB9ANQ, has suggested that it is time to consider exploring the possibilities of 4800 baud operation on the Microsats, starting with AO-16, as a means of fully exploiting our resources in Space.

The DOVE, DO-17, team of N4HY, NK6K, PY2BJO, and WD0E have succeeded in getting DOVE to say a few words for a short time. This test, while not very spectacular, proved the functionality of some of the circuitry that had not been exercised in orbit before. More work is continuing and there is still hope that DOVE, in spite of it's many problems, will eventually realize most of it's potential. Jim, WD0E, spent a lot of time assisting the Physics Department of Chaminade College Preparatory School in California with a spin rate measurement experiment utilizing DOVE for educational purposed even in it's crippled state.

As the year started, UO-14 and UO-22 were both operating as shared assets between Amateur Radio and Commercial interests. The command team at the University of Surrey made a decision to reallocate these assets, dedicating UO-14 to Commercial use and UO-22 to Amateur Radio use. After an initial outcry from the users, this operation has worked out well. Activity on UO-22 is growing every day and KITSAT has come on line in the "nick of time" to spread out the workload for the 9600 baud "birds." Downloading image data taken with the onboard cameras is very popular along with uses as "store-and-forward" mail boxes.

Use of these "birds" to relay traffic between Packet Radio Gateways became a controversial issue in the middle of the year. It should be pointed out at the start that this usage was anticipated and part of the original goals for all of the digital "store-and-forward" satellites. Dave, KI6QE, with the help of many others has developed a successful network of Gateway stations, worldwide, automatically forwarding traffic through the satellites. This activity started on AO-16 and LO-19 but has spread to UO-22 due to the popularity of the higher data rate. Worldwide, some individual users had perceived this Gateway usage as not appropriate and detrimental to their personal usage. A "great debate" was held on INTERNET and other places regarding the Gateway usage. This debate became "face to face" at the AMSAT-UK Space Colloquium this year. Reason prevailed at this meeting and a policy of "wait and watch" was adopted. It was pointed out that: (1) KITSAT should help, (2) the load is not as bad as some think, (3) there are still possibilities for change in the protocol that will help, and (4) individual operations will improve as stations become more efficient through the learning process.

Nothing new happened to UO-11 this year. It continues to operate a full schedule; however, it's updating cycle suffers from lack of dedicated staff at the command station, University of Surrey.

Low Altitude Analog - RS-10/11, and RS-12/13

These two popular satellites serve as entry level "easy birds" for many people just starting out. Mode A has been active on RS-10/11 throughout the year while Mode K has been the order of the day on RS-12/13.

Mode K operation is completely HF (15 m up and 10 m down). Pat, G3IOR, popularized experimentation with this mode for beyond the horizon contacts through the satellite. The mode also works well with only a HF transceiver and a two band antenna. It is not even necessary to work full duplex since the net Doppler through this "bird" is very low.

Low Altitude Mixed - FO-20, and AO-21 (RS-14)

Fuji, FO-20, has performed well throughout the year. It is listed here as a mixed mode satellite since it contains both analog and digital transponders; however, it spends most of its life in the digital "store-and-forward" mode. Occasionally, the analog transponder is turned on and used for a short period, usually not more than a day at a time. Fortunately, one of these days was ARRL Field Day this year and several contacts were made through the analog transponder that day.

The joint Russian and German command team for AO-21 has finally "broken the code" on a pesky problem with power supplies on board the spacecraft and found a workable solution to the problem. The result is a very interesting "bird." Until the break through, operations had been limited to occasional usage of the Russian Mode B linear transponder. Since the break through, the German RUDAK transponder is starting to realize it's full potential. So far, several of the digital modes have been exercised, but the most popular use to date has been the implementation of an FM voice repeater through it's DSP experimental mode. Most recently, this mode has also been used for voice bulletins in the Russian language. With it's strong signals, many modes, and other features, this satellite is becoming the best "bird" in the flock to demonstrate satellites to the average Amateur Radio Operator. Our hats must certainly be "tipped" to the German RUDAK team for designing a very interesting and versatile device and for having the persistence in the face of failure on AO-13 and problems on AO-21 to see it through.

AMSAT NEWS SERVICE (ANS) -

Dave, WD0HHU, has gathered up and published the news weekly for several years now. He does this almost single handed and should be commended on a job well done. "Hitches" develop from time to time and occasionally Dave needs time off. For these reasons, the AMSAT News Service could use some additional volunteer help. This is an excellent opportunity to exercise your writing and editorial skills and help provide information read around the world on a weekly basis. Through a combination of INTERNET, Packet Radio, AMSAT Voice Nets, and Bulletins on the "birds" this service gets distributed as wide and as fast as CNN, but with amateur means.

AMSAT NET OPERATIONS -

Early in the year, our primary international net on twenty meters underwent a crisis. Due to personal commitments and problems the primary net control operators were unable to serve for a period of two to three months. This pointed out how vulnerable we are when we try to provide scheduled service with volunteers. What this means is that we need more volunteers. In the case of the twenty meter net, we now operate the net by committee. There are usually at least two operators available to share the load. This helps in at least two ways. No individual has to talk as long, and multiple operating points helps in the event of marginal propagation. If you have a decent HF station or can operate from a good club station on a regular basis, please consider joining the ranks of the AMSAT Net Control Stations.

Overall coordinator of the HF Nets is Wray, W8GQW; however, he gets assistance from all of the other stations. A list of active AMSAT HF Net Control Stations follows:

75 meters, 3840 kHz, Tuesday evenings

East Coast Net -	2100 Eastern	- W8GUS, WJ9F, K8RST
Mid America Net -	2100 Central	- W0CY, W5IU, W5GEL
West Coast Net -	2000 Pacific	- WB6LLO, KI6QE, W6HDO

20 meters, 14.282 MHz, Sunday afternoons

Pre Net Warm-up -	1800 UTC	- WD0HHU, W5IU, WT0N
Formal Net -	1900 UTC	- WD0HHU, W5IU, WT0N

15 meters, 21.280 MHz, Sunday afternoons

Formal Net -	2100 UTC	- W8GQW

NOTE

Simulcast on AO-13 at 145.955 MHz when in view.

17 meters, 18.155 MHz, Sunday evenings

Formal Net -	2300 UTC	- N4QQ

In addition to these nets, a number of VHF nets exist throughout the country. Martha, at AMSAT Headquarters, has compiled a complete list of all nets and will be glad to supply a copy of this list upon request. This list is published occasionally in The AMSAT Journal and other publications.

AMSAT OPERATIONS NETS are held regularly on AO-13 for the purposes of exchanging information of a more technical nature and to introduce operators to the unique opportunities that exist for net operations when the entire AO-13 footprint is in view at one time. Downlinks are 145.950 MHz for Mode B and 435.970 MHz for Mode JL. Dave, WB6LLO, schedules these nets and keeps a list of volunteer net controls current. These nets cannot always be held at the same time due to satellite visibility and other factors, so the schedule is published weekly in ANS. Dave also schedules and coordinates Slow Scan Television activity on AO-13.

COMMAND STATION DEVELOPMENT TEAM -

The concept of a Command Station Development Team was proposed by Courtney, N5BF, and is currently administered by Bruce, WB9ANQ. This team is dedicated to establishing a method whereby individuals can follow a prescribed program leading to developing and demonstrating the skills necessary to command satellites. With the upcoming launch of Phase IIID, AMSAT-NA must be represented on it's command team in the interest of international harmony. Additional emphasis will be placed on development of Command Stations in the next year. Look for a complete outline of this program to be published in The AMSAT Journal soon.

SUMMARY -

I could go on and on about all of the operations opportunities that exist within AMSAT-NA, but the above discussion should illustrate the scope of our activity and the major problems and accomplishments of the last year. In closing, I would like to re-emphasize three points:

1. AMSAT exists because of a relatively small group of dedicated volunteers. We need to expand that group to keep from "burning out" our key assets, volunteers.

2. We need to learn to communicate better and to be more patient with things that are accomplished by volunteer actions.

3. With our ever increasing number of satellites and the magnitude of the Phase IIID development effort that will be required over the next five years, we need to actively recruit some new blood into the organization from other parts of the Amateur Radio Community. We should also set our sights on bringing new people into Amateur Radio that can help our cause.

Remember - building, controlling, and using Amateur Radio Satellites is fun! When some of the fun disappears, it is time to look for more help to spread the wealth. End of Sermon!

Keith D. Pugh, W5IU

The European Perspective
Whatever that may mean to a European.

A Paper to be read at the AMSAT Space Symposium
Washington, DC USA
9th October 1992
by Ron Broadbent, G3AAJ
Secretary AMSAT-UK

When asked to present the above title for a Paper, to be read at this meeting, I was at a quandary. In as much as:

(a) Most of my peers would be sitting out front expecting to hear how the Limey did things East of the Statute of Liberty. Some of you are aware that there is life 2,000 miles to the EAST, and that we do use amateur satellites?
(b) What the hell to tell you, that you may not already know?
(c) I did not know what you meant by perspective. I suspect you mean What goes on in Europe? Having digested that and found that AMSAT members can sometimes use one word instead of ten, I thought "The biter has been bitten."

With those words of wisdom, I sat down at the PC and the mind went blank, for a week. Some of you will know the feeling. However, because I couldn't sleep this night in August, I am now typing away at 3.30 AM. BST. There you are, you've learnt something already. What! The fact that most people who work for The Cause don't get much sleep. I know this is true because my many friends on this side of the Pond are also just going to bed when I get up in the morning, and I get out of bed at 9 AM'ish. I can hear some of your brains working the time-zones.

In Europe, as elsewhere, we have users of the complete range of amateur satellites, we have the same proportion of alligators, the same proportion who want to change the world, the same number of so called radio amateurs who whine and moan because they cannot be bothered to become real radio amateurs (we do not use the word Ham very much in the UK, it being used by the media to denote a non-skilled, un-technical idiot person who dabbles in radio). We have the same proportion who do not wish to experiment and thus improve their gear. (Most of these go back to CB radio or 2 Metre FM Repeaters and give self praise that they are working great distances, ie five miles to the nearest repeater.)

We also have a slightly less proportional body of radio amateurs who knock (English slang for criticise) everything that the National AMSAT Groups suggest. They not being members of course are able to become instant experts, and TALK but never DO!

How easy it is to sit in front of your keyboard or microphone and have a moan at your fellow man. We must be the only hobby in the world that a small percentage of members can appear to be the voice of the whole, and to be able to tell the world how good they themselves are and how bad the AMSAT system has become. INSTANTLY. One would think that no work has been carried out by dozens of fellow radio amateurs over the past 28 years which enables said groaners the ability to broadcast our problems.

We also have a fair proportion of satellite users who bring everything down to personalities. I hear remarks made that "I will not join AMSAT (where-ever) because I don't like Joe Bloggs the Pres/Sec/Editor or VP. Eng."

Gentlemen, the Joe Bloggs of AMSAT are not AMSAT the organisation, they represent AMSAT and hope to do a good job by their representation, if you want to change what they are doing, and think you can do a better job, you should come on into the pool, (pond) and enjoy the water. You can be assured of a welcome and some hard work. Perhaps the word WORK deters you?

Having given the sermon, and this was really to allow you to get used to my English accent, you will be able better to understand part two of this report, for that is really what it is.

Let me go back a little way and perhaps remind you that a few years ago the co-operation between AMSAT (USA) and the rest of the world was at a low ebb. Mainly because the lines of communications were not good, people in office were overworked and thought that the WORLD would catch up with information if it was put onto the Washington Repeaters. Remember this is not my first visit to USA. One could go on and on about the shortcomings, but it is history and need not be bought up at this gathering. (Over the beer you are going to buy me tonight maybe). Suffice it to say that we have for a great number of years to date, had 100% co-operation between European Groups and Amsat-Na. That there is full co-operation between A-NA and A-UK is not in contention. Long may it continue. Some of your own officials will explain over the afore-mentioned glass of ale tonight. (I hope in my small way I have helped to bring this about.)

This co-operation has come about largely because of INSTANT communication between Officials of every group via FAX, telephone and Email, methods that were not so readily available some 15 years ago. However there is a price to pay for this instant comms. Sometimes things happen, and get discussed (balled-up I think is the American word) before the rest of the satellite world knows whets going on. This in turn provides the minority to stand up like baying wolves and tear AMSAT apart.

I cite two instances.

The case of Satgates. That situation just grew like Topsy, such that we have now reached a situation of one side slanging another side, why? Well my thoughts are that the system was not thought through in the first place. Not every person who wants to use satellites has a PC, and not every one who uses UO-22 wants to download some of the crud that is creeping into the system. Further to have to use an automatic on all day station to get the message that you may want seems to me to be an inefficient way of communication between friends. I sincerely hope we do not have a senerio similar to some terrestrial packet systems across the world. At this time if you go on holiday and by UK regulations turn your system off, you need four days to get the Directory back again, with no certainty of getting "Your Grandson in VK land has had a baby girl name Fred" message.

I must here suggest to the Engineers that they should talk to the users if there is to be harmony from the very beginning. I also do not like to hear remarks from skilled people that , "we are not here to tell you how to use the satellites" If the engineers do not tell us users how to use their brain child how the hell are we to communicate and get the FUN part out of this fine hobby of ours? That may well be the whole crutz of the problem. I will also add the following for what is worth. It is no good saying we cannot test the USER elements until the bird gets launched, why not. As electronic, mechanical, and space engineers you produce a product that is 100% when it leaves the ground, why cannot the users system " engineers" and/or Software Gurus do the same? Mostly I expect, TIME. I know that software is not an exact science, and there will always be bugs but you could start the USER Handbook at the halfway stage instead of Six months after launch. No doubt I will hear the same old reasons after this lecture, but the fact remains that ALL recent satellite launch organisations have fallen down on this prime reason for the satellite launch in the first place. (I do know that even if the User equipment is tested for two years it can still fail, ie RUDAK on the water-tower, but we could try to get it correct in future.) It really is no good saying to 10% of the world that the information is on Packet BBS. For a start most of us never go into a BBS, there's not enough hours in the day.

Perhaps if I can blow our own trumpet a little, AMSAT-UK and UOSAT,s have had a good record on both reliability and users software. However as far as UO-22 is concerned we are still on the upgrade path. It is in this case a matter of how many of the building team can you put on the User problems. It takes, cash, time, and a dedication second to none. I cite Jeff, Neville, Ong, and a few others including the great golfer in our midst, N4HY. but it should be thought out at the same time as the first pen is put to paper when asking "Do we need another satellite" Quote of the Month from an AMSAT-UK member. "How many radio amateurs does it take to change a light-bulb? None!, they all expect Jeff Ward, G0/K8KA to do it for them."

Remember gentlemen, I stand on the side most times, and receive hundreds of "Why don't they letters" AFTER the event. We have always had the scenario of "Lets put system X on this next satellite, it will be good to do this and we will advance the frontiers of space. FOR WHOM? and the next question is.

Who is going to write the USER Manual. BEFORE launch so that AFTER launch anybody can use the satellite when it is opened up after testing?

Tell me, are we all working to the common goal of ENJOYMENT for members, or are we giving our resources to a dedicated few to enable them to build a device that enables very few to use same without having a very long pocket? That is really the thinking in the UK, and I suspect Europe. People are not against the leading edge of technology being strived for, but, when we haven't a 100% satellite for the average wage earning radio amateur to cut his back teeth on we are going down the wrong road. I am not advocating the Mode A syndrome, but we should be looking to a new SSB/CW bird, say on 2 metres/70cms which any fool and his dog can strive for with the wealth of radio amateur knowledge that is freely available. I am not an advocator of spoon-feeding any section of society.

I can also tell you at this date that some officials of AMSAT-UK and members who, in the past have given generously to the cause, are now opting out of being members. The other reason given is that they can get all the information they want FREE of BBS and Oscar 22 and 23. So you cannot win.

Then there is the difference in the way that the USA perceive amateur radio and the way we do in Europe. I suggest that this little problem needs a sort out.

In the USA I believe the attitude is fostered that amateur radio is for Education and that Education means of use by Educationists ie Schools and Universities. In Europe the Radio Amateur License Schedule states that it is awarded for SELF-Training in the hobby of Radio. A subtle difference which I personally believe will cause problems in the future. Why, because gentlemen I predict that if Educational Establishments get their hands on our bands you will not have many bands to play satellites as you know them today. I predict that the Civil Servants in The Ministry of Education will regulate the bands such that we will all have to have cap and gowns before we can attempt to use a satellite. I hope I am wrong, and in any-case will have parted this earth probably by that time. I see the SARA syndrome as that kind of threat to our VHF/UHF allocations.

Here endeth the Pep-talk.

News and Views.

Radar Interference. UK. That we have a problem with the North Yorkshire NATO radar system is certain. This radar is the cause of great interference from a line mid Wales to the Wash North at least up to the Scottish boarders. That some hot heads have been shouting about what our national society should or should not be doing is also a fact of life. What I can tell you here today is that the same as you have three sites in this country it will be a long time to get them off the 70 cm's Band. The NATO folk know they are Prime users and they all have a dedication that says they are right in protecting the world from you can all guess what.

Suffice it to say however there are a few folk who have been able to get the UK system cleaned up somewhat, not by shouting and sending letters of abuse, but by giving facts and figures to "technocrats" that had no idea what a dB was, or that we do have satellites in the band. At least the UK system O.i.c. the looooong range radar are fully aware of the trouble to ALL services Police, Ambulance, Fire and others, including Amateur. Those people who have helped know who they are and it is not for public record at this symposium.

As an aside, the barbed wire on the perimeter fence some five miles away from the site actually pings when the sweep pulse comes around. This is being looked into by certain parties.

The AMSAT-UK Colloquium 1992.

Some of my audience here today will have been at this annual shin-dig of AMSAT-UK. I know that every one enjoyed themselves, and we were pleased to see the USA AMSAT gang there once again. We had 32 lectures and talks/demos in the Three days, plus at least 8 hours of what we call the International Day. This is a day only of Politics. Anything and every thing to do with changing the world can be input, and always is. Most of the items have in the past not been recorded, which has caused an argument in itself, ie We said at Colloquium we would do so and so, it's not being done, why not. Well, that day is put on and paid for as a talking shop or brain storm meeting. Regulations and Implementation is the job of your elected officials at ITU, IARU, and if you wish National Societies Committees. IF you wish to be seen as a democratic bunch of special interest groups.

I have this year been able to twist the arm of the Opening Speaker to Colloquium to do another job, (nobody get a free meal, hi) that of Minute Secretary, or Put it down in shorthand form I'll sort it out. Ing" Smudge" Lundagard, G3GJW. RSGB Past President. Chairman of RSGB Finance Committee, did just that, and you can read the results if you purchase the Proceeding of 1992 Colloquium. A copy is shown here today. Colloquium next year, which I have already booked the University of Surrey for is on 29th July 1993 for four days.
You are all welcome, why not hire a 747 this time.

SARA. We have had a few folk who wish to buck against the system and allow others to use radio amateur communication frequencies which have been very hard fought for, to put non-radio amateur (as defined by ITU regulations) into the two metre band. What ever there reasons SARA is not a RA satellite, and I would suggest AMSAT-NA comes off the fence and says so. It also is not Oscar 23.

It may be in an amateur band by various means best known to certain back doors merchants but because you place a dog in a cats basket it ain't a cat, it's still a mongrel. Which of course brings us nicely to KITSAT-1. Because of the planned confusion about "Oscar 23" the world became confused about what to call Kitsat. Luckily we had our friend Jeff Ward at the Command Station in Korea to advise and assist the Koreans. They must have thought the world of amateur radio mad at that time. Jeff advised that it was KO-23, and I hope now that the matter is closed. I will add that the WARC'92 Papers do now state a band of frequencies right across all ITU Regions that designate where amateur and scientific satellites should be placed in. it is not Two metres. See Final Acts of the World Admin. Radio Conference. 1992. in the UK available from: Radio Agency. London. SWI. UK. 137.00-137.175-137 and 137.175-138 Mhz. There are also others. This came about, I am informed, by the strong protest by UK at the WARC'92. So you see radio amateurs can get things corrected if they go about it in the right way.

I would command you to the teaching of a profit in your own land. W. Deming, who by his example and teaching in Japan , and later in his own land (USA) that Competition, ie Incentives to make a bigger and better Yo-Yo is not the answer to a better output or profitability. He advocates that not only does Co-operation between ALL parties produce more output but can improve the end product by cutting out Waste, Time and Fatigue. This is Quality Control at it's best. Should be the aim of a lot of factions within our hobby, but NOT to the extent of a prize for best effort. In my Bowling Club in Wanstead, London, (where some of you have tasted a good glass of English Beer) there is written a notice. "Let it be an honour that you have been selected to play the game, we cannot all be Captain of the team."

During the year three European AMSAT Groups asked and were granted Affiliation to AMSAT-UK. Some of you may have seen my ugly mug presenting various Presidents Of National and AMSAT Societies with our fine Affiliation Award. Those Groups are Spain, Denmark, and Portugal. We, AMSAT-UK have already started some dialogue with the Portuguese Authorities over there intended use of an amateur band for non-amateur radio use. I do not wish to say any more on that subject except that both sides are being very responsible in their approach against certain I fear Political demands.

During and after Colloquium'92 we had full information about Arsene and the long delays to that launch. Bernard Pidoux has stated that he thinks the launch is firm for 1993. He has written a Paper on this which is in the Proceeding of Collq. It is long overdue, but I believe there were problems from the beginning with one faction against another. There should be a lesson there for us all.

Band Piracy. We appear to have certain groups within the UK and across Europe who find the areas of top end of bands seldom used. ie the Amateur Satellite Service Bands. Said groups are looking at these bands to extend their own particular mode of operations in our joint hobby. If I may, as one who has been at the forefront of most of the RSGB IARU potifications for the past 30 plus years, and present at the last four IARU Tri-annual Conferences make this plea.

We, on your behalf fought for a long time for recognition for amateurs satellites and for those satellites to have a series of bands where we would not interfere with terrestrial signals and terrestrial stations would not interfere with satellites. Like all people starting a new hobby there is a period, about six months where most newcomers begin to feel they know every thing there is to know about their particular mode of operation. They then start to look at ways to increase their pleasure. One way is to get other frequencies because "we are too crowded". Such is the case in some parts of Europe, including the UK. That there is not too much satellite activity in their neck of the woods, is thought to be an absence of amateurs in the area. Lets grab it, if we can!. Little do these people realise that the very bands they are trying to grab for Packet, EME, Moon Bounce or SSB Repeaters are the reason we enjoy TWO services in ITU not ONE as previous to 1979.

I firmly believe that if it were not for the stalwarts who stood up to defend our bands in 1979 WARC, we would not be in a position today to ask for more bands on SHF and the Gigahertz range. I would ask those people who have only the Grab at all costs attitude to amateur radio to step back a pace and think long term. Radio amateurs do not get credence from maintaining a FM Repeater Network be it Packet or Voice. They do get credence from showing the commercial and military world that we can go up to and beyond the leading edge. Mainly because we are radio amateurs and have no budget to worry about, (well most times) and no masters to satisfy.

That appears to be all I wish to say, no doubt there will be questions or even answers knowing some of my friends here today. I hope I have given you a feeling about Europe AMSAT, and not bored you to tears.

Finally. Thank you for having me at Symposium, although I can come by right of Life Membership it is always nice to be asked by your peers to speak. Mr. President and members of AMSAT-International. Thank You.

Ron Broadbent. G3AAJ. Editor Oscar News Honorary Secretary AMSAT-UK. IARU Region 1 Rep. IARU. Member IARU-RSGB Steering Committee.

Third International AMSAT Phase 3D Design Review Meeting
May 25 - 28, 1992
in Marburg, Germany

Minutes by Peter Guelzow, DB2OS

AMSAT-DL Journal, Nr.2/19 June/August 92
Translated by Don Moe, DJ0HC/KE6MN

Monday, May 25th

Karl Meinzer welcomed the numerous participants attending the third international Phase-3D Design Meeting in Marburg.

Launch status

He went on to report on the current status and development schedule of the Ariane-5 rocket. Previously P3D had been assigned to flight AR402, which is scheduled to launch in the Spring of 1996. Due to several delays however, a reassignment to AR401 is under consideration. The first test launch of a Ariane-5 with P3D would then occur in October, 1995. Karl Meinzer emphasized that we should not count on any launch delays in our plans.

Review of action items

The list of action items from the previous meeting was then reviewed and the various groups and individuals reported their progress.

Propulsion

Karl Meinzer reported on the possible availability of two 400N motors and is rather optimistic. On Wednesday Mr. Messerschmidt from the University of Stuttgart will report on the plasma thruster. Dick Daniels and Dick Jansson will report on the progress in obtaining tanks and the associated plumbing and valves.

Flight attitude control and determination

Unfortunately no answers were available regarding use of star sensors and possibly a CCD camera with a fish-eye lens, nor for the gyro or an X-band receiver as earth sensor. Karl Meinzer and Tom Clark will report on the possibilities of determining flight attitude by means of FM interferometric techniques. Karl Meinzer will then report on a study to use momentum wheels for 3-axis stabilization. Tom Clark will report on antennas for the GPS system; however, an engineering model for 3-axis position determination using GPS is not available. For general demonstration purposes, he brought along a commercial portable GPS system, which allowed a comparison with Matjaz Vidmar's home-built GPS receiver (including both hardware and software). In a field test, both units provided nearly identical results. Tom Clark would like to propose a clock standard based on the GPS signals or the Swiss atomic clock.

Orbit

Unfortunately the participants concerned could not provide a long-term analysis of the orbit in regards to the launch time, argument of perigee, etc., so that Karl Meinzer will ask Victor Kudielka, OE1VKW, to perform an analysis.

LAN

Peter Guelzow and Bob McGwier will report on the early results and suggestions for a LAN (local-area network) for the IHU.

Payloads

Mikiyasu Nakayama from JAMSAT will present an extensive report on the development progress regarding a CCD camera for observing the Earth and the planets. No other groups or experimenters have proposals for building a CCD camera or their projects have been withdrawn.

[As to other items on the action list, there were various announcements or reports which will be covered in the course of these minutes.]

Satellite structure

Before Dick Jansson proceeded to describe the aspects of the satellite structure in detail, Karl Meinzer commended his particular contribution and the quality of the results.

Since the first meetings, Dick Jansson has investigated various configurations from a 6-sided to a 12-sided structure and their associated advantages and disadvantages. The result is a 6-sided structure with hinged solar panels. In the meantime numerous modifications have been made to it, including the use of so-called heat pipes to conduct heat away from the sources. Various possibilities were investigated for the hinge mechanism of the solar panels. With the aid of very extensive AutoCAD drawings, Dick Jansson explained the important mechanical details of the P3D satellite structure and the standardized module boxes. The corresponding drawings are available to the experimenters upon request.

Additionally, Wilfried Gladisch has designed a new AMSAT P3D emblem which was presented to the participants. The Weber State University may produce the corresponding T-shirts.

Dick Jansson reported further on the mechanical design of the conical adapter based on the design and suggestions by Konrad Mueller. The raw material for manufacturing the adapter rings is already underway to Germany for the precision work at a facility in the vicinity of Marburg, where the cost of US$ 30,000 is considerably cheaper than in the USA. There the cost would have amounted to between US$ 80,000 and $100,000. Unfortunately ESA still has not provided final dimensions for the adapter rings, only preliminary values, so that the work on the flight versions cannot yet be started.

Dick Jansson also presented very encouraging results of a finite element computer analysis in which the static and dynamic behavior of the conical adapter was simulated.

The Weber State University in Utah will provide an integration room where the entire adapter can be assembled using appropriate assembly and measuring equipment. An assembly table with a mini-crane has already been built. A 72x72 inch shake table is also available. However, it is still uncertain whether this table is suitable for the entire satellite. Karl Meinzer expressed the reservation that ESA only accepts a qualification test with a satellite model in which the load of the other satellites (Cluster) is taken into consideration. For P3D this would mean an additional mass of nearly 3 tons on the upper adapter. Furthermore, the vibration test must take place with the final solar panel configuration.

Dick Jansson continued his presentation with a report on the use of so-called honeycomb material in place of sheet metal and proposed areas for its use in the P3D satellite. However, Karl Meinzer expressed great reservation about its use particularly in regards to the electrical properties, such as ground and HF shielding. In order to obtain reasonable grounding points, additional ground connections would have to be mounted, since the honeycomb material is non-conductive internally and thus no reliable ground contacts are possible at the mounting points. This results in a significant number of grounding lines and the danger of ground loops. There is also the danger of electrostatic discharges, such as ECS has experienced. Hanspeter Kuhlen mentioned that in P3D significantly greater currents will be flowing due to the high power transponders. The ground potential for the module boxes is normally the satellite structure and Karl Meinzer considers a ground resistance of less than 10 Milliohm to be essential. An additional disadvantage is the HF shielding, which is very important due to the number of transponders and other experiments. Dick Jansson then explained the mounting of the high power modules which are equipped with additional heat pipes and corresponding cooling surfaces. Tom Clark regards sheet metal as preferable due to the better heat conductivity, which also should be considered. Karl Meinzer identified the main problem in effectively conducting the power dissipated by the high power modules, such as transponder power amplifiers and the power supply for the plasma thruster. The antenna surfaces cannot be used for radiating the heat since the dielectric of the patch antennas acts as a heat insulator.

Sheet metal also has a significant weight advantage over the honeycomb material, by nearly a factor of 2. In order to achieve the same stability, additional reinforcements (stringer) will be attached at the necessary locations. The correspondingly positive experiences have already been made with Oscar-10 and Oscar-13 and have already been demonstrated in the 1:1 P3D model at AMSAT-DL. Karl Meinzer would only use the honeycomb material where it is sensible or absolutely necessary.

Dick Jansson emphasized that the current design still is not final and that several improvements and refinements will be performed on the structure.

In conjunction with his slide presentation, Kelly Harward introduced the Mechanical and Manufacturing Engineering Department at Weber State University. The institute is equipped with very good machines and also has suitable facilities for building the large P3D structure. On the basis of a friendly partnership, a great deal of support can be expected, from which both AMSAT and Weber State University can benefit.

The unfinished rings for the conical adapters were evaluated there before being repacked in appropriate transportation crates for the journey from the USA to Marburg. The four unfinished rings have a total weight of nearly 4 tons!

Ralph Buttler of Weber State University reported on the possibilities of performing a vibration test and possibly even the thermal vacuum test.

Dick Jansson then reported on the mounting platform for the motor and with the aid of additional AutoCAD drawings showed the assembly of the individual fuel tanks and the motor. Approximately 220 KG of fuel and oxidizer are required, plus 45 KG of ammonia for the plasma thruster (ArcJet) and a helium pressure tank.

Using slides and drawings by Wilfried Gladisch, Karl Meinzer explained the design of the AMSAT-DL P3D 1:1 model in all detail, built however without honeycomb material. The AMSAT-DL P3D structure was designed and built by Konrad Mueller and his team. A common terminology was defined for the three arms and the inner segments based on the X, Y, and Z axes as references.

Dick Jansson further presented a study concerning the thermal design of the satellite structure, assuming a power dissipation in all three segments together of approximately 400 Watts. Two alternatives had been investigated: three solar panels, two of them on hinges and the third on the front side, along with 16 heat pipes; or only two hinged solar panels without heat pipes. The 16 heat pipes cost approximately US$ 60,000. This configuration yields temperatures between 20 and 30 degree C depending on sun angle. For Karl Meinzer this range is too high. Only sun angles between +/-45 degrees are relevant and the temperature should be reduced by at least 10 degrees C. A temperature range between 0 and maximum 20 degrees Celsius should be the goal. The inside temperature of Oscar-13 was calculated for 10 degrees C, which has a correspondingly positive effect on the power stages and systems with higher dissipation as well as the lifetime of electronic components in general.

Another aspect was the mechanism for extending the large solar panels. During launch and the initial orbital maneuvers, the solar panels will remain flat against the satellite. Only after the satellite has accomplished the transition from spin to 3-axis stabilization, will the solar panels be extended. Dick Jansson briefly described the design of the solar panels using honeycomb material as support and presented a design for the retaining clamps and the extension mechanism. Karl Meinzer criticized this mechanism due to its complexity. Any mechanical distortions, for example caused by large temperature differences, would cause serious problems. He referred to the adverse experiences with comparable extension mechanisms on some commercial satellites. This mechanical link must be as simple and secure as possible. Instead of a mechanical latching arrangement, he considers pyrotechnic cable cutters to be significantly more reliable. This approach also applies to the hinges and spring mechanisms. A swinging-door mechanism, similar to a department store or saloon as suggested by Werner Haas in Orlando, is much more secure in his opinion. In this area further study definitely still needs to be done. Bob Stilwell will provide design drawings of the saloon-door mechanism.

Batteries

NiH batteries manufactured in 1983 and currently in cold storage have been made available to Weber State University. Since these batteries have no further commercial value after such a long storage period, they have been donated to the project at no cost. The cells have a design capacity of 35 Ah. Karl Meinzer considers it essential that a test procedure be developed to ascertain the condition of the cells. Furthermore information is needed regarding their long-term behavior. In the operational phase of the P3D satellite, these batteries would be nearly 20 years old. Weber State University will contact the manufacturer to obtain further information and will possibly strive to acquire newer batteries. Freddy de Guchteneire and Hennie Rheeder will look into test possibilities and the corresponding procedures. James Miller will contact the University of Surrey whether they might be willing to develop a appropriate testing program and to define which parameters of the 10-20 year old NiH batteries need to be evaluated so that their suitability for P3D is assured. In regard to the whole question of the batteries, Larry Kayser in Canada should be consulted. Dick Daniels and Karl Meinzer will conduct the corresponding conversations.

Satellite antennas

Jack Colson and Bob Stilwell from John Hopkins University reported on the progress on development of suitable antenna fields for the P3D structure. Involved in the project are primarily engineering students who have a challenging field of endeavor and the results benefit AMSAT. The conceptual study mainly concerns antenna system designs for the 435 MHz (70cm), 1269 MHz (23cm) and 2401 MHz (13cm) bands. Building the corresponding antennas later is also possible. With the aid of a 24 page presentation, Bob Stilwell explained the process of developing the various antenna designs and the results with each one.

At the start, the requirements of the antenna pattern were determined based on simulations of P3D's orbit taking free space attenuation into consideration and then the necessary antenna groups were computed. For all bands, short backfire antennas (SBFA) were selected. Short helix antennas and micro strip patch antennas were also investigated, but they yielded lower gain. For 70cm the likely candidate would be a short backfire antenna with a diameter of 1.35 wavelength, gain of 14.1 dBi and a beam width of +/-20 degrees. For the 13cm S-band, an array of 19 short backfire antennas has been chosen. A single antenna achieves a gain of approximately 15 dBi at a beam width of approximately +/-16 degrees and will be used in the perigee period for better coverage of the earth. At apogee all 19 antennas will be driven together to provide a gain figure of 18.5 Dbi at a beam width of +/-9 degrees. In order to realize a better antenna pattern, the gain is reduced from the maximum possible. The space required for this array is less than 1m in diameter. For the 23cm L-band, a comparable antenna design with seven elements is currently being investigated.

A network for feeding the antennas is being recommended in which each antenna is associated with a power amplifier stage, as had also been suggested at the previous P3D meeting. Further design studies and refinements based on the results from this P3D meeting are planned in the future. Additionally an electrical model of the various antenna elements should be built and tested on an antenna test range. A further area of activity is a design of the antenna matching and feed circuitry and further computer simulations of other antenna configurations.

Karl Meinzer was impressed by the outstanding results and emphasized that this study answers most of the questions raised at the P3D meeting the previous year. He suggested looking into the possibility of a continuously variable phase shifter.

Matjaz Vidmar expressed the opinion that it is even possible to achieve around 18 dBi gain with a single short backfire antenna. He will provide Karl Meinzer with a reference to the corresponding literature as soon as possible. A physical separation of the antennas would also not be absolutely necessary.

James Miller raised the question about what would happen if an antenna or final amplifier stage should fail. Karl Meinzer explained that this should not have any catastrophic effects, the antenna pattern would only be somewhat distorted. The redundancy with one PA per antenna is quite high however and there is no danger of the domino effect, as could happen when the final stages are combined.

Stan Wood then explained his results for antenna designs for 10m and 2m. On 10m he considers an X arrangement of the antennas a good possibility for achieving 3-4 dB gain with circular polarization. He then described the 2m antenna design in detail. A circularly polarized 3 element beam would yield a gain of approximately 10.5 dB. However this would require an element on the front side of the satellite, thus casting a shadow on the solar panel. For 1.6 mm spring steel wire this would amount to nearly 2% of the electrical power. Karl Meinzer suggested analyzing the applicability of the HB9CV antenna with just two elements. For thermal design reasons, the antenna elements should be attached on the upper and lower sides of the satellite; this would also reduce the amount of coaxial cable required. Stan Wood went on to describe another antenna design with 6 elements and nearly 10.6 dBi gain.

In a detailed presentation Stan Wood described micro strip and patch antennas and their functional principles and characteristics and explained his test results. With the aid of exact scale models on his antenna test range, he has undertaken a series of measurements in order to verify the theoretical computations. With an array of 7 patch antennas, a gain of nearly 18 dB can be achieved for Mode-L (23cm). On 70cm we could expect around 16.85 dB. The antenna pattern could be optimized continuously for the desired radiation angle by controlling the power level to each individual antenna.

Karl Meinzer expressed his thanks for the comprehensive explanation of the concept. In his opinion, problems could arise due to the nature of patch antennas for filtering the transmitted signal to suppress undesired frequency spectra. The effort to provide the filters is not negligible, as with Oscar-13 for example, and will multiply in an array of separate power amplifier stages. A possible solution would be to combine the final power stages with a power combiner prior to filtering with a common filter stage, followed by a power splitter to feed each antenna. Serious problems could arise however due to lack of redundancy if a power amplifier stage should fail or a fault should occur in the common filter.

Jyri Putkonen explained the concept for the X-band antennas for the 10 GHz transponder under construction by AMSAT-OH. He was able to report significant progress and the first samples of the horn antennas and mechanical parts are already being built.

Flight attitude control and navigation

With the aid of a block diagram, Karl Meinzer explained the required system components for navigation and flight attitude control of the satellite. The core is the 300x200 mm SEU module (Sensor Electronic Unit). This unit controls the three momentum wheels that are required for active 3-axis stabilization and are each mounted in a 300x400 mm box. Additionally the SEU controls the magnetic coil system for spin stabilization and flight attitude correction at perigee. Several sensors are needed for navigation, including sun sensors and earth sensors which will be needed both during the spin-stabilized phase and later after the transition to 3-axis stabilization. A relatively inaccurate "out of range" sensor should allow a coarse determination of the Sun's position in an emergency. In the simplest case, this could be a sensor on each of the upper, lower and back sides of the satellite. A "wine glass" or fiber-optic gyro should provide short-term attitude information. This will require a module box with the dimensions 200x100x100 mm.

In contrast to Oscar-10 and 13, the primary attitude control system in P3D is based upon the momentum wheels. Additionally a magnetic attitude control system will be needed, which has performed outstanding service in the two previous satellites. Compared to AO-10 and 13, the P3D structure is even more advantageous for orienting the coils for very effective operation of the magnetic system. Karl Meinzer briefly explained the switching and positions of the magnetic coils; further study is still needed however. As in the P3A structure for Oscar-10 and 13, an exact scale model will be used to simulate the attitude control. To dampen any undesirable motion, passive nutation dampeners will be installed once again.

Karl Meinzer then went on to describe the launch scenario. Following separation after launch, AMSAT P3D will rotate at 5 to 10 revolutions per minute about the Z axis. Prior to the first motor ignition, a flight attitude correction will be performed in order to orient the satellite properly and to increase the spin rate to 10 to 20 rpm. After successful orbital maneuvers, the spin can be reduced to zero. An investigation of the dynamic processes and the best procedure for accomplishing the transition from the spin stabilized mode to 3-axis stabilization still needs to be performed. James Miller will attend to this matter. Since no other group offered to do so, AMSAT-DL will develop and build the Sun and Earth sensors.

Because the high-gain antennas will only rarely be pointing to Earth during the early phases following launch, it will be important to have low-gain omni-directional antennas on the satellite so that a secure command and control link is continuously available regardless of flight attitude. Stan Wood offered to include such omni-directional antennas into his studies.

Power supply

Karl Meinzer described the layout of the entire energy supply for the satellite. Three solar generators are connected to the battery charge regulator that will supply a regulated bus voltage of 28 Volts at up to 800 Watts of power. A NiH battery plus a spare are used for storage. Furthermore an umbilical connection to an external power source is required during the integration, test and launch phases. According to Andras Gschwindt, the efficiency of the BCR should reach nearly 99%, yielding a power dissipation of 80 Watts, which can only be conducted away via two 300x200 mm module boxes.

An additional voltage supply module with the designation EPU (Electronic Propulsion Unit) is required for the plasma thruster.

Global Positioning System (GPS)

Tom Clark reported on the possibilities of using signals from GPS satellites for interferometrically determining the flight attitude of the P3D satellite. He first explained the principles of operation and position determination with the GPS satellites and then went on to discuss experiments that would be possible with the help of GPS. With just a single antenna, an analysis of the ionosphere and troposphere could be performed by evaluating L2 and the L2 downlink, as well as determining the exact position of the P3D satellite in orbit. Thus Kepler elements would be readily available for further calculations of the orbit. During periods when the plasma thruster is continuously energized to change the orbit, such a capability would certainly be welcome. The VSOP satellite (7378/26378 km) will use GPS for the first time to obtain its own orbital data.

Two antennas would allow interferometric measurements in order to obtain flight attitude information. First however, we need to clarify how well the GPS signals can be received in the P3D orbit, since the Earth blocks the signals at times and the GPS satellites operate with directional antennas. Following an extensive discussion, Tom Clark came to the conclusion that although the GPS signals cannot be exploited continuously, they would be available at predictable times in order to calibrate the gyros, for example. The hardware for a C/A code receiver could be based on the corresponding subassemblies offered by Collins/Rockwell (Navcose) and Motorola (Six Shooter), but Matjaz Vidmar's GPS receiver could also be used after making certain modifications. A four-channel receiver (L1 downlink) from the Ashtech company may possibly be made available for use as interferometer at no charge in order to qualify it for space. The Ashtech system is currently being used aboard aircraft and determines the position with an accuracy of 0.001 degree!.

Karl Meinzer considers a test demonstration important. If this concept should prove to be a viable measuring method for long-term navigation of the P3D satellite, a much higher resolution would be available than ever before and we could possibly forego the Earth sensor. The availability of suitable hardware must still be determined.

Andras Gschwindt reported that AMSAT-Israel wants to install a GPS receiver in their Techsat satellite. Karl Meinzer may be able to exchange information in this regard at the AMSAT-UK meeting in Surrey.

P3D orbit

Tom Clark reported on his observations regarding the orbital stability of Oscar-13 and the consequences for the Phase-3D orbit. He mainly repeated the study that he had presented to a smaller audience at the P3D meeting in Orlando.

Hennie Rheeder next raised a matter regarding the intended orbit for AMSAT P3D. He had been asked by AMSAT-LU to represent the concerns of stations in the southern hemisphere. Graham Ratcliff of AMSAT-Australia had also sent Peter Guelzow a corresponding report. Both discuss a scenario in which the P3D orbit would have an argument of perigee of 270 deg. and how this would result in poor accessibility from the southern hemisphere and the lack of DX possibilities between stations in the northern and southern hemispheres. Without elaborating on the content of these opinions, Karl Meinzer stressed that at no time had an orbit with an argument of perigee of 270 deg. been stipulated, although this has apparently been incorrectly assumed. Peter Guelzow quoted a few paragraphs from the minutes of the P3D meeting in May 1991, where only an argument of perigee between 200 deg. and 225 deg. had been discussed. All concerns and agitation about a 270 deg. orbit are absolutely groundless and possibly a consequence of misinformed and non-official sources. Karl Meinzer reemphasized that the southern hemisphere is being considered in the configuration of the P3D orbit and that there are no changes in this objective.

Frequency planning

Freddy de Guchteneire is involved with the frequency coordination and has evaluated all potential frequency bands regarding their availability in the various IARU regions. For the X-band transponder, the band at 10.450 GHz is being recommended so that terrestrial users could experiment via P3D without making major changes to their equipment. Mutual interference is unlikely due to the extreme directivity of the antennas. Similarly there are no problems in the 24 GHz band. The proposed 5.6 GHz transponder presents difficulties however since there is no downlink allocation in Great Britain, for example. The 2.4 GHz band is in jeopardy (WARC92), since various radio services (mobile radio, digital broadcasting) are applying pressure for access to this range. There is unfortunately still no news regarding an allocation for a 23cm satellite downlink, however the efforts are continuing. On 70cm and 2m there are no problems other than numerous satellites must share the up and downlink frequencies. For P3D the same downlink frequencies on 2m will be recommended as Oscar-13 since it will likely reenter the atmosphere by the time P3D is launched.

Peter Guelzow reported on the significant problems with radar interference on 70cm which severely hinders command of Oscar-13 and Oscar-21. Freddy de Guchteneire indicated that all frequencies above 146 MHz in the amateur radio service are only a secondary allocation and thus nothing can legally be done about the radar interference.

In the 10m satellite segment there are basically no difficulties. However, Freddy de Guchteneire was asked to check the allocations in regions 1 and 2 for a 10m downlink. The RUDAK group has also requested suggestions for suitable downlink frequencies for the RUDAK beacons. In this regard, Freddy asked all concerned groups for more exact specifications such as bandwidth, transmit power, etc. for the intended transponders.

In conclusion he considers it important that P3D be more widely promoted to the public as an international amateur radio project in order to receive stronger support through the IARU.

10 GHz transponder

Jyri Putkonen, Michael Fletcher and Esa Haakana presented an extensive report on the progress in developing an X-band transponder by AMSAT-OH. With the aid of diagrams, the limitations were explained regarding accessibility and Doppler shift in the P3D orbit. At apogee the Doppler shift amounts to only 200 Hz per minute, at perigee however around 5 kHz per minute. Currently they are checking into the possibility of performing a coarse compensation of the Doppler shift in the satellite transponder in order to minimize the frequency shift on the ground. Problems can arise however for ground stations that compute the Doppler shift by computer and compensate for it automatically.

Following a thorough discussion of the hardware for the receivers and transmitter modules, the matter of antennas was addressed. The X-band antenna consists of a 2x2 array of horns whose antenna pattern can be aimed in any direction up to 10 degrees by means of a phase shifter stage. Control of the amplitude is currently under review.

RUDAK-III

Hanspeter Kuhlen presented a progress report on the RUDAK system for P3D. But first he reviewed RUDAK-2 on the AMSAT Oscar-21 satellite and expressed his thanks particularly to Gerhard Metz and Peter Guelzow for their tireless efforts in putting the RUDAK experiment into operation. Following the launch significant difficulties arose due to irregularities in the command and control system as well as the power system of AO-21. Only after numerous attempts and with the help of AMSAT-U could the problems be localized and a suitable solution devised.

Just prior to the meeting and for the duration, RUDAK was in operation in an FM repeater mode using the RTX-2000 DSP processor. Operation over the RUDAK transponder using only a normal hand-held radio was impressively demonstrated to interested participants on several occasions. The RUDAK-2 hardware functions perfectly well and is in excellent shape according to recent tests.

With the help of a block diagram Hanspeter Kuhlen then went on to describe the concept for a RUDAK system aboard P3D. RUDAK should provide a mailbox system with store and forward (S&F) capability as well as support real-time contacts as a digipeater and gateway. The S&F mailbox will need a large capacity RAM disk. Additionally RUDAK should provide storage of the extensive data from other experiments, primarily photos taken by the CCD cameras of the SCOPE experiment, and make them available via the mailbox system. RUDAK will thus exchange picture data with SCOPE via a high speed link.

For the radio links, receivers and transmitters are planned for 1200 Bit/s PSK (compatible with FUJI), 9600 Bit/s RSM and 64 KBit/s QPSK. The 64 KBit/s link should be used mainly for gateway operation and teleport stations, but also for high-speed transmission of photos from the SCOPE camera system. However this would require more elaborate antennas than for 1200 Bit/s. To the extent that resources and space permit, as many uplink channels as possible should be implemented to minimize collisions. Extensions to the protocol, such as DAMA, are also under consideration. Two or three modules of 200x300 mm each are currently allocated to RUDAK.

S-Band transponder

Josef Koeferl reported on his concept for an S-band transponder based on the HELAPS principle. The output power should be in the range of 40 to 50 Watts. The 50 W S-band transponder is being suggested in addition to the high-power Mode-S transponder. Higher transmitter power levels are possible in his design according to Josef Koeferl, but he anticipates problems in accomplishing the work. Freddy de Guchteneire, Hermann Hagn and Knut Brenndoerfer offered their support. AMSAT-DL will assist in obtaining the high-power HF transistors.

Subsequently Dick Daniels reported on the latest status of development of the high-power Mode-S transponder from Jan King and Gordon Hardman, in which a PA module has been built with 20 Watts of output power. According to this concept, each individual antenna is assigned to a separate PA module, so that a high power level is achieved by phasing the individual antennas.

24 GHz receiver

Knut Brenndoerfer and Hermann Hagn expressed their willingness to build a 24 Ghz radiometer. A small horn antenna will be mounted on the satellite.

10m transmitter

Hennie Rheeder reported on the status of the 29 Mhz high-power transmitter from AMSAT-SA. The transmitter employs compatible AM modulation (CAM) and can thus be received with simple AM broadcast receivers. General amateur radio bulletins and educational information will be transmitted in voice that is stored in the control computer. Hennie Rheeder reported further that in the meantime a third engineering model consisting of an HF section and final amplifier has already been tested. The complete system, mainly the digital section, has been reworked almost completely.

A CAM transmitter with 100 Watts of output power and 75.4% efficiency has been tested over a longer period of time. The flight version should achieve 200 to 300 Watts at an efficiency of 77%. To dissipate the heat, two stacked module boxes of 200x300 mm were allocated. Hennie Rheeder was asked to provide an estimate of the entire power consumption.

Mode-B and Mode-L

Werner Haas of AMSAT-DL will build the 70cm and 23cm receivers, the LEILA system, the modulator as well as the 2m and 70cm high-power transmitters. Three module boxes of 200x300x20 mm will be needed for the Mode-B and Mode-L HELAPS modulators and receivers. These modules can be stacked. Due to the power dissipation, six additional module boxes of 200x300 mm will be needed for the transmitters. One more module of 200x100 mm will house the transponder matrix.

RF Ambient Monitoring System

A year ago Andras Gschwindt from the University of Budapest had proposed a receiver covering the range from 100 Khz to 50 Mhz for monitoring the condition of the ionosphere. At this meeting he presented the first status report. Current planning provides for a combination of receivers aboard a satellite in a low Earth orbit (LEO) and aboard the P3D satellite. At present the project is still only a feasibility study and financing remains questionable. The project is being promoted by the university as a scientific program, but partners are needed to build the experiment and to evaluate the subsequent data. The power consumption will be less than 10 Watts and a single module box of 200x300 mm will suffice.

Scientific experiments

Under this heading, Tom Clark presented several proposals from various groups and institutions. One involves using GPS for tomographic analysis of the upper layers of the Earth's atmosphere. Other proposals from GSFC concern particle detectors for measuring particle radiation, as well as a VLF/LF plasma experiment for measuring lower frequency spectra. Some doubts arose due to possible HF interference from the many microprocessors that will be in operation aboard P3D.

In this regard, Karl Meinzer indicated that inside the satellite there will be high levels of interference and HF noise, whereas the environmental conditions outside the satellite can be considered "clean" and this should be maintained appropriately by the payloads. Andras Gschwindt is interested in a cooperative effort on the VLF/LF experiment and that group should make contact with him. Tom Clark reported further on a proposal from NRAO to fly a 47 Ghz beacon for calibrating radio telescopes, but its signal would be too weak for use as a beacon by most amateurs.

SCOPE

Mikiyasu Nakayama presented a status report on the SCOPE project of JAMSAT. (Spacecraft Camera experiment for Observation of Planets and the Earth) SCOPE should provide the users with various types of color photos in a suitable picture format, such as GIF or JPEG. In all, three different CCD cameras are being developed which will take photos of the Earth, of the Earth with stars in the background and of the planets. The cameras can be operated independently and contain their own control electronics with 4 MByte of RAM for picture storage. The picture resolution will be 732x580 pixels, although an alternative with 1024x1024 pixels is currently under study. SCOPE will communicate via a high-speed data link with the RUDAK system which would handle the transmission of the pictures as part of the PACSAT S&F facility. All control functions of the camera and loading of software would also be handled via RUDAK. If necessary, SCOPE could also have direct access to one of the receivers. Additionally, SCOPE could conceivably broadcast real-time photos over a suitable high-speed beacon. Exploitation of the picture information for navigation and flight attitude determination would also be possible.

There is some concern about the lifetime of the organic color filters within the CCD chip in a radiation environment. According to Karl Meinzer, a one-hour radiation exposure with Cobalt-60 is equivalent to 10,000 rad and would be an adequate test. Cameras A and B each need module boxes of 300x200x100 mm, and because of the large lens, camera C requires a box with 200x200x800 mm. At present two experimental versions of the cameras are being tested and the first prototypes should be ready next year.

GPS receiver

Matjaz Vidmar reported on his GPS receiver. He has developed the receiver, the computer and all software himself. The system is based on a 68020 processor for computing the exact position based on the C/A information being transmitted by the GPS satellites. An exploitation of the P code, which allows an even more precise determination of position, is too complicated and this code is also not available continuously. For the GPS interferometer he recommends a configuration with 4 individual antennas, where three antennas are separated by 2m and the fourth antenna is mounted 20cm from one of the other antennas. This would allow ambiguity to be readily resolved. Matjaz Vidmar has built not only a GPS receiver, but also a receiver for the GLONASS satellites of the CIS (former Soviet Union). The GLONASS satellites are principally comparable to GPS. For Phase-3D he recommends receivers for the GPS and GLONASS satellites. The hardware can be built around processors from the 68000 family, as in his own design, and only 64 KByte are needed for the software. A single module box would suffice for the entire system.

ESA experiments

Karl Meinzer reported that as part of a research program, ESA (ESTEC) will provide the solar generators for the P3D satellite. Furthermore there is interest in flying a rubidium atomic clock as a time standard aboard P3D. The time information must be broadcast via beacon in some suitable manner. Tom Clark suggested simply determining the difference to GPS time and regularly broadcasting the result over the RUDAK downlink and in the telemetry. A 200x300 mm module box was allocated for the atomic clock.

IHU-LAN

As next in line, Peter Guelzow described the idea behind a local area network (LAN). The term LAN means a local network over which all modules communicate with each other and in particular with the IHU (Integrated Housekeeping Unit). The IHU receives all telemetry data from the various satellite systems via the LAN and sends appropriate control commands to specific modules, such as to switch the transponder on or off. The main purpose is to drastically minimize the cable harness, which had already become quite extensive in Oscar-13. This would also improve the flexibility during the development phase. The LAN could be simulated on a PC in order to test the corresponding modules on the work bench completely without needing a connection to the remainder of the satellite. Furthermore, without additional wiring it would be possible to add new modules or experiments to the system or leave out experiments that were not functional in time for the launch. Point-to-point wiring presents additional difficulties in tracking down errors and the reliability decreases with the increasing number of cables and contacts, along with the added space and weight. The electromagnetic susceptibility is also a factor to be considered and a LAN offers several advantages in this regard.

Peter Guelzow outlined initial ideas for implementing a serial bus system, but a final solution was not yet available. The module controllers for the LAN bus consist of a suitable microprocessor with digital inputs and outputs, as well as numerous ADC inputs for analog signals. Bob McGwier recommended the 68HC11 micro controller and presented an initial prototype.

A discussion then ensued about the demands on the LAN regarding safety in case of failure. It must be assured that no module controller can block the entire bus if, for example, a driver stage should cause a short circuit or a module controller experiences a software crash and continuously swamps the bus with random data. The LAN bus must also be suitably built to prevent a short or open circuit. Karl Meinzer considers the safety factor for a single mode failure to be adequate. For this second case, Peter Guelzow suggested an additional EB line over which an individual module could be completely switched off by hardware command decoder, so that it would no longer block the LAN. Gerhard Metz suggested including the module controllers themselves into the failure analysis and by means of additional hardware be able to take over the function of the controller with a hardware command decoder with exclusive-OR gates. In the following discussion, this idea was not regarded as particularly sensible since it increases the complexity and would not necessarily improve the system reliability.

Following further debate about the various possibilities and demands upon the LAN, the consensus was that a serial bus system (LAN) would definitely be desirable for P3D. A LAN working group should work out a concrete concept as quickly as possible, whereby the most important aspect would be safety in case of a single point failure (defective bus driver) in the LAN. The question of safety in case of single point failures of the module controllers also needs to be investigated. The IHU LAN serves strictly telemetry and control. Experimental data will not be transported via this bus, since a separate high-speed LAN is planned for RUDAK.

Joining the LAN group to work on the IHU and RUDAK LANs are Peter Guelzow, Bob McGwier, Gerhard Metz, Matjaz Vidmar, Hanspeter Kuhlen, Tom Clark and Mikiyasu Nakayama. The coordination of the IHU LAN is being handled by Peter Guelzow. Within two months, by the start of August 1992, a complete rough design for the IHU LAN should be presented to all groups. After an additional period of four weeks for comments, Karl Meinzer will critically analyze the concept. By the P3D meeting in November in Orlando, five module controllers (one for each group) are to be built and the functional operation demonstrated. In Orlando, the final decision regarding the LAN will be made. The LAN working group then met outside this P3D meeting for initial preliminary discussions.

Module boxes

With the aid of numerous drawings, Dick Jansson explained the construction details of the various module boxes and made suggestions for attaching the modules and mounting the circuit boards and connectors within them. Dick Daniels and Karl Meinzer emphasized that the boxes must be made available to the individual groups as quickly as possible. Furthermore Karl Meinzer considered it important that the mounting of the circuit boards be defined as soon as possible so that the various groups could begin designing the first circuit boards. A critical review of the individual modules is important in order to reduce the space requirements as much as possible. There are already several offers to build the modules, such as by Weber State. A central manufacturing and distribution to the groups should be arranged. By the end of July, Dick Jansson and Dick Daniels should finalize a production facility.

400 N motor

Dick Daniels presented a design for the motor platform for the 400N motor from MBB. Six fuel tanks and two 400 bar helium tanks are mounted in the six arms of the platform that is itself mounted in the conical adapter. In a thermal design study he computed the heat radiated by the motor. For a heat emission of 5000 Watts, the motor nozzle will reach a temperature around 880 degrees C. The heat shield will warm to between 30 and 40 degrees C.

The fuel tanks weigh 220 Kg for 104 liters of nitrogen tetroxide, N_2O_4, and 82 liters of aerozine, AZ50, plus 40 Kg for ammonia, NH_3. Additionally there are 25 liters of helium. Regarding the tanks, Dick Jansson reported on the availability of tanks from

Structural Composite Industries, which would start production upon receiving an order. At a cost of US$ 250,000 however, the price is certainly not trivial. Professor Ernst Messerschmidt suggested that the availability of tanks from the Russian space program should be looked into. Peter Guelzow was asked to contact Leonid Labutin in this matter.

Regarding the plumbing for the motors, Dick Daniels has determined that all necessary parts are available on the market and the design is comparable to Oscar-13. Still to be determined however, is to what extent the tanks could be emptied after filling, since the C.S.G. has issued corresponding safety regulations.

ATOS

To perform fine adjustments to P3D's orbit, a plasma thruster will be supplied by the Institute for Space Systems (IRS) at the University of Stuttgart. The institute is directed by Professor Dr. Ernst Messerschmidt, who participated as a German astronaut aboard the D1 mission and operated amateur radio from the Space Shuttle under the callsign DP0SL. His own callsign is DG2KM. Professor Messerschmidt and his team came to the P3D meeting in order to present their ATOS project to the other participants.

First however, he provided an overview of the facilities at the University of Stuttgart, which among other things is also involved in space flight research. At the Institute for Space Systems different variations of electrical plasma motors have been developed and tested over a long period of time, including for example MPD motors at power levels of 20 KW to several megawatts. The institute has eight vacuum test chambers for motors up to a electrical power level of 1 MW. The necessary power supplies can provide up to 6 MW of power or 48 KA with less than 1% ripple. A 800 KW motor achieved an ISP of 1500 with an efficiency of 25%. Besides the MPD motors, which operate with ionized gas, the so-called thermal arcjet plasma motors are a further area of interest. Various high power motors with 1N thrust up to a 1KW hydrazine arcjet have been developed.

Ernst Messerschmidt then invited his team member, Dieter Zube, to describe further details of the ATOS thruster and present a status report. ATOS is the project designation for Arcjet Thruster on Oscar Satellite. Nearly 600 Watts of electrical power have been allocated use by ATOS on Phase 3D. The thruster employs ammonia as fuel which is heated in an electric arc. Conventional chemical motors, such as the 400N motor, are limited in energy, meaning only as much energy is available as is bound into the fuel as chemical energy. Electrical thrusters however are only power limited, thus dependent only upon the available electrical power. Electrical arcjet thrusters heat up the fuel in an arc so intensely that the resulting expansion provides thrust. Nearly 35% of the electrical power can be thus converted to propulsion. With the aid of a scale model, Dieter Zube explained the internal features and the functional principles of the ATOS thruster.

To ignite the arc, a voltage of nearly 3000 Volts is required, then the arc continues to burn at 28 Volts and 20 Ampere (+/-10 A), so that the EPU power supply must provide approximately 600 to 750 Watts of power. A laboratory model of the thruster has already been successfully tested and additional work is being done on the geometry of the jet and the electrode. The preliminary test results are very positive. AMSAT-DL, under Karl Meinzer's direction, has developed a high capacity power supply (EPU) that is currently in an early test phase. In contrast to customary power supplies, this EPU is significantly lighter and smaller. At a mass flow rate of 30 mg/s, a thrust of nearly 120 mN can be achieved at a specific impulse (ISP) of 425 s.

The flight version of ATOS is in an advanced design stage and construction should begin in the Summer of 1992. A test fixture for determining the lifetime of the thruster should be completed in June 1992. The measuring equipment will be complete in the Summer so that the first long duration test can begin in September 1992. The control electronics for the thruster (ACE) and the fuel system have also been completely specified.

The flight version of the thruster has a length of 200 mm. To minimize the electromagnetic interference (EMI), a coaxial construction was chosen for the thruster. The supply voltage must be fed via a connector capable of handling 3000V/30A and of withstanding a temperature range of 150 to 200 deg. C. If a suitable connector cannot be located, a screw attachment may have to be used. The thruster nozzle will reach temperatures around 1200 deg. C. A 75 liter tank containing pure ammonia (NH3) at a pressure of 12 bar maximum provides fuel for nearly 550 hours of operation. A main valve pre-heated to 20 to 25 deg. C assures that only gas and no fluid reaches the thruster.

The control electronics (ACE) will be in communication with the IHU via the LAN to allow the IHU to specify the activation times for the thruster and to monitor the power consumption and other parameters. Various telemetry data should provide an overview of the condition of the thruster. To this end several sensors will be needed, such as pressure sensors on the main tank, temperature sensors on the main valve, three sensors for the valve position and a sensor for the fuel flow rate (MFC).

Dieter Zube also outlined several critical effects of the thruster on the P3D satellite. The thruster nozzle will reach very high temperatures requiring that appropriate heat shielding be provided, and the thruster also conducts very high temperatures to the P3D structure. Karl Meinzer believes that these problems can be adequately addressed in the structure. During ignition and operation of the thruster, EMI problems can possibly arise in the transponders. Karl Meinzer again does not see a problem here since a simultaneous operation of the transponders and thruster is out of the question due to the high power consumption.

The lifetime of the ATOS design is uncertain. Operation with over 800 ignitions and 800 hours of operation must still be verified in a test series. Dieter Zube requested support in development of the ACE control electronics. Karl Meinzer was of the opinion that the majority of ACE tasks could be handled by the EPU, which is being built by AMSAT-DL anyway. The important decisions will be made in software by the IHU, where the entire intelligence is located. Only simple sequencers and control lines are required in the ACE/EPU. The ATOS thruster will be mounted in the vicinity of the 400N motor at the center of mass when the solar panels are unfolded.

The IRS team expressed the wish for a redundant thruster. Due to weight and space restrictions however, this will not be possible. Additionally it would complicate the fuel system and EPU so that a greater safety margin would not be achieved. In case the EPU fails and only cold gas is emitted, the thrust would amount to 40-45 mN at an ISP of 75s, so that only slight orbit corrections could be performed.

In regard to the impending orbital maneuvers, Karl Meinzer reported that with the aid of the 400 N motor, the perigee would first be raised and the orbital inclination increased to 60 degrees. The apogee would then be allowed to drift before later setting the inclination at 63.4 degrees. P3D would then be in a stable orbit. Nearly 2/3 of these maneuvers as well as later fine adjustments to the orbit would then be carried out by the ATOS thruster several times per year.

Karl Meinzer reported further on the current status of the EPU (electric propulsion unit) for ATOS. The EPU supplies approximately 750 Watts of electrical power. A first prototype version achieved an efficiency of 85%, and 95% is the goal for the flight version. Since the thruster behaved somewhat differently than anticipated following ignition of the arc during transition from the so-called low mode to the high mode, consequently certain problems were discovered in the EPU. Karl Meinzer is quite confident however that a fully operational EPU will be available by September 1992.

Organizational matters

Tom Clark reported that AMSAT-NA has terminated the AMSAT mailbox and information service via Telemail in June due to the cost. Just for AMSAT-NA alone, the yearly costs amounted to nearly US$ 25,000! In its place he recommends that the individual groups acquire access to the Internet system, over which more than 500,000 host systems can be reached. Many universities and educational institutions are already connected. Those who cannot get direct access can use the CompuServe gateway to Internet. AMSAT-DL will check into the possibility of a direct connection or at least be accessible via CompuServe, now that Tmail has been shut down.

The AMSAT P3D design meeting for 1993 will again be held in Marburg from May 17 to 20. In the meantime an additional meeting is being planned for the period from November 9 to 11, 1992 in Orlando, where decisions on several important questions will be taken. The LAN group will meet in August in Munich to determine a design for the IHU LAN. As soon as the date has been set, Karl Meinzer will attend.

AMSAT-DL will again provide proceedings of the 1992 meeting to the participants. Deadline for the corresponding contributions is July 1, meaning that they should already be in the mail by mid-June.

Karl Meinzer reminded the participants to take into consideration the effects on electronic components of strong radiation in the high elliptical P3D orbit and to provide appropriate protection. Capacitors lose capacitance, EPROMs erase themselves and are thus totally unsuitable, transistors change their operating points, power MOSFET transistors must be biased with -2 V so that they will actually shut off, just to name a few examples. Nobody should treat this matter lightly! Karl Meinzer is certainly willing to provide information where needed and/or to subject circuit designs to critical scrutiny. Those having the facilities should test their circuits under radiation conditions, such as 20,000 rad (<1 MeV) with the aid of a Cobalt-60 radiation source. Many hospitals work with such radiation sources for treating cancer and should be approached for such experiments.

Karl Meinzer emphasized that we now only have 3 years until the launch of Phase 3D and there is still a lot to be done. The integration of the satellite should begin in the Summer of 1994. Dick Daniels would like to publish a P3D newsletter every two months so that all groups are informed about the progress of the various projects and can possibly exchange information. The editorial deadline for the next issue is mid-August. Corresponding status reports can be sent to his address.

In conclusion the new action list was reviewed in which the various activities of the individual participants and the deadlines have been assigned.

After Karl Meinzer expressed his thanks to all participants for the work done thus far and the valuable contributions to the success of this P3D meeting, the participants set out on their return journeys home in order to continue the work on their projects.

List of participants

Auweter-Kurtz, Monika, IRS, U. Stuttgart
Brenndoerfer, Knut, DF8CA, AMSAT-DL
Butler, Ralph, Weber State U.
Clark, Tom, W3IWI, AMSAT-NA
Colson, Jack, W3TMZ, John Hopkins U.
Daniels, Dick, W4PUJ, AMSAT-NA
Fletcher, Michael, OH2AUE, AMSAT-OH
Gladisch, Wilfried, AMSAT-DL
Gschwindt, Andras, HA5WH, U. Budapest
de Guchteneire, Freddy, ON6UG, AMSAT-Belgium
Guelzow, Peter, DB2OS, AMSAT-DL
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Metz, Gerhard, DG2CV, AMSAT-DL
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Rinaldo, Paul L., W4RI, ARRL
Stilwell, Bob, John Hopkins U.
Vidmar, Matjaz, YT3MV
Wood, Stan, WA4NFY, AMSAT-NA
Zube, Dieter, IRS, U. Stuttgart

The Global Position System (GPS): Applications for Amateur Radio and Amateur Satellites

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This paper discusses the military's NAVSTAR Global Positioning Satellite (GPS) which now consists of 17 operating satellites and how it can be used in various amateur applications.

Basically, each these satellites consist of stable atomic frequency standards (Cesium and Rubidium) which broadcast spread-spectrum coded timing signals at L-band (1575.42 and 1227.60 MHz) frequencies. The satellites are maintained in stable 12-hour period orbits and the coded signals also contain high accuracy ephemeris data.

Depending on how these signals are used, the GPS system permits a user to determine his position to a few meters, to synchronize his time to the sub-microsecond level and frequency to $1{:}10^{-10}$ or better, to determine relative positions between stations to cm or sub-cm levels, and measure velocity to a few cm/second.

We will begin with a tutorial on how precise timing extracted from these signals is used for navigation. This is followed by a discussion of the signals transmitted by the GPS satellites. All transmissions from each of the GPS satellites is derived from the 10.23 MHz output of the atomic frequency standard. The signals we will discuss are:

SIGNAL NAME	10.23 MHz TIMES	Frequency and Characteristics
L1 Carrier	* 159 =	1575.42 MHz, 19 cm wavelength L-Band carrier (C/A + P + Nav)
L2 Carrier	* 120 =	1227.60 MHz, 24 cm wavelength L-band carrier (P + Nav only)
C/A Code	÷ 10 =	1.023 Mb/sec, 1023 bit unique satellite code repeating every msec
P-Code	* 1 =	10.23 Mb/sec, 2^{48} bit code repeating every 267 days = 38 weeks
Navigation Message	÷ 204600 =	50 bits/sec, with 1500 bit data frames & 300 bit sub-frames

We then will discuss spread-spectrum techniques in order to understand what is required to receive and make use of the signals transmitted by the satellites. This discussion will include examples of some typical GPS receiver technology.

After we have a basic understanding of the basic nature of the military's satellites and the user's receivers, we will discuss one of the more controversial aspects of GPS -- the military's decision to "spoil" the GPS system accuracy with Selective Availability (S/A). S/A is man-made encrypted phase noise which intentionally degrades the stability of the master 10.23 MHz spacecraft oscillator to decrease the inherent GPS system accuracy. In the absence of S/A, the most elementary receiver detecting only the Coarse Acquisition (C/A) code on the primary L1 signal will produce positional data accurate to ≈ 10 meters. With S/A activated, the simple user interested in point positioning and navigation finds his accuracy degraded to ≈ 100 meters and velocities "noisy" at levels of about 2 km/hr. We will show examples of this degradation and discuss the "tricks" (especially real-time differential measurements) being used to circumvent the position and velocity degradation due to S/A.

During the Desert Shield/Desert Storm activities in 1990 and early 1991, the military found it necessary to disable S/A since the troops in the field were using many low-cost commercial (mostly Trimble and Magellan) GPS receivers. In mid-1991, after hostilities ceased, the military chose to re-activate S/A.

We will then proceed to describe the second military encryption scheme called Anti-Spoofing (AS). AS affects only those applications which make use of the precision P-code which is available on both the L1 and L2 carriers. AS encrypts the P-code by convolving with a new secret polynomial; the encrypted P-code is called the "Y-code". The military activated AS on weekends in August, 1992.

After this description of the basics of GPS, we will discuss some possible future amateur applications of GPS. Here are a few common questions we will try to answer:

- **How can I get a GPS receiver? Can I build one myself? How much will it cost?**
  Simple, off-the shelf hardware is now down to a few hundred dollars. We will describe the efforts of YT3MV at building his own receiver from scratch. We will suggest the possibility of an AMSAT and/or TAPR GPS receiver project.

- **Given that a simple GPS receiver can provide information on my location to, how about using it as proof that I was at a particular Grid Square for contests and awards?**
  Yes, providing ARRL HQ can be convinced that it is for real!)

- **I am flying balloons carrying amateur radio. Can I use GPS to help track the balloon's location?**
  Yes -- this is an application just made for GPS.

- **GPS can provide sub-microsecond accuracy for my clocks. Is this of any use?**
  Yes -- you no longer will even need to set your clock to WWV. And timing with this accuracy will make amateur applications of direct-sequence spread-spectrum communications be viable.

- **Can I use GPS to give me have a very stable and accurate frequency standard?**
  Yes, this is another "natural" which will be especially useful to those involved in weak signal VHF/UHF/microwave activities. Even the simplest of GPS receivers can give you a clock accurate to better than one μsec and will allow you to set your frequency standards to $1:10^9$ (10 Hz at 10 GHz).

- **With its L1 and L2 dual-frequency signals, can GPS be used to monitor the ionosphere in real-time?**
  Yes, but it requires a much more complicated receiver than the other applications, and the task is made even more difficult by Anti-Spoofing.

- **Are there areas where amateurs can do significant independent research using GPS?**
  Yes! Here is just one example: One of the most important developments in civilian applications of GPS involves real-time differential measurements to cancel the effects of Selective Availability (S/A). This involves the transmission of correction information from a fixed "base" site to users up to a few hundred km away. How about amateurs using the packet radio networks to develop low-cost ways to send this data?

While all these topics have regarded "down-to-earth" GPS applications, several amateur satellite applications are under consideration and will be discussed. These include:

- I recommend the amateur satellite community plan on flying a simple GPS receiver onboard all future OSCAR satellites: This would allow us to produce our own high-accuracy Keplerian elements without needing to depend on NORAD. Every time we have flown as piggy-back mission, there has been confusion about which object is us. Now we have the ability to fly our own precision orbit determination (POD) capability. And the educational worth of developing our own POD capability is inestimable.

- Further, the same simple GPS receiver that is would be used for POD is capable of keeping our onboard frequency standards and clocks on frequency and on time.

- Attitude determination: Our earlier satellites have used combinations of Sun sensors, Earth limb sensors and magnetometers to deduce their orientation in space. If a satellite is equipped with multiple (at least three) GPS antennas and a receiver which can process the data from them as an interferometer (by precisely determining the difference in phases of the L-band signals), we have an RF- based system which can determine the orientation of our satellite in space. This is of particular interest in the case of Phase-3D which will use momentum wheels for active attitude control to keep high-gain antennas pointed at the earth.

- If high-quality GPS dual-frequency GPS receivers can be developed for use in amateur satellites, we have the possibility of amateurs contributing significant scientific research results in real-time world-wide atmosphere and ionosphere mapping and in accurate determination of the Earth's gravity field.

In this paper we will address some of the design considerations of GPS receivers suitable for space flight. And with some luck we will demonstrate conceptual prototypes for some of these concepts assembled using commercially available GPS receivers.

Ed Krome KA9LNV
August 1992

SATELLITE S BAND: HOW TO BECOME QRV ON OUR HIGHEST BAND

INTRODUCTION

As both commercial and amateur spacecraft technology has evolved, there has been a trend toward higher frequencies in both control and communications arrangements. This paper will briefly explore the reasons for this trend, and then discuss practical methods of becoming active on the highest frequency band currently implemented in amateur satellites. Becoming QRV on 2400 MHz is surprisingly easy and within the grasp of most experimentally inclined satellite operators. And this is just the beginning- Phase IIID, presently on the drawing board (or, more accurately, drawing screen?), promises transponders and beacons operating through at least 10 GHz and possibly even 24 GHz.

S BAND

As background information, the use of alphabetic band designations is from an obsolete but still used radar frequency range division convention. The frequency range from 390 to 1550 MHz was called "L band", 1550 to 5200 MHz was "S band" and 5200 to 11000 MHz X band. Beyond that, K band stretched all the way to 36 GHz. Amateurs are allocated several frequency bands within each range, including the 70cm (420-450 MHz), 33cm (902-928 MHz) and 23cm (1215-1300 MHz) bands within L band and 13cm (2300-2450 MHz) and 9cm (3300-3500 MHz) in S. Satellites are allocated subbands within most amateur bands. The highest frequency beacon used on an amateur satellite to date was a 10.47 GHz beacon on UoSAT-OSCAR 9. Presently, the highest frequency is 2401 MHz, which is used on 3 active satellites.

TREND TO MICROWAVES

So why do satellite designers keep putting higher and higher frequency equipment on these new birds, anyway? What's wrong with mode A, anyway? It all boils down to one word: performance. Satellites are difficult enough to build and launch without having to contend with unreliable or unpredictable communications systems. What makes higher frequencies perform better? First, we need to go back to the very basics of reception- the desired signal has to be separable from the "other stuff". That "other stuff" includes both undesired signals and noise and interference, both of the natural and manmade varieties. Tuned circuits and filters can take care of most of the undesired signals, but noise and interference are a different story. The easiest method of separating desired signals from "other stuff" is to make the desired signal stronger. This is usually referred to as a ratio of signal strength to background noise and is called SNR or signal to noise ratio.

If the first part of the equation for reception is signal strength, the second part is noise. The nature of the naturally occurring variety requires a brief discourse into what noise is.

Natural (galactic) noise is a function of electron activity. Electron activity is a function of temperature. The higher the temperature, the faster electrons move and the more noise they generate. On a galactic level, noise is measured as temperature, in absolute terms of degrees Kelvin at a given frequency. As the frequency goes higher, the sky gets cooler and the noise generation goes down. And at 2400 MHz, the sky is naturally pretty quiet.

Other forms of naturally occurring noise, such as that from lightning and weather disturbances, which cause maddening fades and crashes on HF, do not generate appreciable noise even on 144 MHz and are of no concern above that.

Another kind of noise, the manmade stuff, is pretty scarce on 13 cm also. Not too many handheld transceivers or kilowatts with more spurs than a porcupine. Compare this almost interference-free situation to 2 Meters in any metropolitan area. Or compare it to trying to work a mode B station in Japan, and hoping the JA can at least pick your call out of the splatter from several hundred thousand 2 meter FM rigs, all operating at once.

As well as being quiet, the 13cm band is huge! Just the satellite sub-band contains as much bandwidth as the entire HF spectrum up to 6 meters! A full 50 MHz for satellites only. With all this room, lots of different stations and modes can be accommodated simultaneously without clobbering each other. Another benefit of having lots of available bandwidth really manifests itself in the opportunities for data transmission. As the baud rate of a frequency shift keying data transmission increases, the required bandwidth of that signal increases. With lots of room and little interference or noise, the opportunities exist for robust, very high speed data links that are fairly easy to implement.

High frequencies also mean high gain antennas in small physical packages. Real Estate is expensive everywhere, both in your own back yard and on a satellite. Small antennas make good use of limited available space. PACSAT has a tiny little 3 turn helix, only a few inches long, as its 2400 MHz transmitting antenna. A usable PACSAT ground station antenna is only 2 feet long. Even a large loop yagi for 13cm is only 8 feet long and less than 1 1/2 inches in diameter.

High gain antennas have their price, and that is narrow beamwidth. But, like most things, this has both advantages and disadvantages. The advantage is that the narrow beam width insures freedom from reception of unwanted signals, including multi-path distortion. The disadvantage is that the higher the gain, the more critical antenna pointing is. Many satellite ops make this disadvantage transparent by use of automated antenna tracking systems. With at least 3 ready-to-run tracking systems on the market, these are becoming more common all the time.

Next reason for becoming QRV on 13cm? Remember the old adage "use it or loose it"? With ham bands, that, unfortunately, is all too true. Just a few years ago, we lost the bottom 2 MHz of our 135cm (220 MHz) band. The 13cm band is in jeopardy to world-wide commercial concerns, and we may yet loose a portion of it. One of the best ways of insuring that we hams keep our frequency allocations is to show that we actively use them. And to become very vocal when commercial concerns try to take them away.

This all sounds great, but it must all be very technical and expensive, right? As my teenagers, say, "NOT". The beauty of 13cm satellite operation is that, for a UHF band, it is remarkably easy and inexpensive to get going on. Most satellite active hams already own the expensive parts. Remember that 13cm satellite operation only requires the ground station to receive. It is much cheaper and easier to attain a low receive noise figure and good signal to noise ratio than it is to generate appreciable transmit power. Safer, too, with no high voltage or radiated microwave energy. Receiving S band is MUCH easier than becoming active on mode L, where transmit power on 23cm (1269 MHz) is required. This is the voice of experience; building gear for mode L took considerably more time and money than mode S did.

And one other important consideration. It's fun! This is an accessible leading edge technology. AO-13's S band transponder is populated by a friendly, relaxed and competent crew, always eager to help new comers. And there are plenty of people to talk to up there, too. Some operators boast over 100 QSO's on mode S. More are always welcome.

OPERATIONS

Up to this point, we have only mentioned the existence of S band life on AO-13. That is just a part of operation common to the band. On satellites, 3 currently operating birds use the 2400 MHz band in 3 different arrangements. AO-13, a high elliptical orbit bird, has a full-featured transponder, referred to as "mode S". This non-inverting transponder uplinks in the 70cm band and downlinks in 13cm. Remember I said that most satellite operators already had the most expensive part of mode S operation? 436 MHz uplink gear is used on mode B, the most popular AO-13 mode. So all you need to add is 13cm receive equipment.

Two of the MICROSATs also contain S band transmitters. PACSAT's flying mailbox normally operates in mode J, with a 2 meter uplink and 70 cm downlink, but also has a 13cm downlink. Normal mailbox operation is available with this frequency scheme. DOVE also has a 13cm downlink, designed only as a beacon. That signal, unfortunately, is corrupted and unusable for data transfer due to a phase modulator failure, but the beacon has still proven very important. Even in its corrupted state, it has provided the only control downlink for much of the software uploading. DOVE's operational glitches cause it to revert to the S band beacon mode when the operating system crashes. The ability to monitor DOVE's S band downlink has kept DOVE from being completely lost.

Satellite operation isn't the only thing on 13cm. Some regions of the country have active terrestrial operation on 2304 MHz, and there is even some EME (moonbounce) activity. And, any station's ability to transceive even at extremely low power on 2304 MHz will make them extremely popular with regional UHF contesters!

RECEIVING

Now the fun part- how to become operational on 2400 MHz. Remember that, for satellite operation, you only need to receive. But, an immediate problem presents itself. 13cm is the lowest band for which absolutely no integrated commercial equipment is currently available. No Kenwoods or ICOMs. No plug in modules for FT736's. Which really isn't all bad, since integrated gear for 13cm would probably be rather expensive. And the limited population of 13cm sure wouldn't grow much if everybody who wanted to operate there had to shell out big bucks just to try it. This is a self-perpetuating problem. Just obsolete. Fortunately, a better alternative exists. For this band, standard procedure is to hang a separate converter on the front on an existing HF or VHF radio. These converters function the same as any other converter. The RF input signal (in this case, 2400 MHz) is mixed with a fixed frequency local oscillator signal (usually 2256 MHz). Mixing two frequencies provides 2 different output frequencies, which are the sum and difference of the RF and LO. A filter separates the desired frequency, in this case the difference, 144 MHz, from the undesired ones. This difference frequency is then fed out to an existing receiver, which treats it just like it would any other signal. Nothing too it.

Fortunately, at least 2 converters are presently available. One is ready made, the other either ready made or in kit form. Both perform the same function, which is taking a 2400 MHz input signal and converting it to a 144 MHz output, but they do it in different fashion.

The ready-made version is from SSB Electronic of Germany and distributed by Jerry Rodski K3MKZ. Their converter is small and finely crafted. Internally, its design is conventional, incorporating a 94 MHz crystal oscillator and 4 stage x24 multiplier to generate the required 2256 MHz LO signal. The RF input is routed into a GaAsFET amplifier, then through a 3-section bandpass filter to a second GaAsFET, where it is mixed with the LO. With their built-in GaAsFET RF amplifier, these units have a low noise figure and good gain and are marginally usable without any additional RF preamplification.

The second device is from here on the East coast; up in Maine. Bill Olson W3HQT's Down East Microwave handles one of the most innovative concepts in RF to come along in years. These are high performance transverter modules that require no tuning! A complete 13 cm transverter has only a single trimmer, and that is to peak the crystal oscillator. No adjustment are required or even possible in the RF or LO sections. These transverters were designed by Rick Campbell KK7B and Jim Davey WA8NLC and use quite different design techniques from the SSB device.

The success of these transverter boards are based on two recent developments. First, the development of multi-section printed hairpin filters with extremely predictable and repeatable characteristics. These printed filters have broad, flat top passbands with steep sides. And their performance is consistent when reproduced with normal printed circuit board etching techniques. The second recent development is commercial- the MMIC or Monolithic Microwave Integrated Circuit. These small, inexpensive amplifiers require only external DC blocking capacitors and a bias resistor to provide broadbanded high gain and usually unconditional stability with 50 ohm input and output impedances. Their stability makes them cascadeable; need more gain in a given stage? Add another MMIC. The No-Tune transverter boards make extensive use of MMICs in conjunction with the printed hairpin filters to provide good gain over a controlled passband.

The design scheme for these transverters is rather unconventional. The LO starts with a crystal oscillator, but instead of multiplying it in several active multipliers with the filters between each stage, it uses two stages of passive diode multipliers to generate harmonics. Printed bandpass filters are used to select the harmonic of interest. MMIC's amplify the desired signal to the required mixer injection level. The RF signal from the input jack is cleaned up by several printed hairpin bandpass filters and amplified by MMIC's. Both signals are fed to a printed ring mixer. Again, no tuning is required in any stage. No spectrum analyzer or signal generator!

The No-Tune boards are available in two versions. The transverter version consists of 2 circuit boards. The first board is a 540 MHz local oscillator. The second board includes an additional diode multiplier, two mixers and two RF sections, and will not only receive 13cm signals, but will also transmit 10mW on 13cm! Since transmitting is not required for satellite operation, a receive-only converter is also available and includes both LO and RF sections on a single board. Down East Microwave supplies kit or ready-made versions of either. While these kits are rather more complicated than a toaster, with a little care they are quite easy to build.

ANTENNAS

A complete 13cm receiving system consists of not only the receive converter, but also of methods of capturing and amplifying the signal. Antennas for 13cm take somewhat different forms than antennas for lower frequency bands. While a conventional yagi design is possible, required element length tolerances are so small (a few thousandths of an inch) as to make them difficult to produce. Antennas in common use are the loop yagi, the helix and the dish.

The loop yagi is one of the most popular designs. It is readily reproducible by homebrewers, is very compact and offers quite good performance. Developed by Mike Walters G3JVL, this device is a variant of the yagi that replaces the normal straight near-half wave elements with full wave loops. One of the most appealing features of the loop yagi is that it requires no matching network for use with 50 ohm coax. The driven element loop is simply soldered to a piece of small diameter hard line. An additional feature of the loop yagi is that all elements are attached directly to the boom and are therefore at DC ground. This will prevent preamp-killing static buildup in actual installations. Loop yagis are available both as kits or ready made from Down East Microwave for those who don't care to "roll their own". A note about loop yagi performance... Loop yagis are available cut for either 2304 MHz or 2400 MHz. The nature of the design is that the actual antennas have a significant low pass characteristic. Which is to say that one cut for 2304 MHz will be one lousy performer on 2400 MHz! My own experience is that the 2400 MHz versions perform acceptably on 2304, but not vice versa. If you intend to work mostly satellites, be sure to get the ones cut for 2400. Those popular for satellite work are usually either 45 (from DEM) or 52 (homebrew) elements. The 52 element version fits nicely on an 8 foot length of 1/2 inch aluminum tubing.

Another antenna popular with homebrewers is the helix. Since they are little more than a coil of wire stretched out in front of a reflector, they are easy to duplicate. The nature of the design is that it is extremely broadbanded, which most builders seem to rely on to compensate for imperfect construction techniques. Additionally, the helix is inherently circularly polarized, a definite advantage for satellite operation. Just be sure to wind them in the correct hand! Broadband, circular polarization, easy to build, seems like the perfect antenna. Unfortunately, such is not the case. There seems to be a length (typically 15 to 20 turns) beyond which the performance does not improve, even though the computer programs that are used to design them indicate that they will. Performance appears comparable to a similar length loop yagi, but only up to the 15-20 turn limit. Additional gain can be had by stacking 2, 4 or more units and feeding all in proper phase (and matching impedances), but the mechanical complexity and difficulty in feeding everything properly quickly becomes overwhelming.

Experience has shown that a simple 20 turn, 2 foot long helix is adequate for PACSAT reception when conditions are good. I have experimented with several stacked helix arrangements using helixes as long as 4 feet (40 turns), but never found the performance as good as a single 8 foot loop yagi. Lots of room to experiment here.

The third popular type of 13cm antenna is the dish. Most of those in satellite service seem to be of the 4 foot diameter variety, usually liberated from someone's backyard who bought one back when CATV direct access was a hot item. A dish this size will have almost 20 dbi gain and provide a very strong downlink. Dishes are easy to feed and readily lend themselves to either linear or circular polarization. Their physical size and wind load makes them challenging to mount and steer. Small dishes are also home-buildable.

What type of antenna you choose will depend on your operating expectations. The MICROSATs are strong and easy to hear but very fast moving. Therefore, less antenna gain is a reasonable trade for wider beamwidth and easier pointing. AO-13, in its high elliptical orbit, is much weaker, but slower moving and easy to stay pointed at. You won't even detect AO-13 with the 2 foot long helix. A single 8 foot loop yagi is a little weak for AO-13 but entirely usable, especially if you like CW. The MICROSATs absolutely roar in on one. This makes it probably the best compromise antenna and a good place to start.

PREAMPS, FEEDLINES AND NOISE

If this were HF, all you would have left is to run a feedline from the antenna to the converter and operate. But things are a little different on microwaves. First, the received signals are pretty weak. Second, coax starts to look a lot more like an attenuator than like a signal conduit. So, to preserve what little signal the antenna captures and make it usable, you need to mount a low noise RF amplifier, called a preamp, as close to the antenna feed point as possible. This preamp will set the noise figure and the signal to noise ratio of the entire receive system. Remember that no amount of amplification will separate signal from noise, so the idea is to amplify the signal with as little added system noise as possible. This added system noise, from the cable attenuation, poor matching or poor preamp noise figure is probably the largest signal problem encountered in S band reception. The cable connecting the preamp to the receive converter is less critical, since the system noise figure has already been established. Good quality RG213 or 9913 is adequate. Many users have had good results using two preamps in series up at the antenna.

To insure the least possible system degradation, it is common to mount the preamplifier not just up on the tower, but directly on the antenna boom, a few inches from the driven element. A few feet of cable can be the difference between success and failure. One interesting advantage of using an all-metal loop yagi with a boom-mounted preamp is that since the antenna is all at DC ground potential, any atmospheric static electricity picked up by the antenna will be directed to ground, rather than through the expensive GaAsFET in the front end of your preamp. In my own installation, I have never lost a preamp in spite of some spectacular thunder and lightning shows over the past 3 years.

Preamps are available from both Down East Microwave and SSB Electronic. Down East preamps are of a no-tune design by Kent Britain WA5VJB and Al Ward WB5LUA and are also available as kits.

SATELLITE CHARACTERISTICS

Once you have your setup installed, it is helpful to know what to expect from the various satellites.

On the MICROSATs, DOVE's beacon is frequently operational and is quite easy to hear. Although its telemetry is undecodeable, tracking DOVE is good practice and good for system performance verification. One interesting characteristic about DOVE was brought up by Junior DeCastro PY2BJO, who said he receives DOVE with only a 3 turn helix! DeCastro is in South America, and DOVE is magnetically stabilized to be nadir pointing in the Southern Hemisphere, which makes it much louder for him than for us Northerners.

Due to pointing angle difficulties, PACSAT is only active on experimenters days (typically Wednesday) from January through March. PACSAT uses a 1200 baud BPSK downlink, the same as it uses for normal mode J (436 MHz downlink) operation.

The biggest problem with hearing the MICROSATs is tracking them. Since these are LEO birds, they fairly scream across the sky. Horizon to horizon in less than 15 minutes makes manual tracking a bit of a challenge. Of course, a lower gain antenna like a short helix simplifies pointing, but even the 8 foot loop yagi is not impossible. The other tracking problem is Doppler shift. Doppler shift is extremely pronounced at 2400 MHz, causing a shift in apparent received frequency of as much as 110 KHz in one pass! Fortunately, both commonly used PSK modems, (G3RUH and TAPR) have AutoTune functions that, when linked to digitally tuned receivers, automatically tune the radio to compensate for Doppler shift. Once you acquire the signal and get modem lock, all you have to do is keep the antenna pointed correctly. But loose lock and watch the signal simply disappear.

AO-13 mode S operation is similar to any other satellite transponder. Unless otherwise commanded, mode S is regularly scheduled on every orbit, with both beacon and transponder. Since AO-13 uses a high gain antenna, mode S operation is limited to a few MA either side of nadir pointing to keep the earth in its beamwidth. Probably the biggest problem with AO-13 reception (besides lousy receivers) is finding the signal. Antenna pointing is critical. With homebrewed receive converters, the LO frequency may not be exactly what you think it is (the crystal frequency is multiplied by 24), so it is necessary to tune around a lot until you find the signal. My own receiver is over 50 KHz off from where it "should" be. A single 45 to 52 element loop yagi is adequate, but a stacked pair is excellent for SSB operation. This transponder is of the non-inverting type and requires about a 1 KW ERP on the 436 MHz uplink.

THAT'S ALL THERE IS TOO IT

That's all there is to becoming QRV on our highest frequency satellite band. You can either buy all the parts ready-made, or do a little of your own work, save a bundle of money and have the satisfaction of doing it yourself.

SOURCES AND REFERENCES

Down East Microwave (Bill Olson W3HQT)
Box 2310, RR 1
Troy, ME 04987
(207) 948-3741

SSB Electronic (Jerry Rodski K3MKZ)
124 Cherrywood Drive
Mountaintop PA 18707
(717) 868-5643

Loop Yagi design:

Joe Reisert W1JR, "Designing Loop Yagis for 13 and 23 cm", Proceedings of the First Annual 1296/2304 MHz Conference, Estes Park CO, Sept 19-22, 1985

Ed Krome KA9LNV, "Elementary Mode S", 73 Magazine, March 1991

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PHASE 3D, A STUDENT MANUFACTURING ENGINEERING CHALLENGE

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ABSTRACT

The development of the Phase 3D "Falcon" spacecraft is presenting a major challenge to the AMSAT amateur radio community in that it is the largest and most sophisticated spacecraft attempted to date. The major problem (beyond the technical challenge) is to build this spacecraft with a micro budget as compared to commercial and military spacecraft. One way to meet the challenge of this budget is to enlist the assistance of the educational community and in the process provide an exceptional educational challenge to students and faculty. The engineering technology programs at Weber State University have been facing such challenges since 1982 in developing spacecraft with micro budgets. Weber State teamed with AMSAT-NA in 1988 to assist in the development of the four microsat OSCARs that were launched on the Ariane V35 in January 1990. This paper describes the first year's activity of the Weber State's participation in the International AMSAT Phase 3D project, the objectives and the results.

INTRODUCTION

The engineering technology programs in the College of Applied Science and Technology at Weber State University provides courses that have laboratories to give students practical application of principles presented in the classroom lectures. The challenge in programs of this type is to make the laboratory exercise demonstrate the classroom principles that will closely match practical industry applications. This can be done by making the laboratory exercises create a product which will be used in "real" applications.

The concept of building a spacecraft was brought to the university by local industry representatives in 1982. The challenge was to build a small satellite that could be launched from the NASA orbiter get-away-special canister. This project would provide the practical challenge that is needed in a technology program. Although the project was supported by the local industry and the challenge was significant, the cash budget was not. This concept of building a small, inexpensive satellite was new to the present aerospace industry, but not new to the AMSAT community.

The development of this first satellite NUSAT I provided all of the challenges needed for the engineering technology students involved. The results of the project was that the NUSAT I was launched on the NASA Challenger orbiter in April of 1985. Many of the engineering principles learned by the AMSAT spacecraft builders were used in this 100 pound, unstabilized spherical satellite. The satellite performed nominally for 20 months until it burned up upon atmospheric reentry.

This program was successful through the assistance of Utah State University, the local volunteer engineers and a significant amount of material and facility service donations by the aerospace industry. Through the success of this program, the Center for AeroSpace Technology (CAST) was formed to provide funding and project management for future aerospace endeavors.

SPACECRAFT DEVELOPMENT WITH AMSAT

In early 1988 AMSAT-NA and Weber State University teamed to build the proposed four microsat type satellites for a 1989 Ariane IV launch. Weber State would provide the manufacturing capability to build the major mechanical components of the space frame and AMSAT-NA and other AMSAT organizations provided the complete spacecraft design and the bus electronics. These team efforts resulted in the development and launch of OSCARs 15-18 in successful launch on the Ariane IV V35 flight in January 1990.

AMSAT-NA wanted to investigate the development of a larger spacecraft for a possible geostationary orbit in 1990. Dick Jansson, WD4FAB, AMSAT Assistant VP for Engineering led a program with CAST starting in the Fall of 1989 to develop a prototype structure for the Phase IV spacecraft. A prototype mock-up of this spacecraft was completed in June 1990. An additional year of work on the antenna structures and deployment techniques was started in the Fall of 1990 and completed in the Spring of 1991. Work on the Phase IV was due to international interest in the P3D.

The concept for the new Phase 3D (P3D) satellite as a replacement for OSCAR 13 was started in 1990 and proposed as a new project to the faculty and students at Weber State in early 1991. This project proposal was accepted by the students and faculty to start in September 1991.

OBJECTIVE OF THE FIRST YEAR OF DEVELOPMENT FOR THE P3D

The lessons learned in the work on the Phase IV project would be put to the test in building a large spaceframe weighing 1100 pounds and having a total solar panel width of over 23 feet.

The plans laid out for this first year on the P3D was to build the tooling required to assemble the adaptor and build at least one adaptor. Other plans were to use the fabrication techniques developed on Phase IV for honeycomb panels as part of the main spacecraft assembly. The student manufacturing team of ten students had two faculty members and a senior student (Ralph Butler, employed) by CAST as the liaison between Dick Jansson and the team. Ralph had experience in the development of the microsat satellites and was responsible for working with Dick to research vendors required for outside part fabrication.

Work was initiated with a small team of mechanical engineering technology students to study the sheet metal assembly that was required as the main support structure on the adaptor.

ADAPTOR ASSEMBLY FABRICATION RESEARCH

The adaptor is the large conical section with a 1194 mm (47 inches) top frame and an 1920 mm (76 inches) bottom frame held together with a sheet metal section. This adaptor is the main structural component of the P3D and is also the support structure between the third stage of the Ariane V launch vehicle and the satellite cluster above the P3D. Early drawings of these frames and the adaptor by Dick Jansson are shown in figures 1-3. The tolerances on the adaptor are very critical to match mating frames on the launch vehicle and satellite support assembly above the P3D.

The initial design for the frames was sent to several vendors on the West coast. Most vendors declined to bid and those that did had costs that were exorbitant. Another fabrication technique was developed with the aid of Louis Timm at United Precision Machine and Engineering Co in Salt Lake City. The initial fabrication approach was to use flat stock aluminum and machine rings for the frames. Through Louis Timm's experience, it was determined that the material for the frames could be made from forged aluminum rings. These rings were subsequently purchased from Earle M. Jorgensen in Seattle, Washington.

One of the major difficulties in machining the frames is keeping the tolerances required after release from the machining fixtures. Dick Jansson, working with Louis Timms resolved this problem with the design of special fixtures and heat treatment to relieve stress in machining stages.

It was later determined that the cost of machining the frames was more economical in Germany. The forged aluminum rings purchased from Jorgensen have been shipped to Germany.

The frames were not completed during the academic year to allow fabrication of the adaptor. The students dedicated most of their time to design and construction of the fixturing assembly that will be used to fabricate the adaptor in the coming year.

DEVELOPMENT OF FIXTURE ASSEMBLY FOR THE ADAPTOR

The students modified a large platform that was developed for the fabrication of the Phase IV to be used as the assembly fixture for the P3D adaptor. This fixture shown in figure 4 has precision ground flanges to which the frames are attached. This fixture allows establishing and maintaining the required concentricity and parallelism of the adaptor.

COMPOSITE FABRICATION DEVELOPMENT

The use of the honeycomb panels for structural components in the spacecraft was developed for the Phase IV prototype. To effectively use this type of materials, the panel must have inserts for fasteners and edge enclosures. This is shown in figure 5.

CONCLUSIONS

The work on the P3D spacecraft development did not proceed as expected in the Fall of 1991 due to extensive redesign of the frames and the adaptor assembly fabrication techniques. However, the adaptor fabrication fixture and the composite technology needed for the honeycomb panels were completed.

The students and faculty got "real" world experience and significant challenges during this last year working on the P3D project. Challenges of this kind not only meet the goals of giving the students excellent experience, but have a significant effect on improving the engineering technology curriculum and capabilities of the faculty.

The AMSAT International amateur community will benefit by the student and faculty manpower, and use of university and local industry facilities.

ACKNOWLEDGEMENT

Weber State University would like to acknowledge the very patient yet demanding and tireless efforts of Dick Jansson in working with these students and AMSAT-NA for their support of the university in this program.

Support funding for this project was provided by the State of Utah Department of Community and Economic Development through the Centers of Excellence Program.

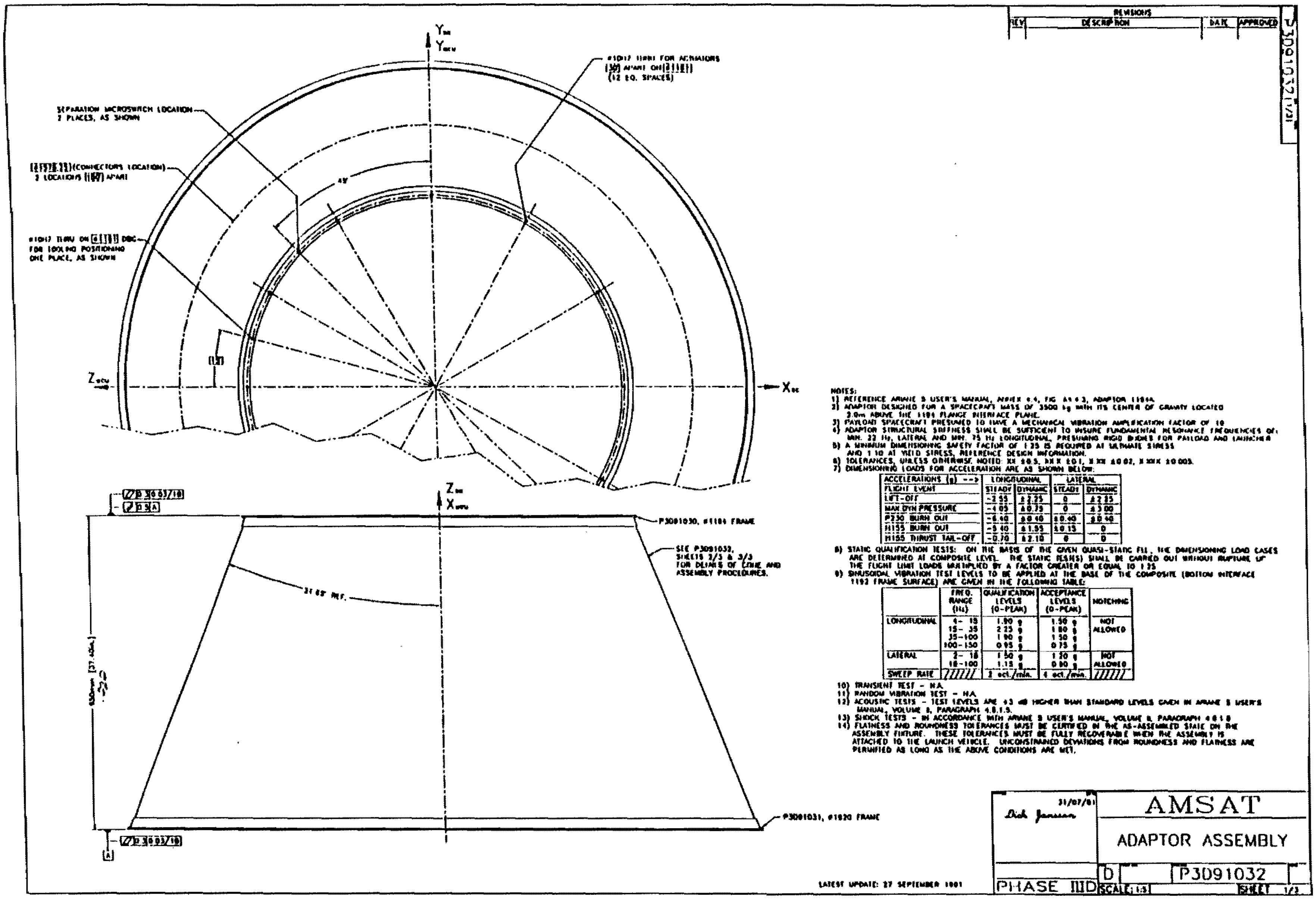

Figure 1
P3D Conical Adaptor Assembly

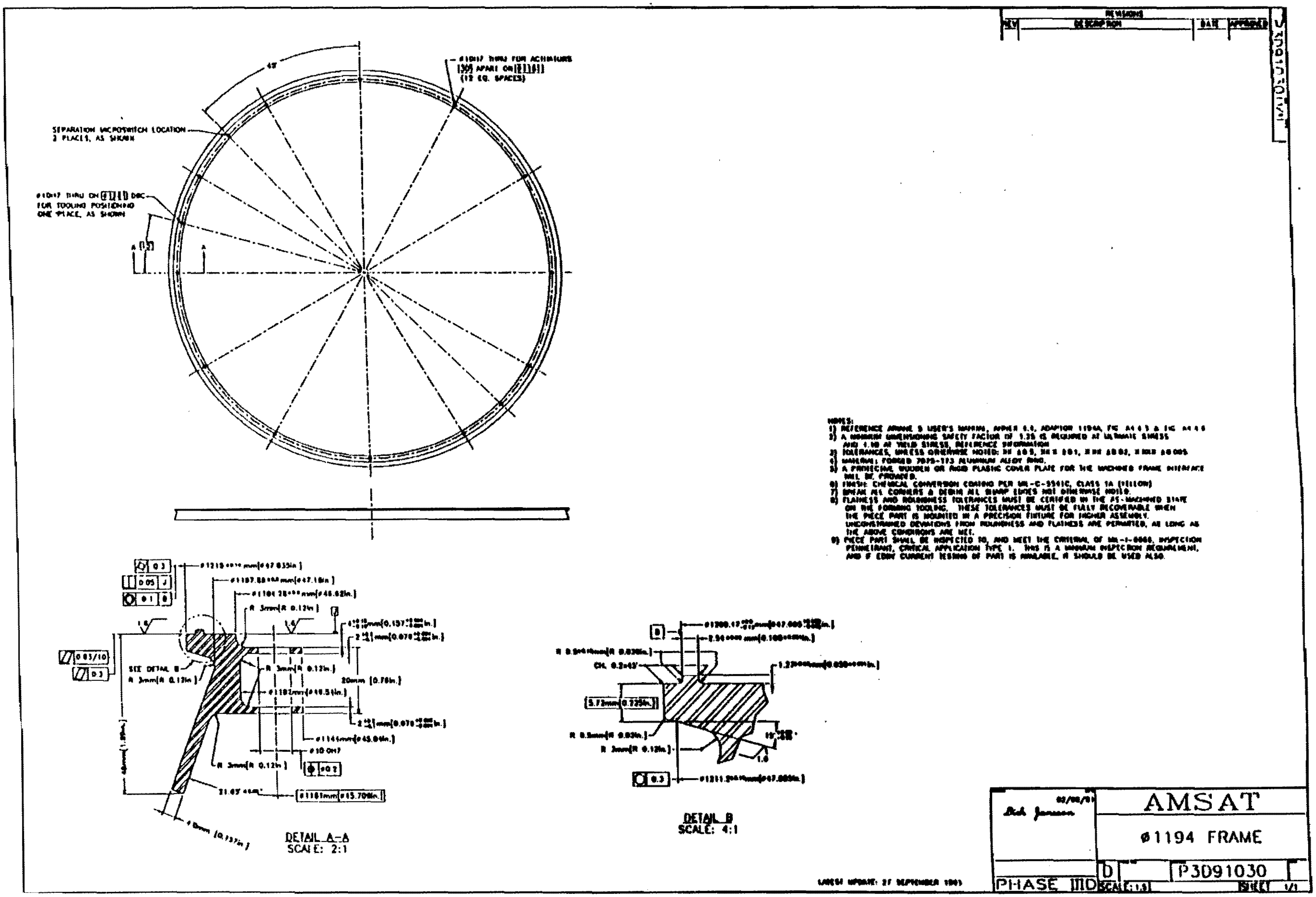

Figure 2
Top Frame for P3D Adaptor Assembly

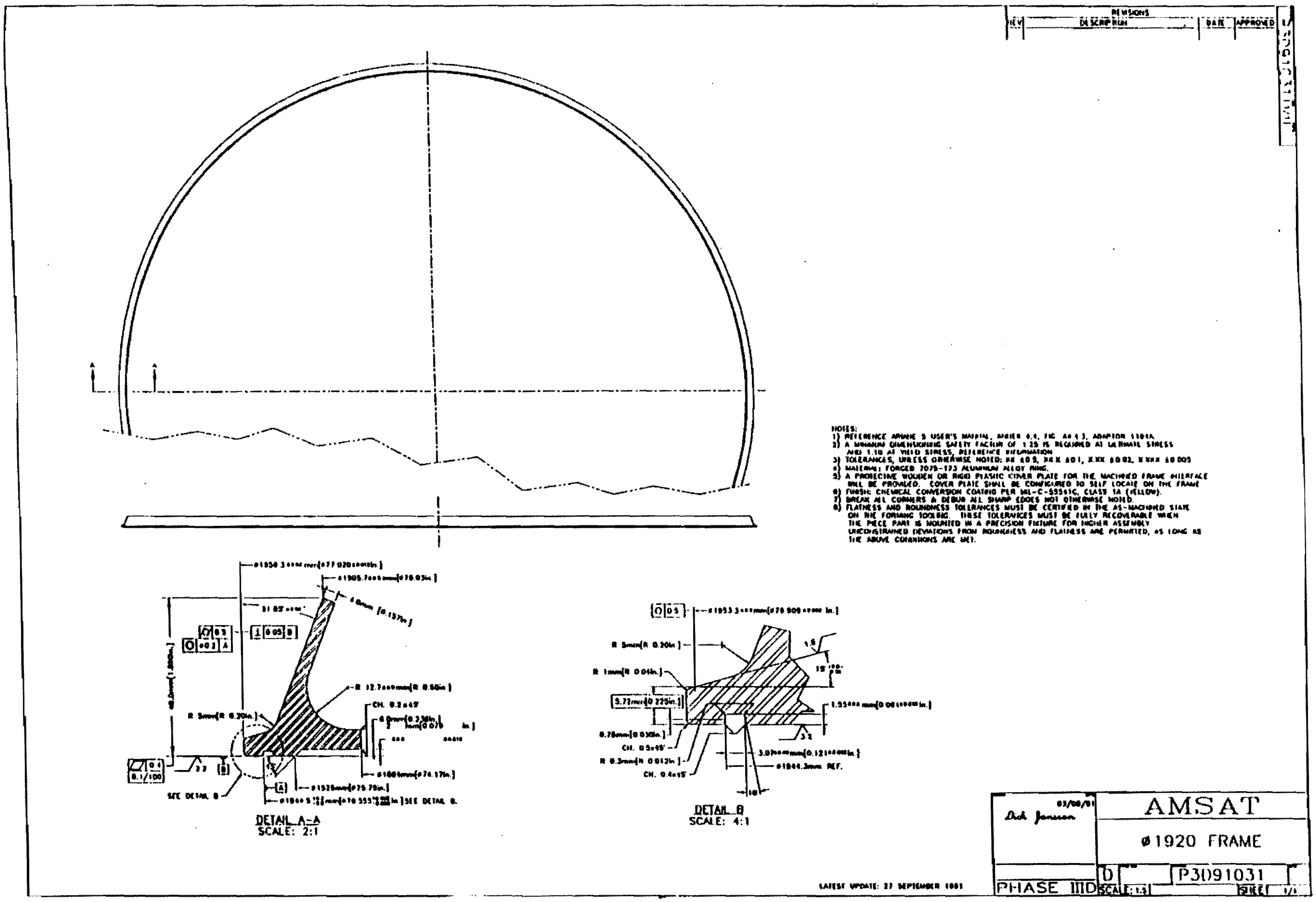

Figure 3
Lower Frame for P3D Adaptor Assembly

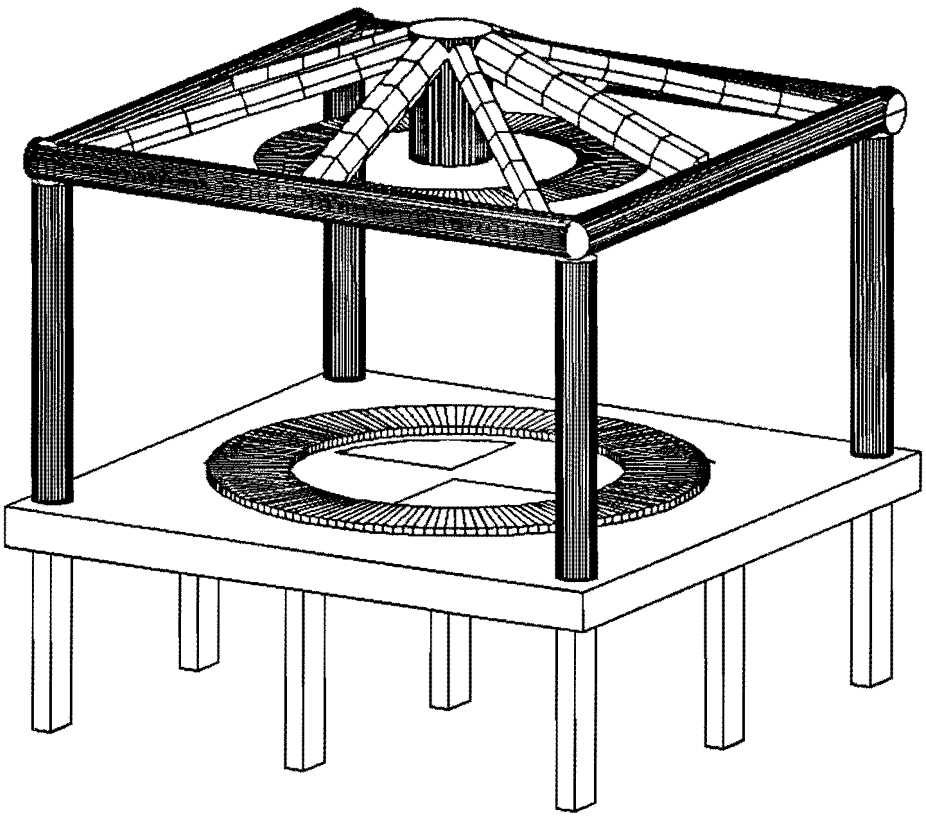

Figure 4
Adaptor Assembly Table

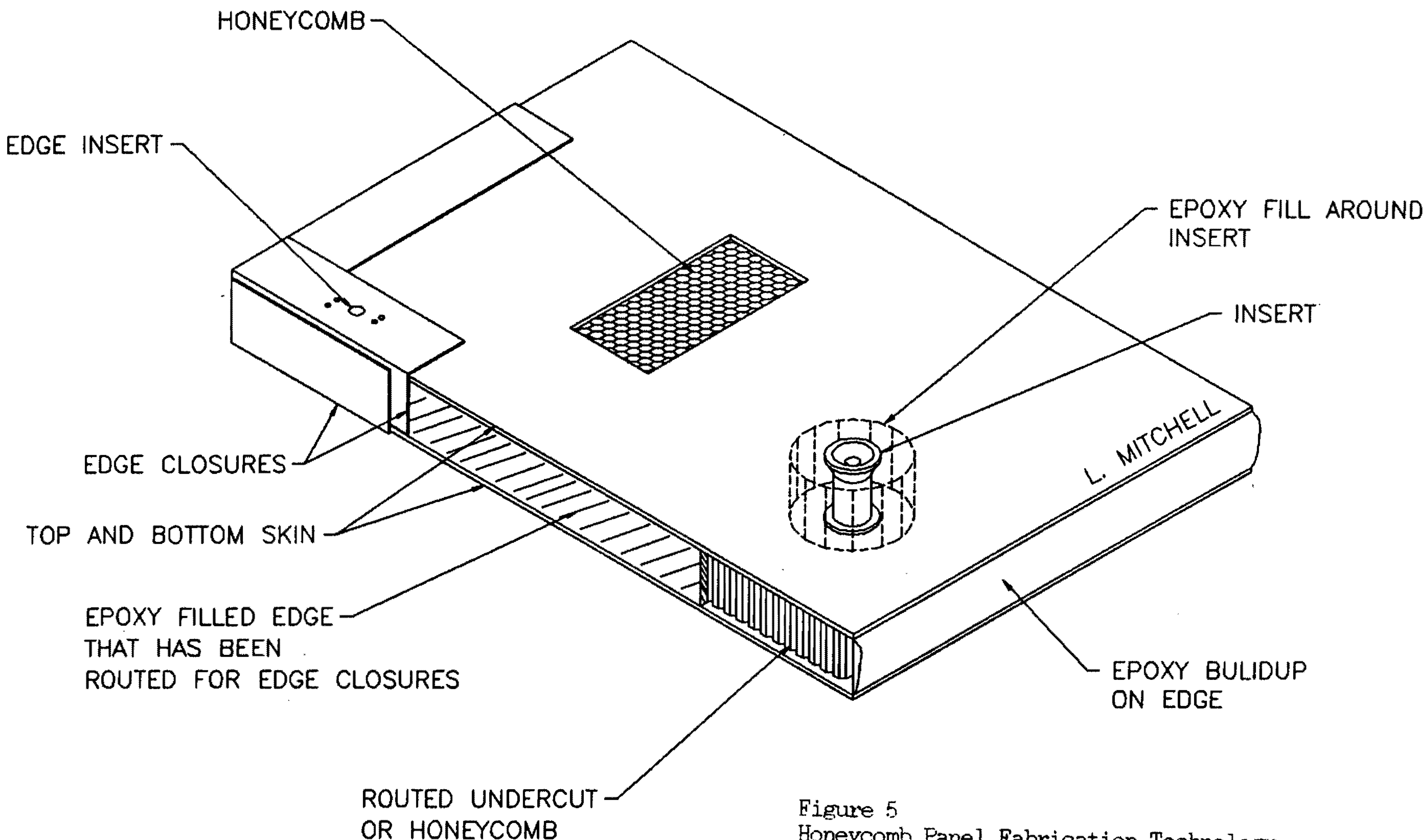

Figure 5
Honeycomb Panel Fabrication Technology

Phase IIID Antenna System Design

by Jack D. Colson, W3TMZ

Introduction

The Phase IIID spacecraft is to be an extremely robust payload carrying a combination of transmitters and receivers for seven bands. Down-link transmitters are provided for 28, 145, 435, 2401 MHz, and 10 GHz. Onboard receiving systems will be used on 435, 1269, and 5.7 GHz. To support these up and down links, a number of antenna systems will be required.

The planned orbit has a period of 16 hours, with apogee at 50,000 KM and perigee at 4500 KM. At apogee, the path loss is approximately 194 dB at S-band. Fortunately, once the satellite is in its permanent orbit (as opposed to its transfer orbit) it will be wheel stabilized such that its upper surface (+Z) is always earth pointing and not spinning around the Z axis. Thus, the spacecraft antennas will be directed towards earth. To overcome the excessive path loss, high gain antennas are desired. Furthermore, to reduce the effect of this increased loss, down-link transmitter powers are being increased.

During the November 1991 design meeting, discussions concerning the antenna system(s) concluded that it may be applicable to use a switchable array(s) to modify the pattern as a function of orbit phase. Moreover, since the transmitters are to be much higher power, they may consist of multiple units and used to drive individual antenna array elements.

Therefore, antenna design goals are: high gain, circular polarization and possibly pattern switchable arrays with the possibility of input multiple transmitters for down-link and multiple pre-amplifiers for up-links.

Dr. M. Lee Edwards, Chair of the Johns Hopkins University, G.W.C. Whiting School Electrical Engineering Program recently became an amateur and is extremely interested in getting students involved in meaningful application programs. This author mentioned the worldwide AMSAT space program to him with an explanation of how many universities and students have played very important roles in these satellite development programs over the years.

Dr. Edwards and this author attended the November 1991 design meeting at which time we were looking for the best application for a student project at JHU. An antenna project seemed to be the best candidate for JHU and AMSAT. Thus, Dr. Edwards started a special project for graduate students whose project would be to work on the conceptual design of antennas for Phase IIID. The JHU student project will concentrate its efforts on 435 (U-band), 1269 (L-band), and 2401 MHz (S-band). The 5.7 GHz link was not firm at this time. We decided to concentrate our initial efforts on system design approach concept.

Three JHU engineers have volunteered to act as instructors/advisors for this special project. Two of these individuals are not involved in amateur radio. All of the staff are professionals in satellite and system design. Bob Stilwell has been designing spacecraft antennas for over 18 years, Allan Jablon has been designing spacecraft antennas for over 5 years and this author has been doing satellite system hardware design for more than 25 years.

Two students volunteered to take this first special project session (one semester). It should be pointed out that graduate students may take only two special projects to be applied to their degree.

Goals

The initial goals of the JHU student project are to perform an antenna systems study for 435, 1269, and 2401 MHz. Specifically:

1) Determine what antenna array would be required to cover the entire orbit.

2) What are the trade offs in array design for various earth coverage.

3) Determine how many antenna configurations make sense.

4) Perform circular aperture synthesis modelling.

5) Select candidate antenna array elements.

6) Model candidate antenna using available software programs.

Study Results

Considering the physical shape of the spacecraft, it was agreed in consultation with Dick Daniels and Dick Jansson that a circular area of one meter in diameter would be a reasonable starting point for an antenna array for each band. Additionally it was at least in concept agreed that antennas may protrude into the body of the spacecraft as much as 200 mm. Note: because of the Cluster spacecraft(s) mounted above Phase IIID, very little vertical clearance is available, making only minimal external vertical protrusions possible. Therefore, it may be practical for antennas to be within the body of the spacecraft.

In Figure 1 a sketch of the planned 16-hour orbit is shown. In Figure 2, a graphic representation of normalized path loss is provided. The curvature at the top of each plot is the variance in path loss over the earth at each range. There is a 20dB delta in path loss from perigee to apogee. This figure defines the range of angles the antenna system must cover from apogee ($\pm$ 6.5°) to perigee ($\pm$ 36°).

In Figures 3, 4, and 5 are shown the results of circular aperture synthesis modelling for S, L, and U-bands, respectively. Based on an one meter aperture, the three curves on each figure represent an antenna which will provide maximum gain at apogee, the widest beamwidth for the perigee coverage and an intermediate pattern that would be a compromise of the apogee/perigee cases.

In Figure 4 the same data is shown for L-band with only minor differences in the attainable pattern shapes compared to S-band. Figure 5 illustrates the U-band synthesis, a significant departure from L and S-bands, because the area in λ^2 is small in comparison. Thus, for a one meter aperture the maximum gain achievable is shown. The question now is what antenna/array of antennas best provide the gain or pattern flexibility.

Quite a bit of analysis was done by the students resulting in what we term the 65% near apogee case, 35% near perigee case and whole orbit case. The near apogee case reduces the maximum attainable gain to achieve a slightly broader pattern yielding whole earth coverage for 65% of the orbital period ($\approx$ 10.4 hours) which is centered on apogee. The 65% and 35% cases are illustrated in figure 1.

Thus, if switching were to be considered a viable approach, then our analysis indicates that three pattern shapes could be considered for L and S-band. U-band data in Figure 5 indicate there is very little to be gained from switching.

What antenna elements are suitable for these apertures? Our design goal, is to select an antenna element that has the highest gain. Stilwell has done quite a bit of work with an antenna called a "short back-fire antenna" (SBFA)[1, 2]. This antenna has been shown to be extremely efficient providing a maximum gain of nearly 15 dBic. In Figure 6 a sketch of a single SBFA is given. Generally, the design is based on a 2λ diameter cup with a wall height of $\lambda/2$.

For our bands of interest the restriction of a one-meter aperture size, the U-band can only support a 1.35λ diameter cup in the one meter area. Simulation results indicate that reducing the cup to this diameter reduces the gain by $\approx$ 1dB. For L and S-bands this is not a problem. A trade off in the number of SBFA antennas could be made in an array with cup diameters ranging from 1.35λ to 2λ.

It comes down to which is better, to use a smaller number of larger antennas as an array or a larger number of smaller antennas. (I don't recall that we actually answered this question to the point where it can be documented). In Figure 7 is a pattern of a 1.35λ SBFA using the AWAS modelling software[3].

Another antenna that was learned about toward the end of the semester is the short helix[4]. This very small antenna is reported to have a gain of 10 dBic, which is quite reasonable considering its size and it is definitely provides circular polarization. A sketch of this antenna is given in Figure 8 with a modelled pattern in Figure 9. In figure 10 a theoretical pattern of a 7 element short helix array is shown. Note: One of the problems in an array of linear elements is obtaining good axial ratios. This problem is compounded with arrays of these elements.

Wood and Jansson have done a great deal of work with what is commonly termed the "patch" antenna. This antenna is gaining popularity because of its low profile. We did not analyze this element because we felt that Wood and Jansson had done this and we could benefit from their results.

As the semester was coming to an end, we had concluded that the SBFA was our antenna of choice for all bands. This choice did not consider how they could fit mechanically into the satellite design. Obviously we were concerned about the large U-band antenna, but we were also concerned that our antenna/arrays have sufficient gain to provide desired link margins.

Our students wrote a collective report on their work from which our presentation for the Marburg meeting was based. Off to Marburg, we were quite enthusiastic to hear the response to our work as well as that of Stan Wood and Dick Jansson and to get some direction as to where the antenna design would head.

Where We are Today

Today we are concentrating on modified design approaches after numerous discussions at Marburg 1992. First of all, our design constraints have become much more defined. Basically, there is no large volume available within the spacecraft structure for antenna array(s) to be recessed. Moreover, Wood has done so much work with antennas for the lower bands that we collectively decided that he will continue his work there and the JHU student effort will concentrate on 1269 and 2401 MHz, and 5.7 GHz.

A relaxation of the absolute external height restriction has not been received, but Dr. Meinzer said essentially, for us to come up with the best design, don't exceed 7 cm above the spacecraft surface and restrict the diameter to 0.5m. Once an acceptable antenna design is completed then space above Phase IIID will be negotiated with Cluster spacecraft personnel. Note: A temporary cover could be placed on our antenna(s) during "build up".

Other major decisions made at the Marburg meeting relating to antenna design were that pattern switching will not be done, and that we will opt for the 65% near apogee case; thus, nearly the highest gain antenna. The idea of using distributed transmitted elements driving individual antenna(s) elements as part of an array was also discarded. It was felt this was just "too risky" considering the problems that would need to be overcome. (i.e., transmitter/ antenna phase relationships to maintain pattern over thermal extremes was a major concern.)

With these constraints, the first work to be done this semester is to perform the circular aperture synthesis based on 0.5m diameter for L and S-bands and, for the moment, limit C-band to a 0.25m diameter, maximum.

These calculations are shown in Figures 11, 12 and 13. The next major question is what antenna element is best for each band, assuming an array of these elements will ultimately be used.

Design considerations are based on:

1) use a basic antenna element which has the highest gain; thus, when arrayed should yield the best that can be done considering the area available and also to minimize the number of elements in the array

2) feed network for the array

3) fabrication of element/array

4) stability of antenna (i.e., how will it behave over environmental conditions)

5) bandwidth, again related to how critical the antenna is

6) ease of feeding for circular polarization.

L-band: The choices for this band basically come down to the short helix or patch. An array of seven helical antennas will fit into the 0.5m diameter area and meets the height restriction. An array of seven patch antennas also will fit into the area and meets the height restriction.

S-band: The choices for this band at present come down to the short helix or the short backfire antenna. An array of 19 helical antennas or seven 1.35λ SBFA should provide approximately 19 dB gain.

C-band: Our present plans are to scale down to whatever array is selected for S-band for C-band.

These antenna arrays must be fed using an efficient means of power distribution. One student is actively designing a generic "microstrip" power divider network which can be scaled for the three bands of interest. This design is being done using "Academy" which is a product of EESOF. This software provides a means to: 1) design these microstrip circuits, 2) optimize the design based on selected criteria, 3) produce a mechanical layout drawing and 4) a data file in various formats which is compatible with various printed circuit board automated manufacturing programs.

The students are starting to build individual L-band antenna elements for evaluation and engineering model power dividers for C-band.

The antennas are being tested using a proven antenna pattern range. When actual power divider hardware is received, they will be evaluated at a Dorsey Center microwave laboratory which is part of the JHU/GWC Whiting School of Engineering. This lab is well equipped with the latest microwave test equipment capable of operating well above 20 GHz.

Based on testing of engineering model antennas, a decision as to the type of element for each band will be made. Fabrication of an engineering model will then start on array of selected antennas along with appropriate power dividers.

A nineteen-way divider is almost complete; it consists of a combination of: 1 to 7, 1 to 2, 3 to 4, 4 to 7, 8 to 11 and 1 to 1 dividers, which are combined. This works out quite well since the 1 to 7 can be used for L and S-bands.

Where We are Going

By the end of the summer semester, the selection of an appropriate antenna element should be complete, thus we will focus on engineering model array fabrication and testing.

We are hoping to possibly involve another student project with the flight mechanical design. There is quite a bit of work also regarding thermal design of the antenna arrays.

It is our goal to have engineering model antennas for L, S and C-bands completed and ready to be presented at the next Phase IIID design meeting in November 1992.

Acknowledgements

We are very thankful that Dr. Edwards had the vision to embark on this program and are proud of our students, David Fritz and Eric Kohls for their work. This author is also very appreciative of the time and work Bob Stilwell and Allan Jablon have given to make this new project a reality and bring it as far as it is today.

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2) Proceedings of the IEEE, Vol. 53 No. 4, August 1965, pp 1138- 1140, "The Short Back-fire Antenna", Ehrenspeck, H.W.

3) Analysis of Wire Antennas & Scatters, Artech House, A.R. Djordjevic, et al. Software and Users Manual

4) IEEE Transactions on Antennas and Propagation, Vol. 40, No. 3, March 1992, "Low-Profile Helical Array Antenna Fed from a Radial Waveguide", H. Nakano, et al.

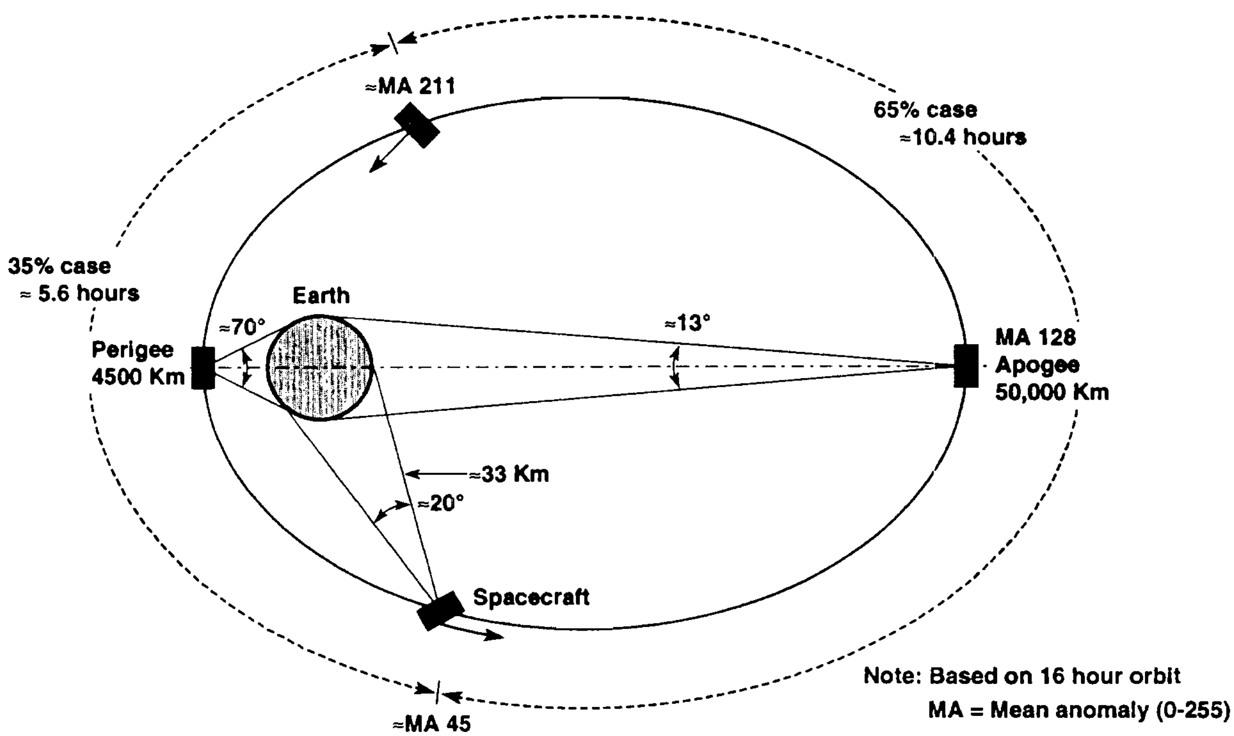


Figure 1 Phase IIID Orbit model illustrating antenna switching concepts

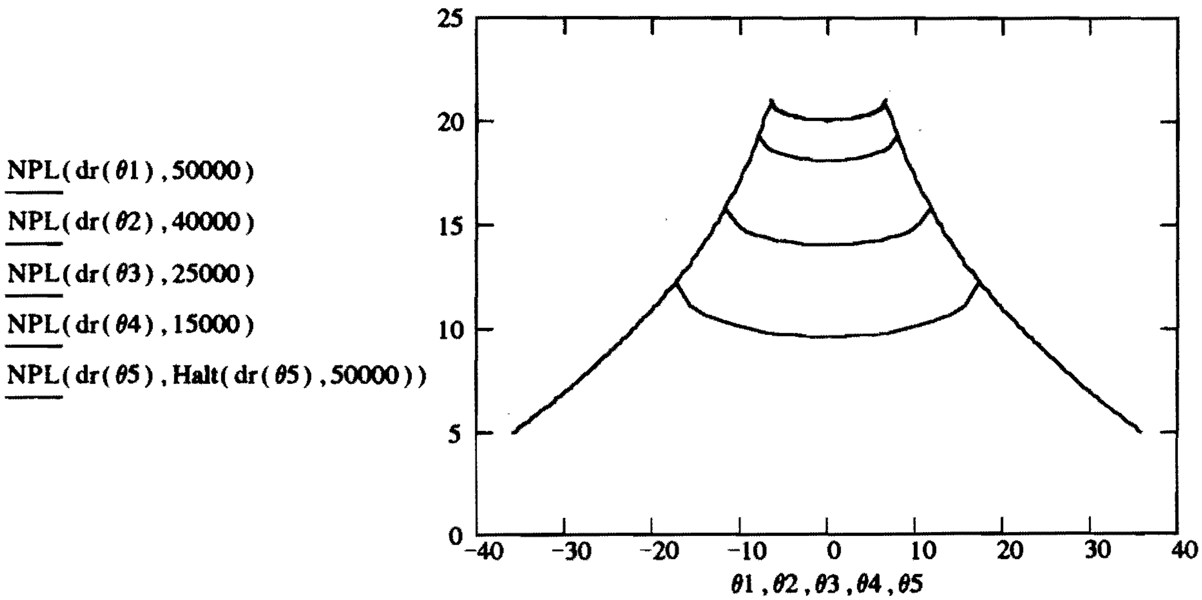


Figure 2 Normalized Free Space Path Loss

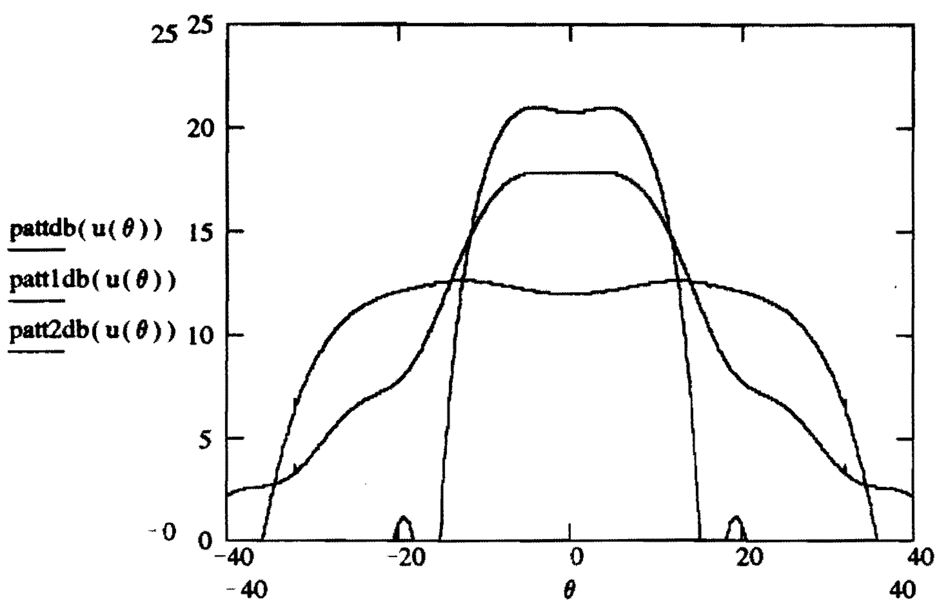


Figure 3 S-band Circular Aperture Synthesis

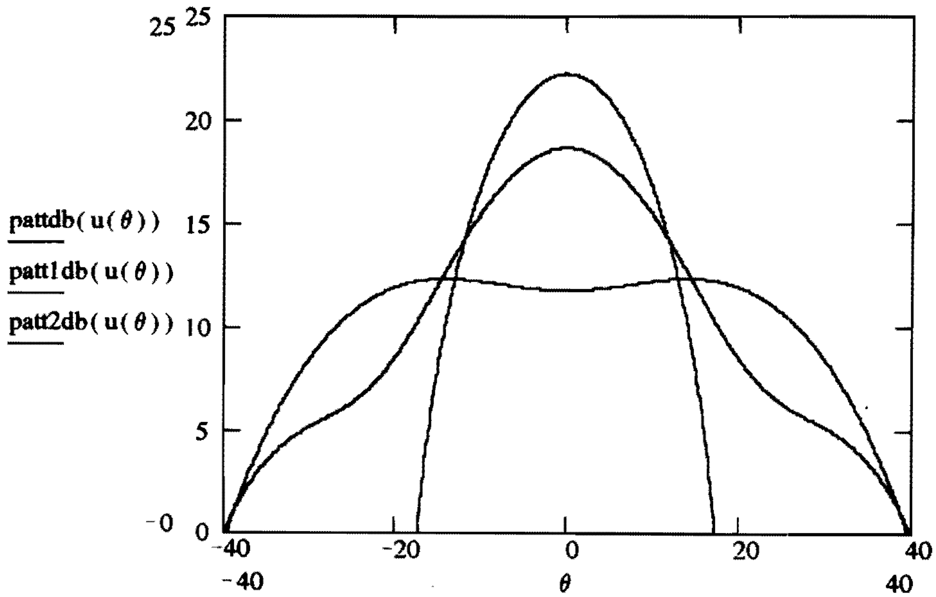


Figure 4 L-band Circular Aperture Synthesis

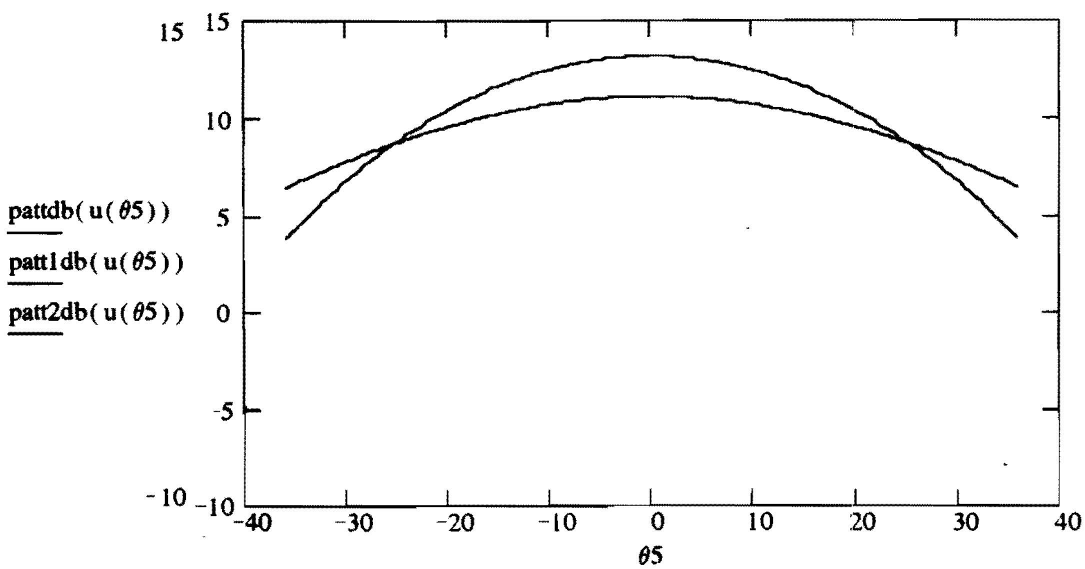


Figure 5 U-band Circular Aperture Synthesis

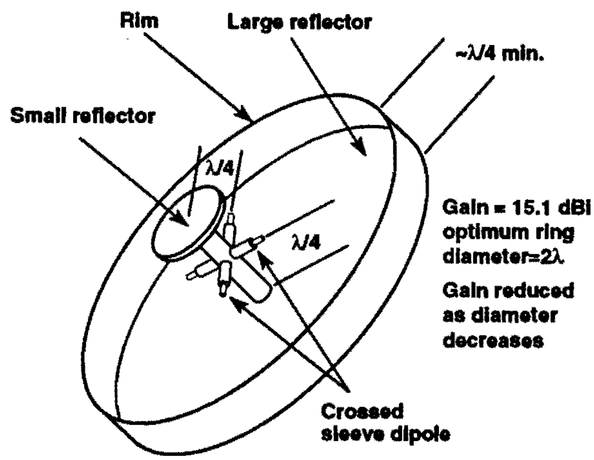


Figure 6 Short-Backfire Antenna (SBFA)

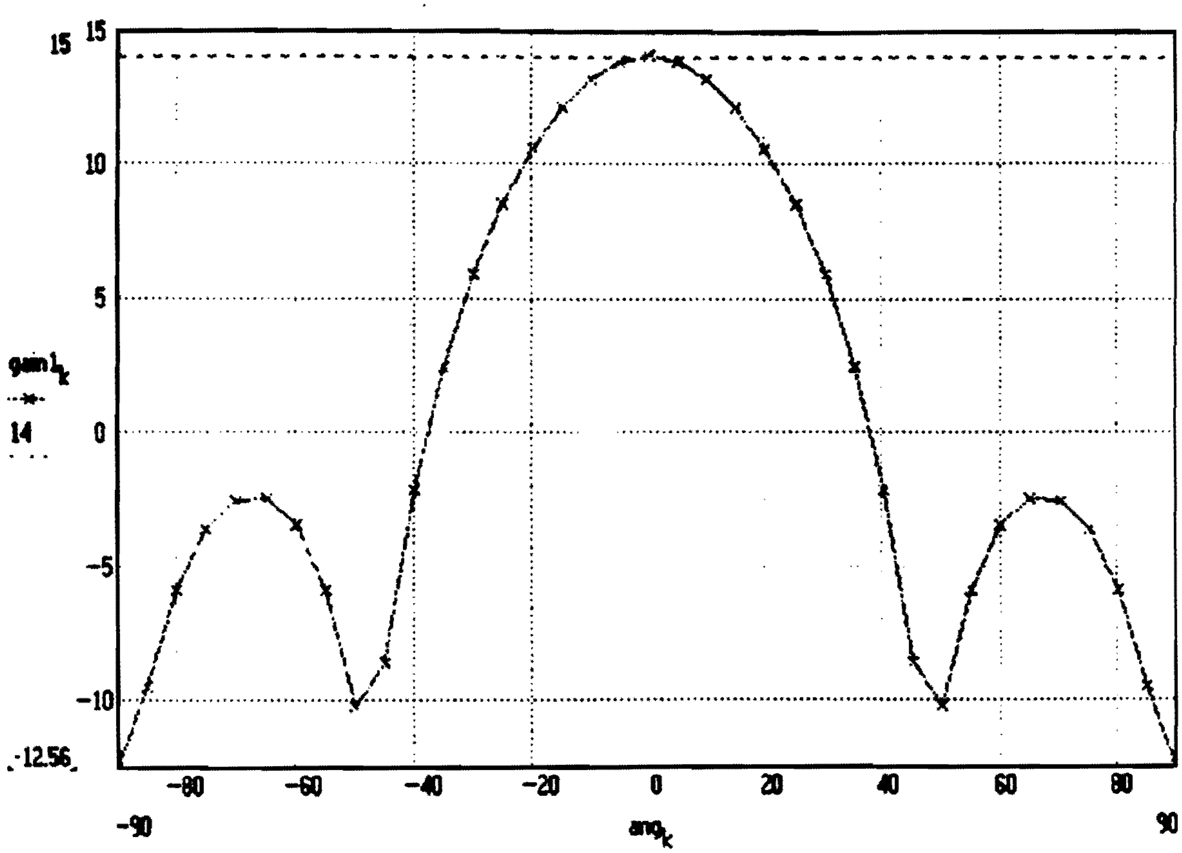


Figure 7 Far-field pattern 1.35λ cup diameter SBFA

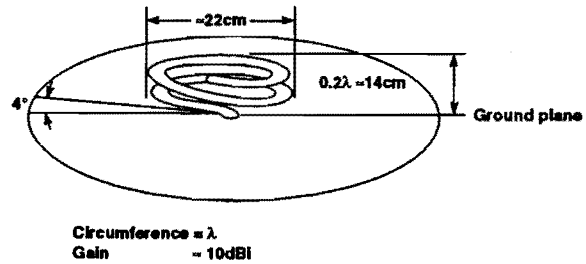


Fig. 8 Sketch of a Short Helix for L-band

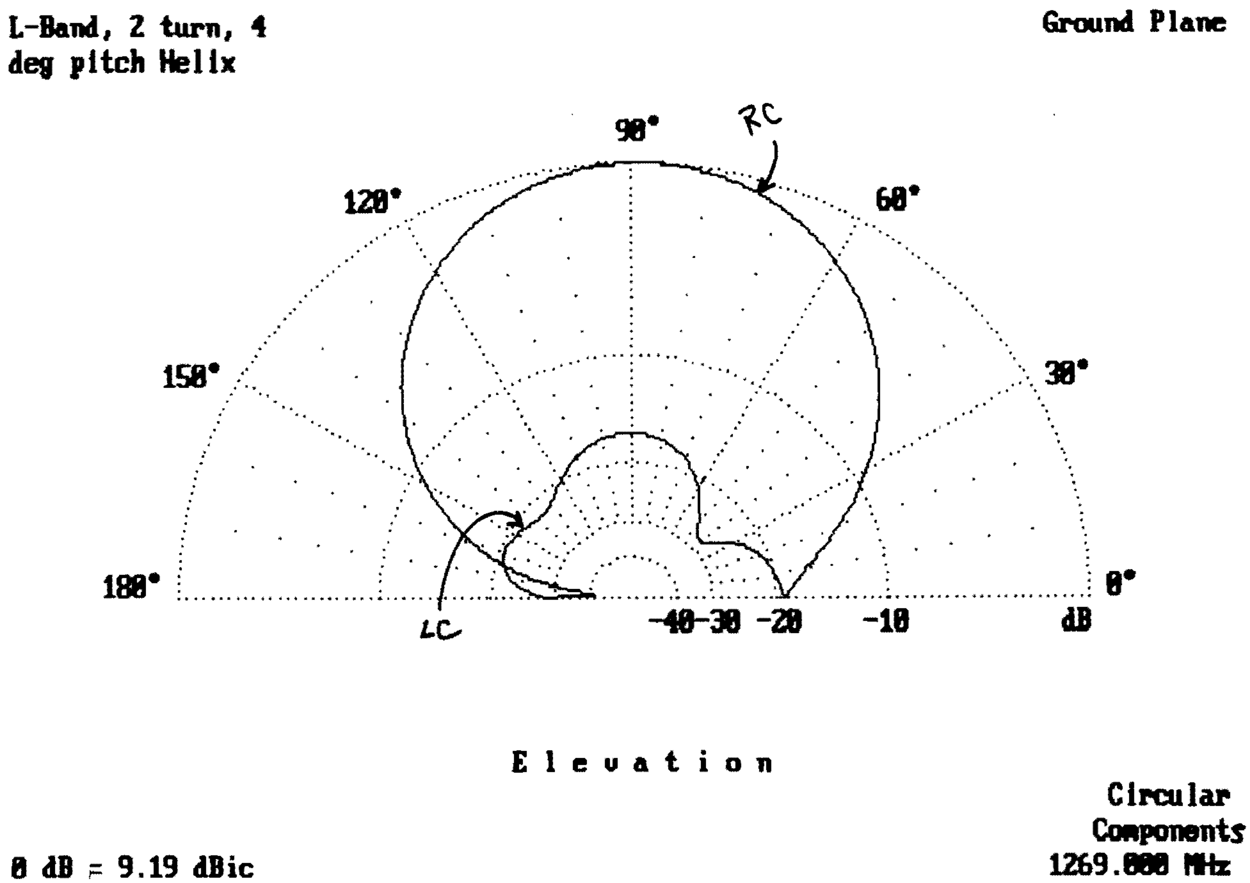


Figure 9 Theoretical L-band Short Helix pattern

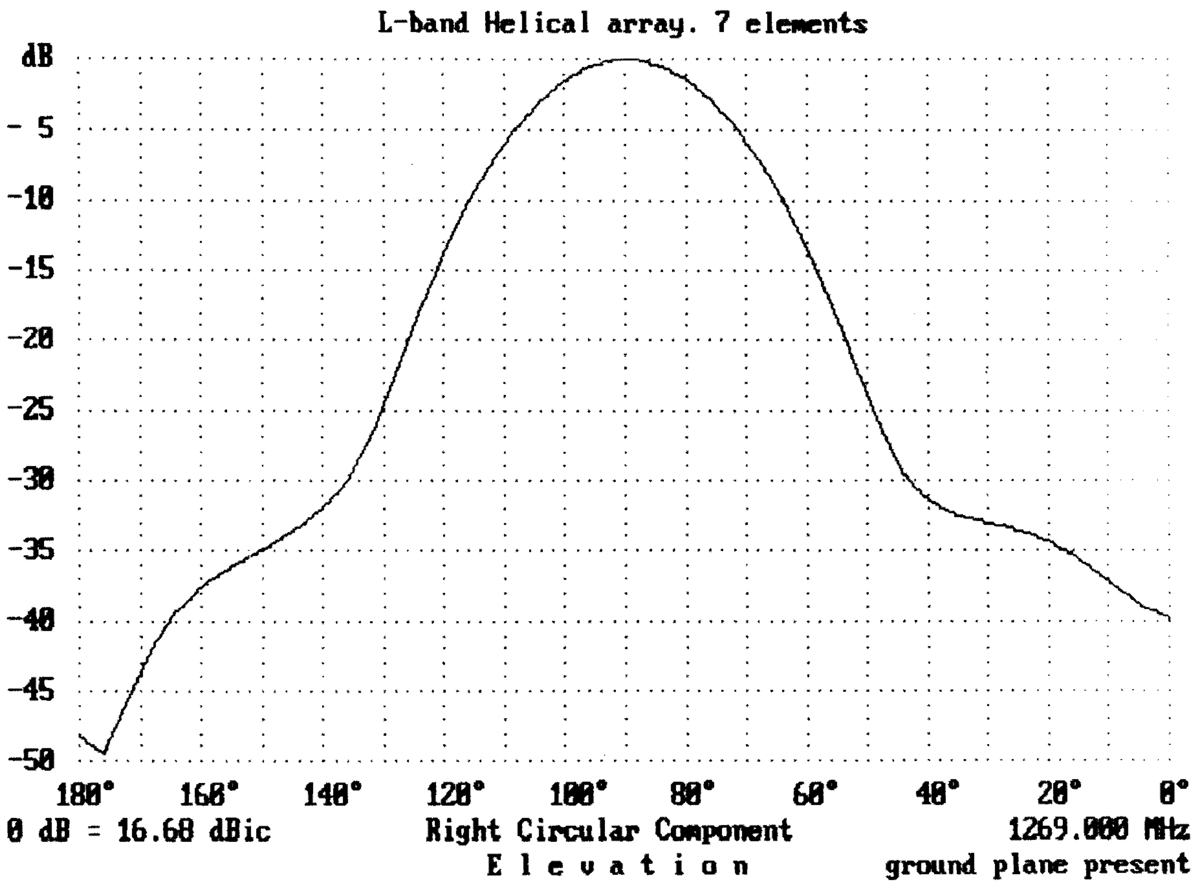


Figure 10 Theoretical pattern for a 7 element array of short helical antenna for L-band

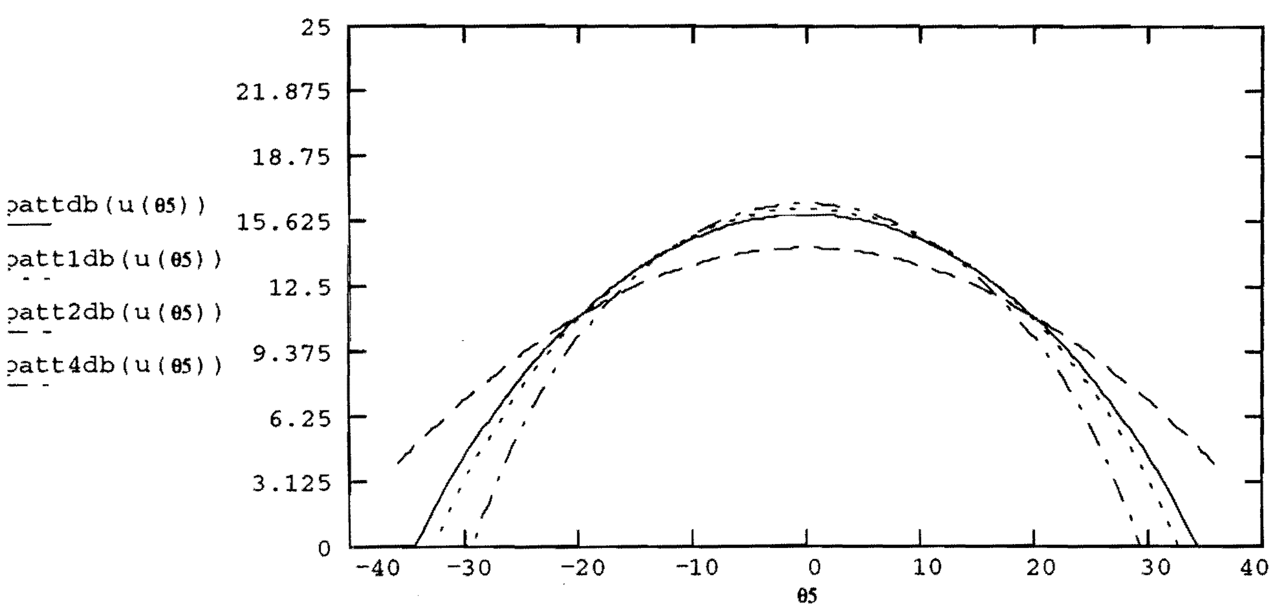


Figure 11 L-band Circular Aperture Synthesis (0.5 meter diameter)

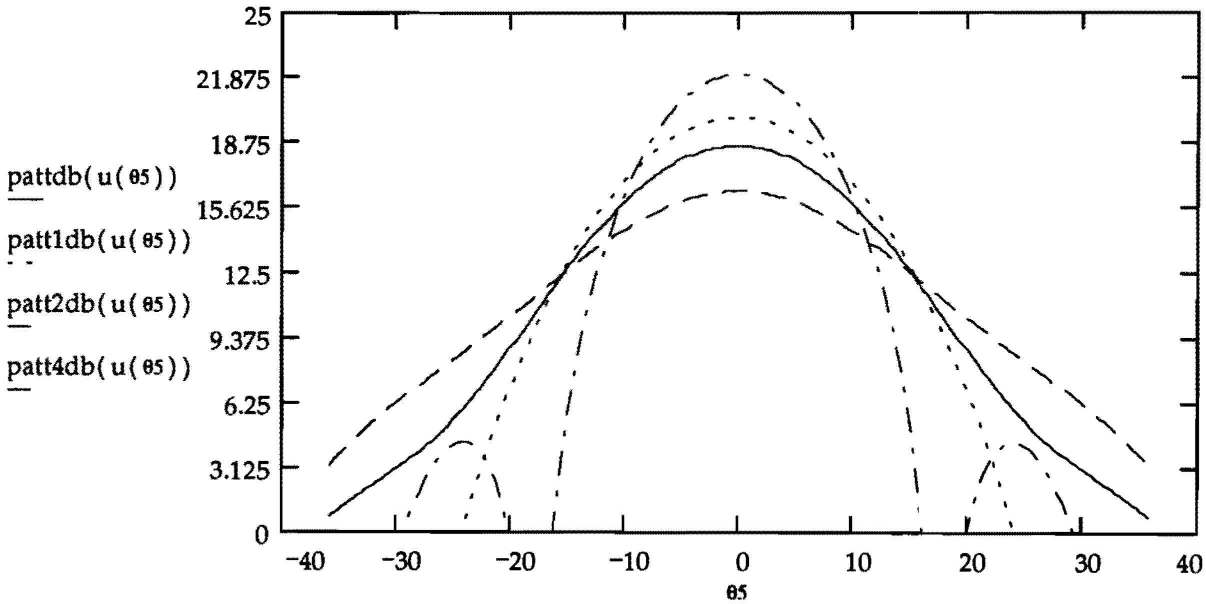


Figure 12 S-band Circular Aperture Synthesis
(0.5 meter diameter)

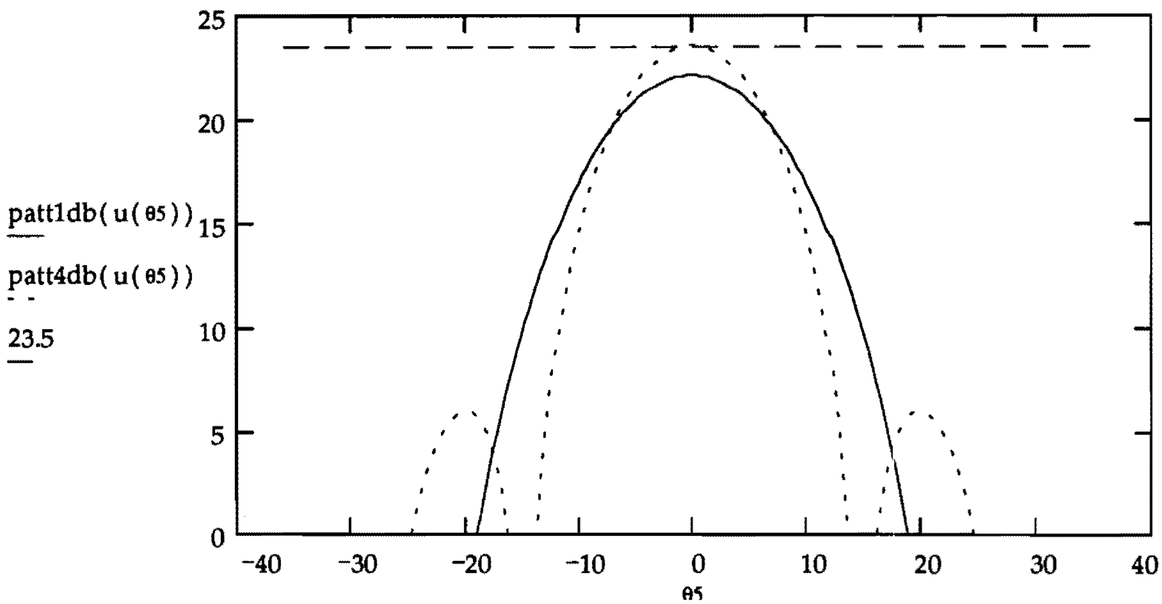


Figure 13 C-band Circular Aperture Synthesis
(0.25 meter diameter)

AMSAT Phase 3D Antenna Design Review
Phase 3D HF/UHF/Microwave Antennas

by: Stan Wood, WA4NFY, and Dick Jansson, WD4FAB

The AMSAT Phase 3D satellite is looking more and more like an Orbiting Antenna Farm. The satellite will have antennas for seven of the eleven of the Amateur communications bands from 0.029 GHz to 10.5 GHz. For the antenna designer, it is quite a chore trying to find antenna designs for all of these bands, and to find space on the satellite to place all of them. There are at least two serious efforts underway to find the most suitable antennas for this application. This report covers the results one of these efforts.

Spacecraft Limitations

Fig. 1 shows a generalized perspective view of the Phase 3D spacecraft. The principal radiation direction is along the +Zaxis, the center line of conical adaptor, toward the top of the illustration. On the Phase 3D satellite we have the entire top surface available for RF capture area, a fact that has not gone unnoticed. While there is a lot of surface area on the top of the spacecraft, there is almost no available height. A limitation of 50 mm (2") in height above the +Z surface of the spacecraft is dictated by the close spacing of P3-D and the Cluster Spacecraft. Any antenna dimensions in the +Zdirection will need to be less than 50 mm above the spacecraft bus structure. In other words, low profile antenna designs are needed. Deployable antennas are limited to flexible whips for high reliability.

Orbit Parameters

The launch of AMSAT P3D into an initial transfer orbit and it's final placement into a 16-hour Molnia orbit places multiple requirements on the antenna system. See figure 2. Initially P3D will be spun on the Z axis to maintain stability for motor firing. The Z axis will be oriented 90° to the major axis of the orbit and in line with the plane of the orbit. Table 1 shows the link variables encountered in this orbit.

Table 1, AMSAT P3D Orbit Parameters

Orbit hr	Phase	Range	Path Loss	Z axis <	Earth <
8 hr	128	49800 km	-185.5 db	90 deg	13.0°
7 hr	112	48900 km	-185.4 db	80 deg	13.5°
6 hr	96	46600 km	-185.0 db	74 deg	14.5°
5 hr	80	43000 km	-184.3 db	67 deg	15.0°
4 hr	64	38000 km	-183.2 db	59 deg	17.0°
3 hr	48	31500 km	-182.6 db	47 deg	20.0°
2 hr	32	23700 km	-180.2 db	28 deg	25.5°
1 hr	16	15800 km	-177.9 db	15 deg	38.5°
0 hr	0	5000 km	-165.5 db	90 deg	68.0°

This table shows the orbital Time, Phase, Range, Path Loss at 1269 MHz, the angle between the Z axis and the Earth (Z axis <), and the width of the Earth as seen from the spacecraft (Earth <). The maximum pathloss at 1.2 GHz is −185.5 dB at apogee (Phase 128) with a minimum pathloss of −165.5 dB at perigee (Phase 0). The path loss varies 20 dB on ALL Frequencies over an entire orbit.

Omni Antennas

While the spacecraft is spinning Omni Directional antennas are required.

Several Omni Directional antennas were evaluated. Fig. 3 is the Omni Antenna used on Oscar-13. It is a two band vertical operating as a 1/4 wave whip on 145 Mhz and a 1/2 wave J-Pole on 435 MHz. The antenna is fed at the base of the longer element with a simple duplexer and matching unit. Fig. 4 shows the expected pattern from such an antenna. Max gain is 2.5 Dbi perpendicular to the Z-axis with a deep overhead null. The main problem with this antenna is finding a suitable mounting point were it produces a usable antenna pattern.

Fig. 5 is a pair of Turnstiles stacked 1/2 wave length apart and mounted 1/4 wavelength above the spacecraft. This antenna has the same gain (fig.6) as the vertical ant with an overhead null of -18 db. With the 20 db change in pathloss encountered in the P3-D orbit a more constant signal level is maintained. There is not sufficient height above the spacecraft (+Z surface) to mount this antenna. But it could be mounted on the bottom (-Z surface) for the higher frequency bands. Computer models of this antenna showed far less distortion of the antenna pattern caused by the spacecraft structure. Further work on the antenna test range is required to verify this result.

Final Orbit

When the spacecraft reaches the final orbit it will be despun and three axis stabilized using momentum wheels and magnetic torquing. The solar panels will be deployed increasing the power available by a factor of three. The spacecraft will rotate to point the +Z surface at the Earth for the entire orbit. All high gain antennas are fixed in the +Z direction. Antenna pointing is done by positioning the entire spacecraft during the orbit so that the high gain antennas can be used continuously.

To properly illuminate the Earth during the final orbit, selectable gain antennas are recommended. At apogee the width of the Earth as viewed from the spacecraft is 13°. This limits the maximum gain of the antennas to 19 dBi, as higher gains would have too narrow a beamwidth and not allow full illumination of the entire Earth. At perigee the width of the Earth is 68° and the maximum gain is 6 dBi for full illumination. A variable gain antenna with a range of 6 to 19 dBi would give optimum performance for the entire orbit. The effect of the 20 dB change in path loss would be reduced to only a 7 dB change. This variable gain operation does not mean that an absolutely uniform illumination of the Earth needs to be obtained at perigee, only that the signal at receivers on the illumination limb of the Earth will be no lower than the signal levels seen with the satellite is at apogee. The antenna arrays shown in Fig. 1 will meet that objective and will be described.

High Gain Antennas

While we cannot pretend to have examined every possibility for all of the antennas needed, the list is significant. For 29.4 MHz the choices were rather limited. As this is also a limited use beacon mode operation, the antenna does not need to be exotic, and the considerations have included a three pole CP "XBeam" and a "dipole" consisting of gamma matching the solar panels as the dipole elements. Computer models showed a two element "X Beam" mounted on the end panel of the rear arm of the spacecraft to give the best results with a minimum amount of interference with other antenna arrays.

The proposed antenna (fig.7+8) is basically a linear polarized two element narrow spaced beam, using a dipole as the driven element and a single director. The director is mounted near the top center of the rear end panel and the driven element near the bottom center of the rear end panel. This gives a spacing between elements of 650 mm which is the height of the spacecraft bus. The element spacing is effectively increased by canting the director elements up 15 degrees and the driven elements down 15 degrees. This increases the input impedance and bandwidth of the antenna. All the elements were then swept back 30 degrees from the spacecraft to reduce interference with solar panel deployment and other antenna arrays. The antenna's computed gain of 6.5 is sufficient for operation in the lower half of the proposed P3-D Orbit.

Another band that has proven to be troublesome is 145.9 MHz. The selections are also limited. The top surface of the spacecraft cannot be totally used for just this band. The first solution (Fig. 7) was a single circular polarized full wavelength loop antenna mounted in the middle of the open throat of the conical adaptor with six 1/4 wavelength three element beam antennas that extend from the sides of the spacecraft. The beams (Fig. 9) are mounted 1/2 wavelength apart on the radiator panels and the front solar panel. The elements on the radiator panels are made of flexible steel tape, while the solar panel elements use 1.5 mm music wire to minimize shadows on the solar cells. Fig. 10 shows the pattern of one side of the spacecraft. Variable beamwidth performance came from varying the power ratio between the center loop and the beam antennas. (Figs. 11,12) Maximum gain requires equal power to all antennas. Minimum gain runs all power to the center loop antenna.

An alternative antenna for 145 MHz is shown in Fig. 13. The antenna is made up of six end-fed 1/2 wavelength dipoles radiating from near the top of the conical adapter. Computer models show a gain of 10 to 12 Dbic (Fig. 14) and a very symmetrical pattern. This antenna is usable through the entire orbit with no gain changes required. We just turn on the transponder and let it run. Figure 16 is a computer generated figure of the antenna pattern projected on the earth with the satellite at perigee. The gain on the Lem (edge) of the earth is .83 Dbic. With the decrease in path-loss this results in a 11 to 20 Dbic in signal level for ALL STATIONS from apogee to perigee. While not shown the gain directly below the spacecraft is 10 to 12 Dbic. Figure 16 is a model of the first antenna at perigee and still set for maximum gain. The gain at the Lem of the earth varies from 6.5 to -25 Dbic. The first antenna requires at least two gain levels to operate through the entire orbit.

For the higher bands the antenna situation becomes considerably easier, as the area available is quite adequate for some really good performance. The considerations have been patches, turnstiles, recessed turnstiles, slots, and short circular horns. The trade offs for this list is complex, but we have concentrated on the most attractive of the bunch, the patch antenna. The 10.5 GHz band will clearly use waveguide horn antennas directly connected to their transmitters.

The Patch Antenna

Patch antennas can be described as a thin square sheet of conductor material, approximately 1/2 wavelength on a side, closely spaced above a larger reflector plane. The center point of this active element may be grounded using a vertical conductor. While not exact, this patch radiator can be thought of as a pair of slots, spaced by 1/2 wavelength and backed by a reflector. Element feed points can be from an edge, or inward with corresponding impedance variations. Patch antenna active elements may be of almost any shape, including round, rather than square. When properly feed, patch antennas operate with good circular polarization (CP) radiation performance. In the CP operation, all edges of the patch are active.

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

Our tests have shown that the construction of these patch antennas requires some careful attention to fabrication methods and dimensional details. We have found that square patch active elements need to be ≈.47 wavelength on each side, while the round versions are .54 wavelength in diameter. Close control of element size is important. Another important dimension is that of the spacing of the element from the reflector, >0.01 wavelength. Spacings of less than 0.01 wavelength result in reduced efficiency. Our need to carefully control the spacing is causing us to seriously consider the use of some repeatable spacing media, such as an open cell low dielectric constant honeycomb material.

With the construction methods being employed, the feed impedance characteristics are somewhat different than those of the PCB microstrip antennas. 50Ω feedpoints have been found to be located at 0.078 wavelength from the center, while a 100Ω feedpoint is located at 0.115 wavelength from the center. These are good dimensions to know, as a simple ¼wavelength coupling line of UG141 coaxial cable connected between quadrature (90 deg) 50Ω feed points, and with the main feed located at a 100Ω point will result in an overall 50Ω feed impedance and a circular radiation pattern for the patch. All coaxial cable feeds are terminated with the outer conductor connected to the reflector plane and the center conductor connected to the active element. The ends of the coaxial cable are located perpendicular to the reflector plane, and the outer conductor should be extended to within a close proximity to the active element.

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

Rules for Patch Antennas:

1. Use only air dielectric. Air (or space vacuum) has the lowest loss and a dielectric value of unity. A dielectric constant, $\epsilon = 1.0$, makes the patch element full size which gives maximum gain. Teflon with a $\epsilon = 2.45$ reduces the size to 64% and with no loss reduces the maximum gain by 3 dB. This is caused by the wider beam width of the smaller patch.
2. Mount patch higher not lower. The height of the patch above the groundplane should be approximately two percent of the width of the patch. With air dielectric a half wave square patch should be a minimum 0.01 wavelengths above the groundplane. Lower heights result in higher Q and high currents resulting in higher losses.
3. Design for maximum bandwidth. The bandwidth of a patch antenna is direct function of it's height. The limiting factor is mutual H-plane coupling in a close spaced planner array. The higher the elements the greater the spacing required between elements. Minimum edge spacing for 20 dB isolation between elements is 0.12 wavelength for a height of 0.04 wavelength.
4. Use coaxial not stripline feed. Patch antennas and striplines are not efficient on the same dielectric material. Strip lines prefer a high dielectric substrate and minimum height to work properly. 50Ω strip lines also require a ¼ wave transformer to match the edge of a patch.

With these rules in mind a (Fig. 17) a 435 MHz seven element circular patch array was designed for the Phase 3D Spacecraft. They are supported by a central grounding post and a dielectric honeycomb under each element. Each element is operated in a RHCP mode. Element center-center spacing is set at 0.655 wavelengths (450 mm) and is limited by the size of the available top plate area of the spacecraft. The most basic of these seven element arrays is a hexagonal pattern with the seventh element in the center of the array. The power to the center element is varied to control the gain of the array. With equal power to all elements, the array is set for maximum gain. With the center element running maximum power and the outer elements running minimum power the array is at minimum gain and maximum beam width. Computer models show a continuously variable gain range of 8.5–14 dBic by only changing the power to the elements. All elements are fed in phase and no phase changes are required.

The patch array for 0.435 GHz needs to have two of its elements repositioned to allow it to be fitted to the top of the spacecraft, as shown in Fig. 1. While this variant of the seven element array does change the overall performance, the deviation is on the order of 0.5 dB, mainly in the azimuth uniformity of the pattern.

For the higher bands, the fully optimized seven element patch array can be employed, as the space occupied is not too demanding of the available area. Computer optimization studies show that the element spacing in the array can usefully be extended up to ≈1.0 wavelength, with corresponding increases in array gain, up to ≈19 dBic, before the fringing effects increase the side lobe outputs to objectionable levels.

Analytic Studies:

In this effort, all orbital parameters have been determined using Franklin Antonio's InstantTrack and antenna parameters using Brian Beezley's MNC4.0 antenna analysis software. InstantTrack provided the orbital RF range, path losses and Earth size information. We have found that the MNC analyses to be useful for this effort, although the package was designed analyzing for wire antennas, and is definitely not designed to evaluate slot antennas, per se. "Substitute" equivalent wire antennas were used with MNC to achieve our analytic goals. All antennas were evaluated over an infinite ground plane, which is less of an approximation with the higher frequencies. We feel that despite all of these analytic limitations for analyzing our highly specialized satellite antennas, the Beezley MNC software has performed superbly and permitted us to achieve given some very good understandings of our Phase 3D needs.

The CP patch antennas were simulated using a two wavelength square loop with four feed points, each located at the center of the sides. Adjacent sides were feed in a quadrature relationship, producing right hand circular polarization. Each of the patch elements therefore consist of four analytic antenna elements. For a seven element patch array, the analysis uses a total of 28 "elements".

Figs. 19,20 show the reduced gain and increased beamwidth performance achieved with the seven element array employing variable power distribution between the center and outer six elements. This performance change is the result of increasing the power to the center element. Fig. 21 shows the gain and side lobe performance of a seven element array with a center to center spacing of 1.0 wavelength.

Test Data:

The antenna test effort has been principally focused on 0.435 GHz operation, due to the availability of test instrumentation. The test conducted have consisted of feed impedance measurements and (separately) gain comparisons. Literally, this has been a back yard operation, with the two types of tests being done in the respective authors' rear lot territories.

For a start, we constructed a textbook EIA reference antenna. This is a dual dipole unit with the elements located ¼-wavelength over a 1.0-wavelength ground plane, a large piece of double sided printed circuit board. The antenna is rated to have a gain of 7.7±0.15 dBd. This translates to a gain value of 9.8 dBi, and has been used to date with that value. A 1/3 scale model of the Phase 3D spacecraft has been constructed to permit the testing of the 0.145 GHz antennas using 0.435 GHz RF instrumentation. Tests of the seven element 0.435 GHz array were done on this model, using 1.2 GHz test equipment.

A standard base for 0.435 GHz patch antenna tests was constructed. This base allowed the feed points to be readily adjusted, and permitted different patch elements to be attached for test. The initial tests were conducted with a patch element with a diameter of 370 mm. In fact, while close, the element size was slightly small and the resonant frequency of 0.439 GHz was just off of the top of the satellite band, although located in the center of the range of our test equipment.

Detailed impedance measurements were employed to determine the operating bandwidth of the test antennas, and to insure that the antenna adjustments would result in acceptable feed characteristics. Impedance measurements were made with the test antenna supported away from the operators in a relatively free field with a skyward orientation. Fig. 22 shows the results of a patch antenna using a circular polarization feed.

Antenna gain measurements are somewhat more involved to make. Obtaining a relatively free field is generally considered to be the root of most testing problems. For these back yard tests, a helical source antenna was placed at 20 ft. on a wooden tower. Test antennas were located nearer the ground on a dielectric support (a wooden support made of 2x4 lumber). The range was about 35 ft., 15 wavelengths. Such a close proximity provides a healthy signal with little source power, allowing us to use a relatively simple, but accurate Boonton Microwatt Power Meter, Model 4200. The negative effect of such a close range is the size of the uniform power volume, which inhibits the use of side by side, direct comparison, differential power measurement of the performance of two antennas. Antenna substitution methods were employed for the necessary comparison of the test and reference units. This required multiple measurements to insure the repeatability of the data.

Gain measurements showed that the linearly polarized patch antenna was -1.2 dB signal level below the linear EIA reference antenna, using a linear source antenna. For the tests of the CP patch antenna, a helical source antenna was used, and the patch measured +2.0 dB above the EIA reference antenna. This data implies that the linear patch antenna gain is 8.7 dBi, while the CP patch antenna has a gain of 8.8 dBic. Despite these two tests being conducted over a period of time, the comparison of the two sets of gain measurements is considered remarkable. Measurements of patch circularity against a switchable CP Yagi antenna show a circularity isolation of greater than 20 dB.

Gain measurements using the 1/3 scale model of the seven element 437 MHz patch array showed a gain of 13 to 14 Dbi. Impedance and power measurements were made on each element of the array. All elements showed very low SWR and very good power balance between elements.

Future Efforts:

We clearly feel that the patch antenna is a usable device for the low profile antenna needs of the Falcon spacecraft. There are a number of fairly obvious matters to be addressed before these antennas can be used on the spacecraft, however, and the following list are those items that we see needed.

1) Verification of test data on a certified antenna test range.
2) Obtain a network analyzer. (Beg, Borrow, or Whatever)
3) Design real hardware implementations of specific antennas for specific bands. This effort would also identify any special adaptations or conditions needed for the spacecraft bus.
4) Fabricate test models of the antennas of item 3, and evaluate the results, especially with a view of obtaining fabrication RF repeatability.
5) Define the implementations of feed systems for the different bands.
6) Model and test antenna concepts for the 0.029 GHz band.

Summary:

These antenna efforts have illustrated to us that reasonable analyses, measurements and tests can be done using unsophisticated equipment. One can substitute patience and ingenuity as replacements for high dollar facilities. We have made a good start on this program and expect to have the right antennas installed on the spacecraft at the proper time.

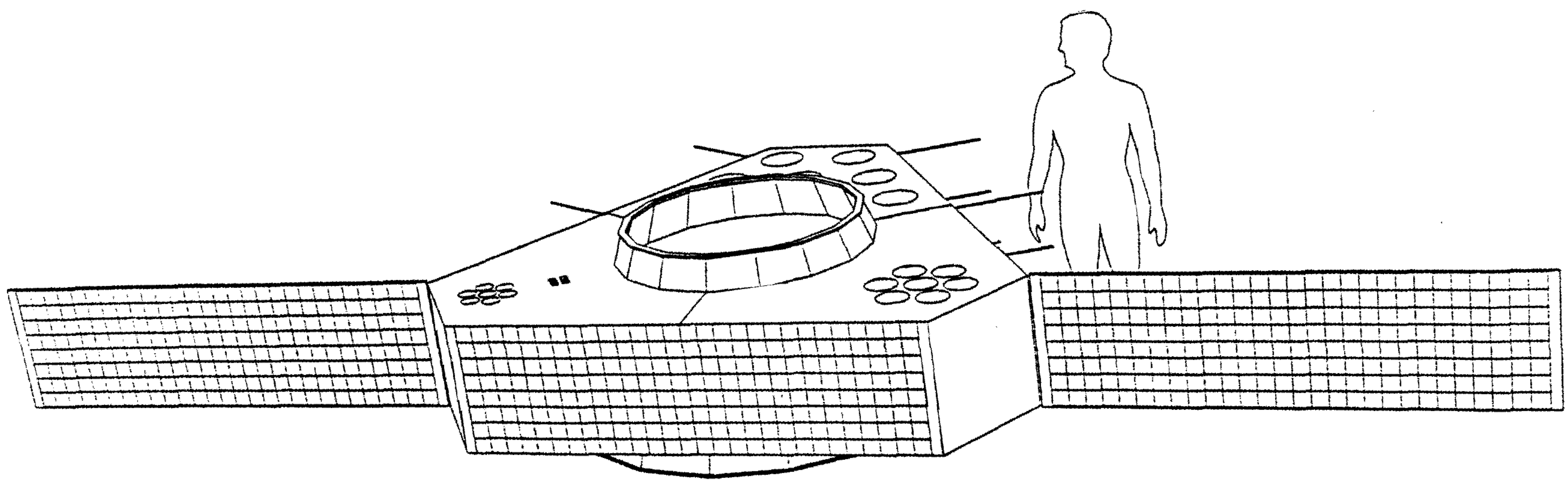
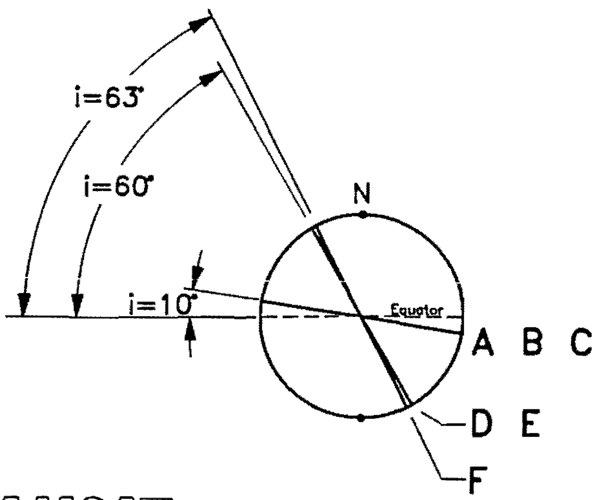
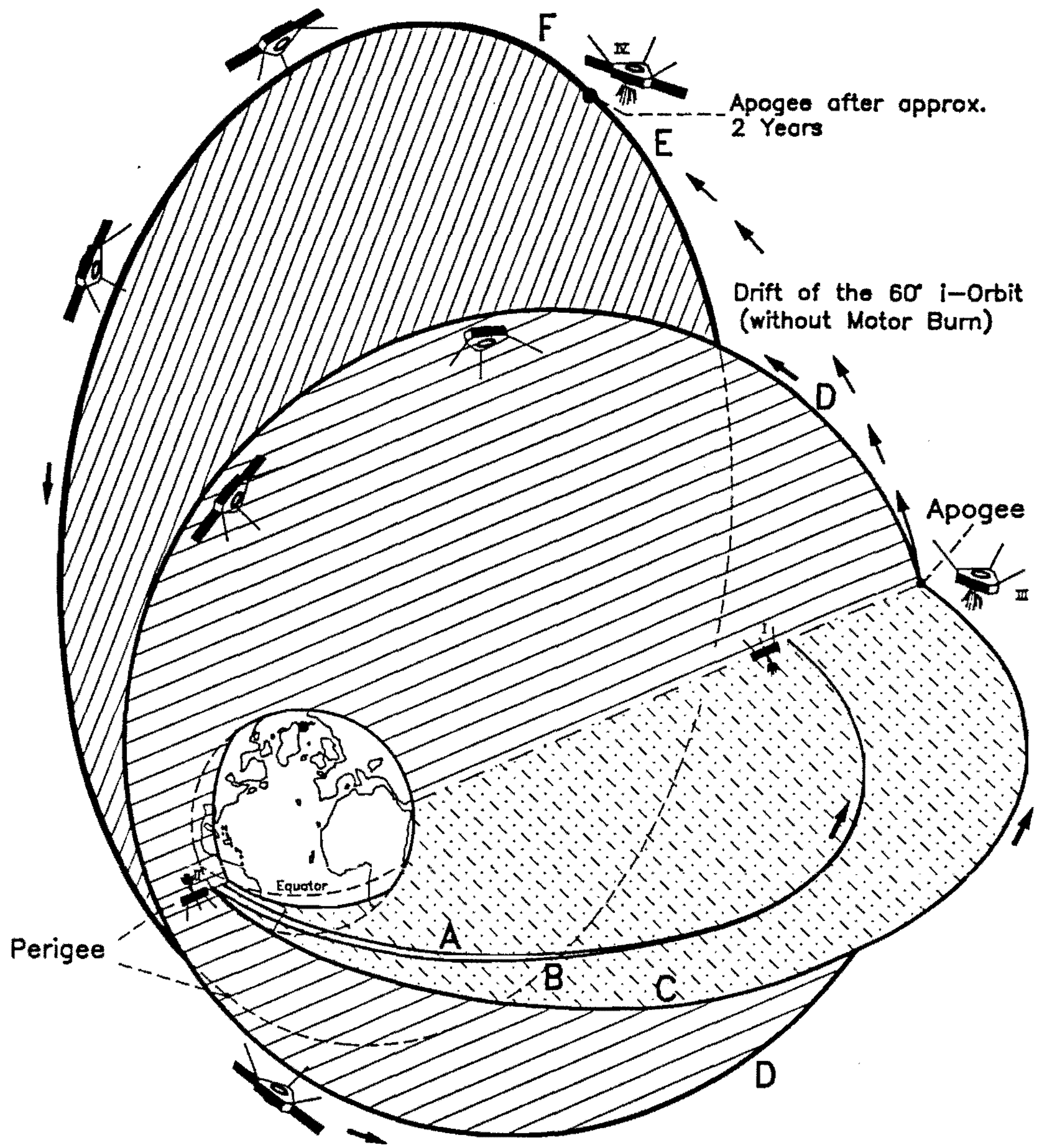


Fig. 1, AMSAT Phase 3D Falcon Spacecraft Configured as in Orbital Position

	Motor Burn	Orbit	Incli–nation	Distance from Earth (km) Perigee	Apogee
1.		A	i=10°	200	35000
2.	I in Apog.				
3.		B	i=10°	500	35000
4.	II in Perig.				
5.		C	i=10°	500	47000
6.	III in Apog.				
7.		D	i=60°	4000	47000
8.		Drift without Motor Burn			
9.		E	i=60°	4000	47000
10.	IV in Apog.				
11.		F	i=63,4° Stable Orbit	4000	47000





AMSAT-DL

P3–D Orbits

FIG. 2

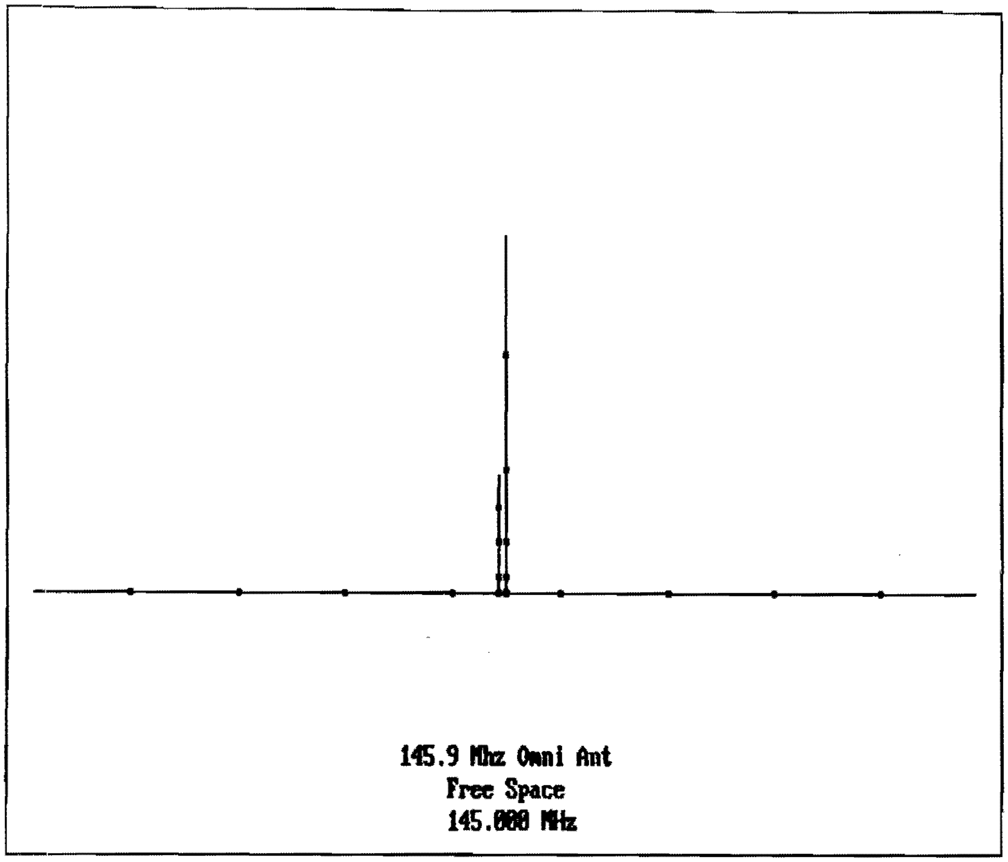

145.9 Mhz Omni Ant
Free Space
145.000 MHz

Fig. 3

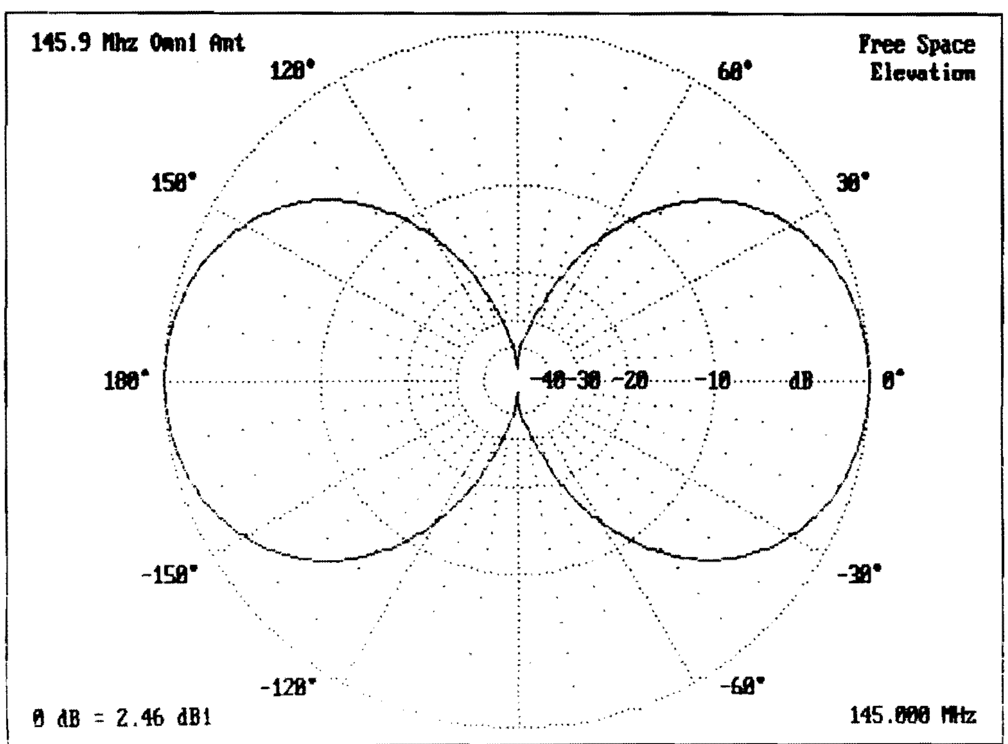

145.9 Mhz Omni Ant
Free Space
Elevation
120°
60°
150°
30°
180°
0°
-40
-30
-20
-10
dB
-150°
-30°
-120°
-60°
0 dB = 2.46 dBi
145.000 MHz

Fig. 4

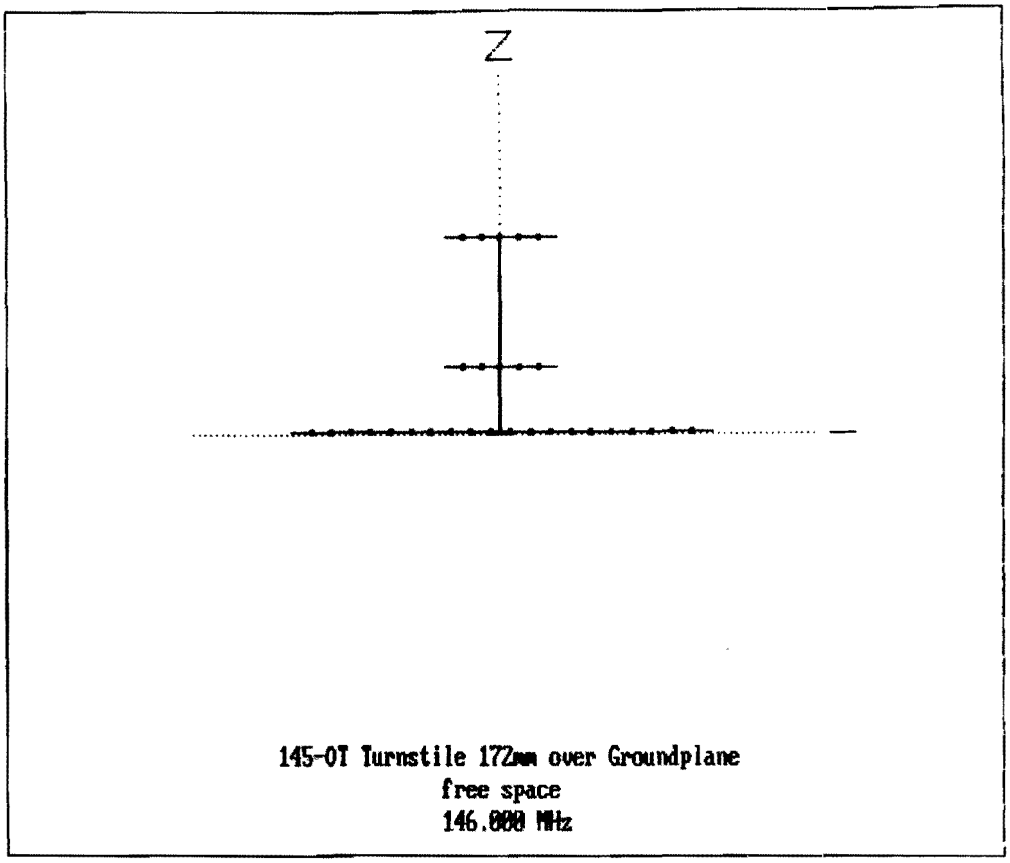

Z
145-OT Turnstile 172mm over Groundplane
free space
146.000 MHz

Fig.5

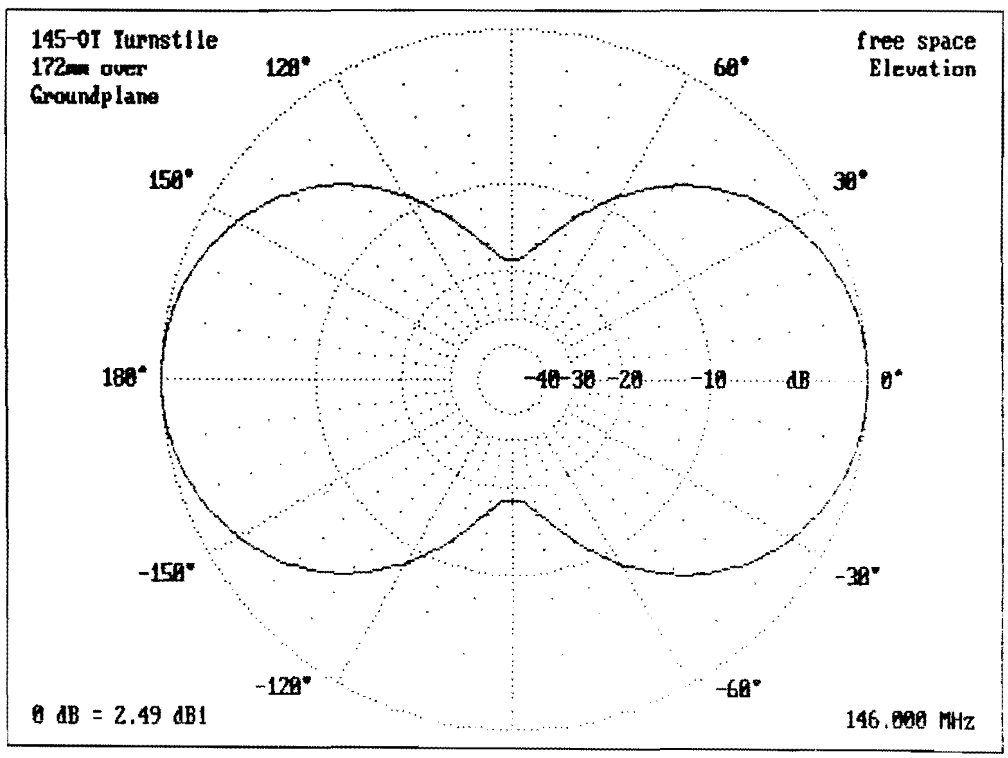

145-OT Turnstile
172mm over
Groundplane
free space
Elevation
120°
60°
150°
30°
180°
-40-30 -20 -10 dB
0°
-150°
-30°
-120°
-60°
0 dB = 2.49 dBi
146.000 MHz

Fig. 6

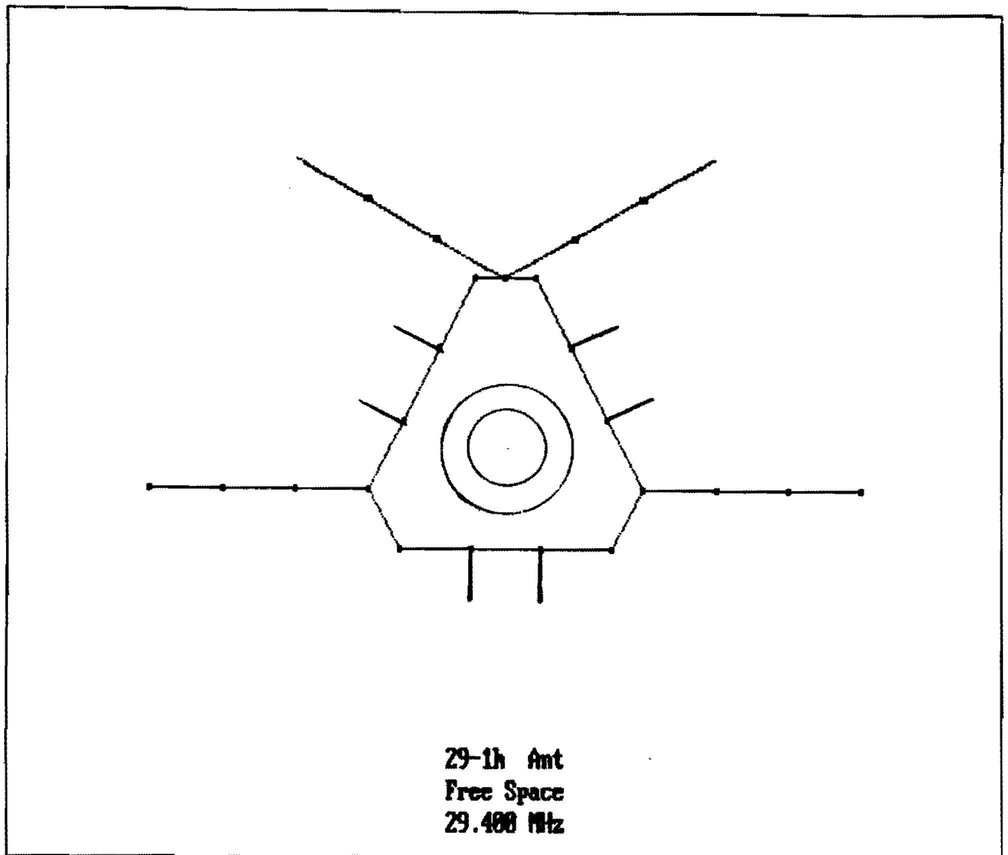


Fig. 7

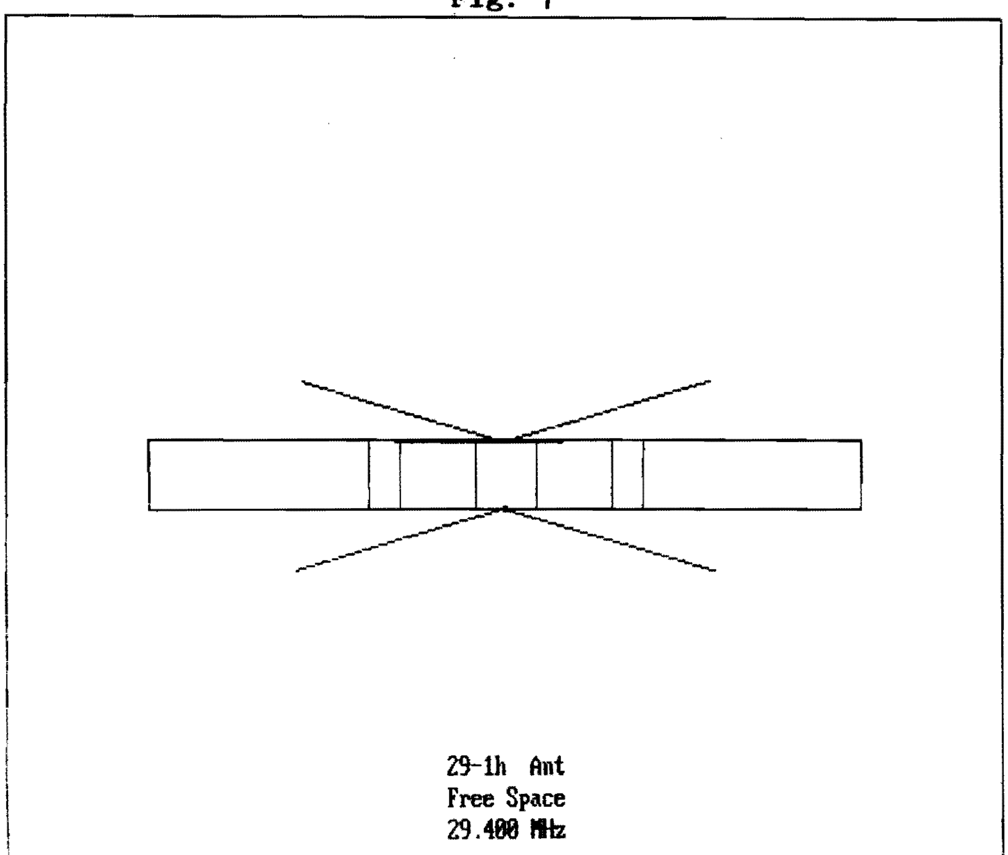


Fig. 8

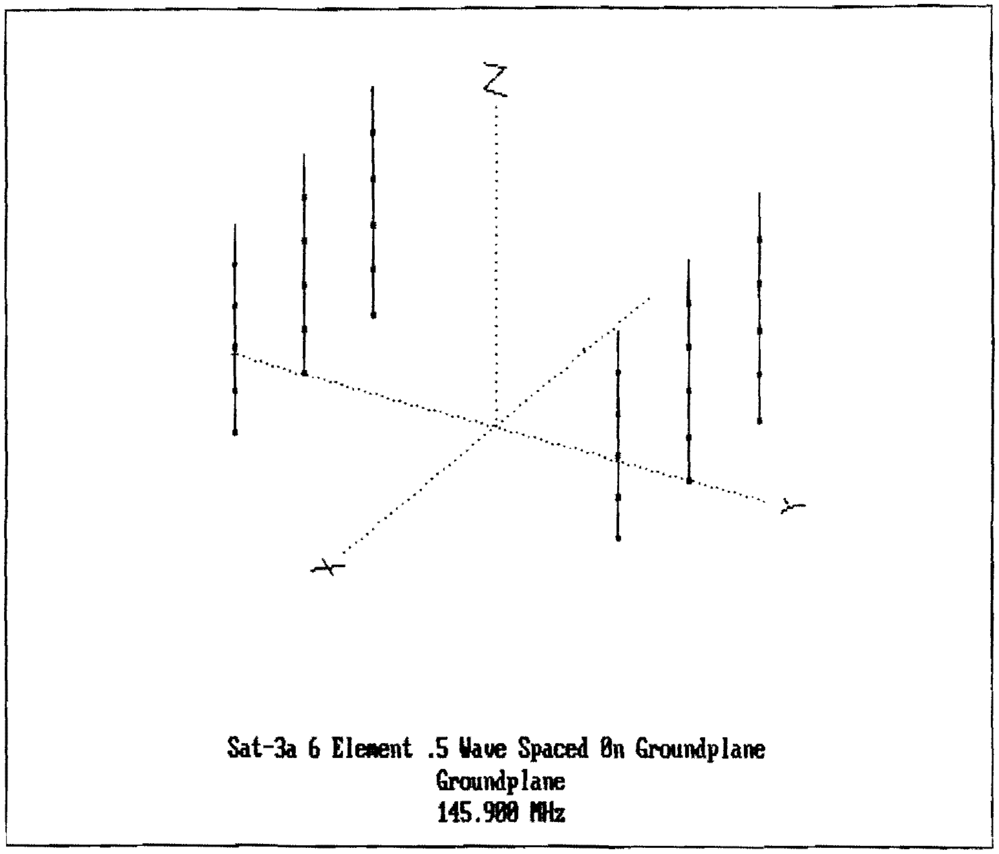

Z
Y
X
Sat-3a 6 Element .5 Wave Spaced On Groundplane
Groundplane
145.900 MHz

Fig. 9

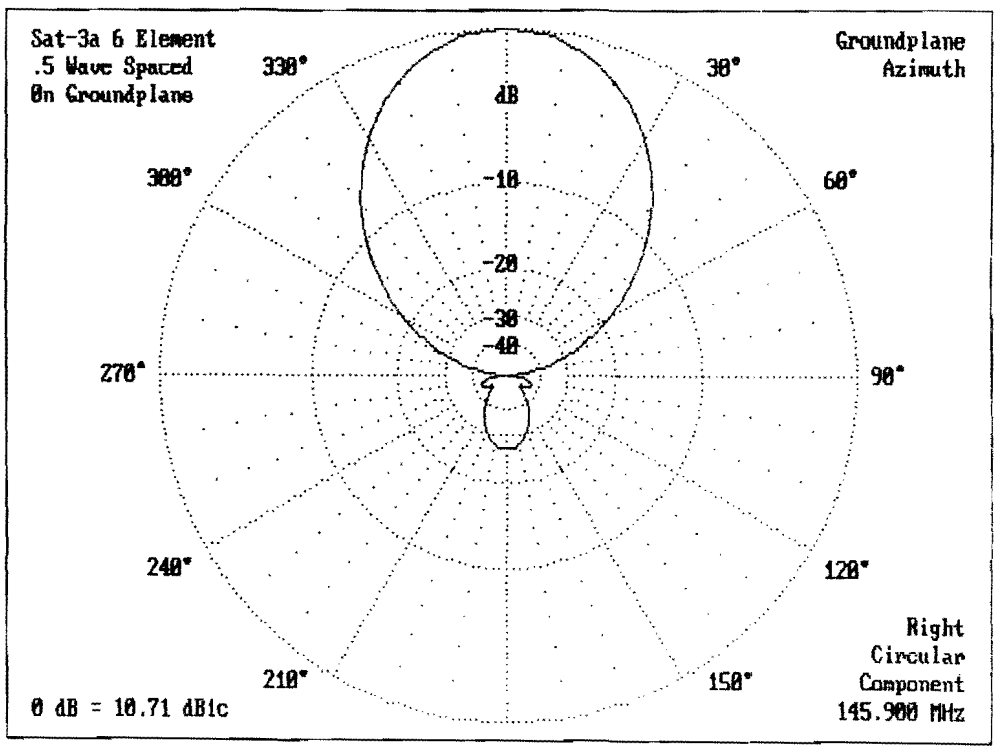
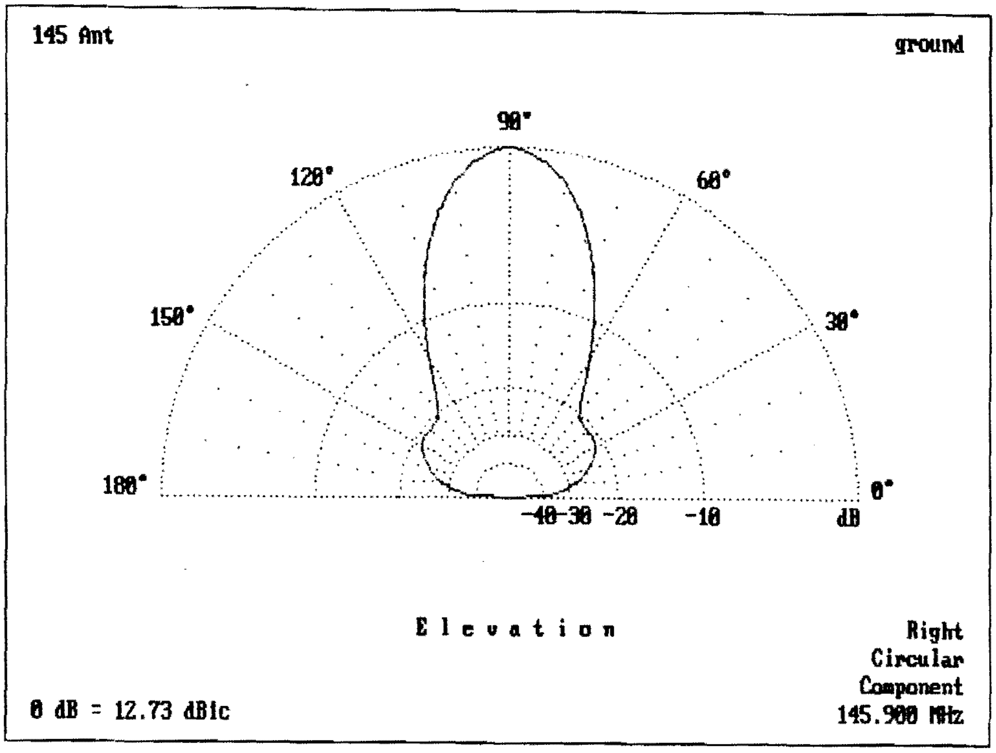
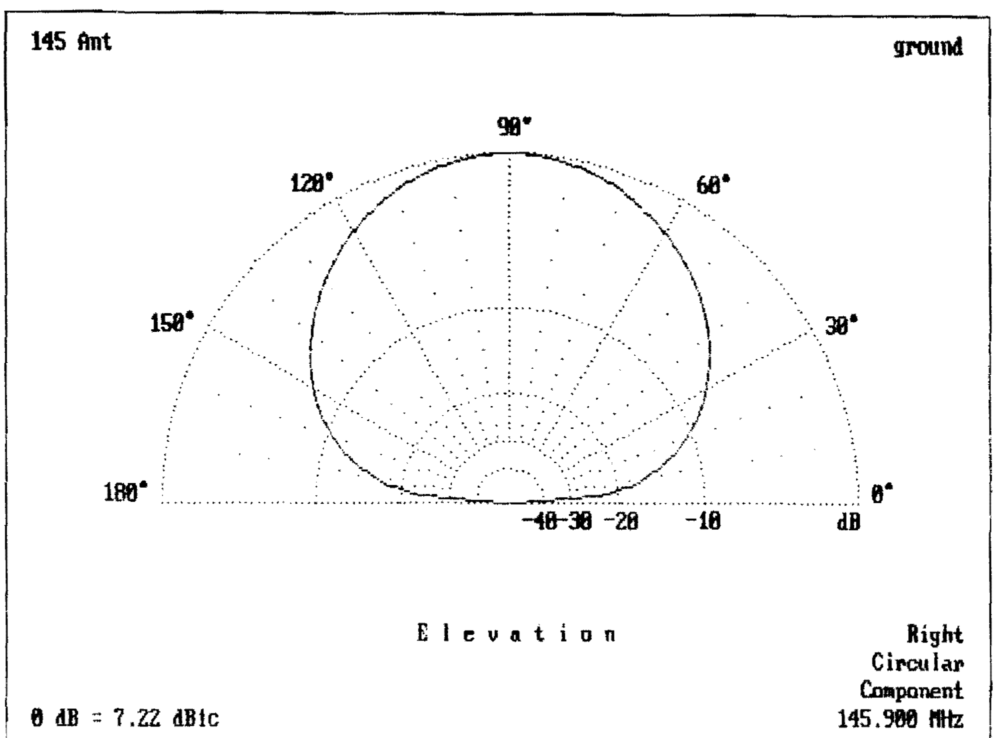

Sat-3a 6 Element
.5 Wave Spaced
On Groundplane
Groundplane
Azimuth
dB
-10
-20
-30
-40
330°
30°
300°
60°
270°
90°
240°
120°
210°
150°
0 dB = 10.71 dBic
Right
Circular
Component
145.900 MHz

Fig. 10



145 Ant
ground
90°
120°
60°
150°
30°
180°
0°
-40-30 -20
-10
dB
Elevation
Right
Circular
Component
0 dB = 12.73 dBic
145.900 MHz

Fig. 11



145 Ant
ground
90°
120°
60°
150°
30°
180°
0°
-40-30 -20
-10
dB
Elevation
Right
Circular
Component
0 dB = 7.22 dBic
145.900 MHz

Fig. 12

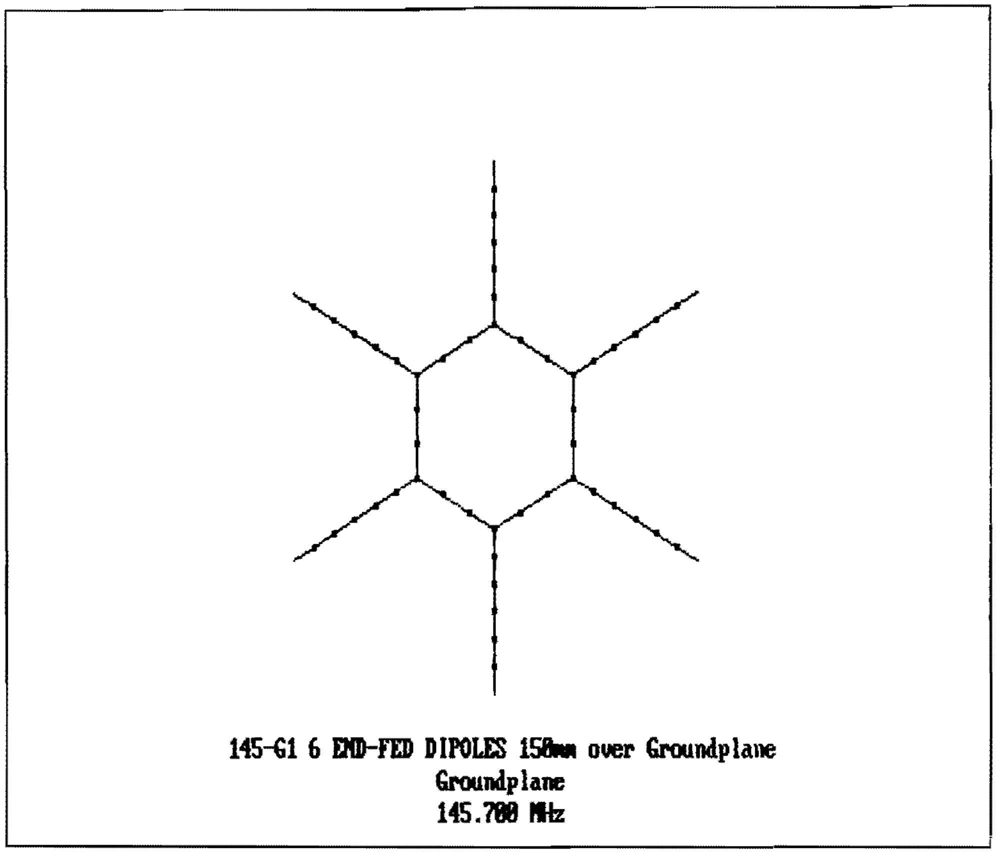

145-G1 6 END-FED DIPOLES 150mm over Groundplane
Groundplane
145.700 MHz

Fig. 13

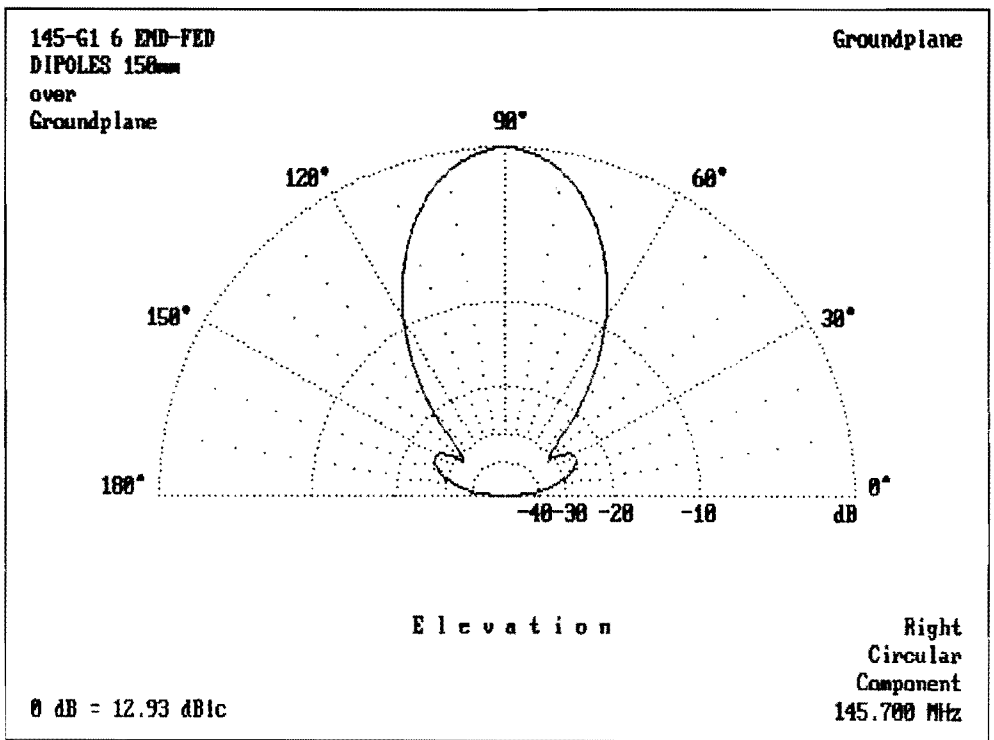

145-G1 6 END-FED DIPOLES 150mm over Groundplane
Groundplane
90°
120°
60°
150°
30°
180°
0°
-40-30 -20 -10
dB
Elevation
Right Circular Component
0 dB = 12.93 dBic
145.700 MHz

Fig. 14

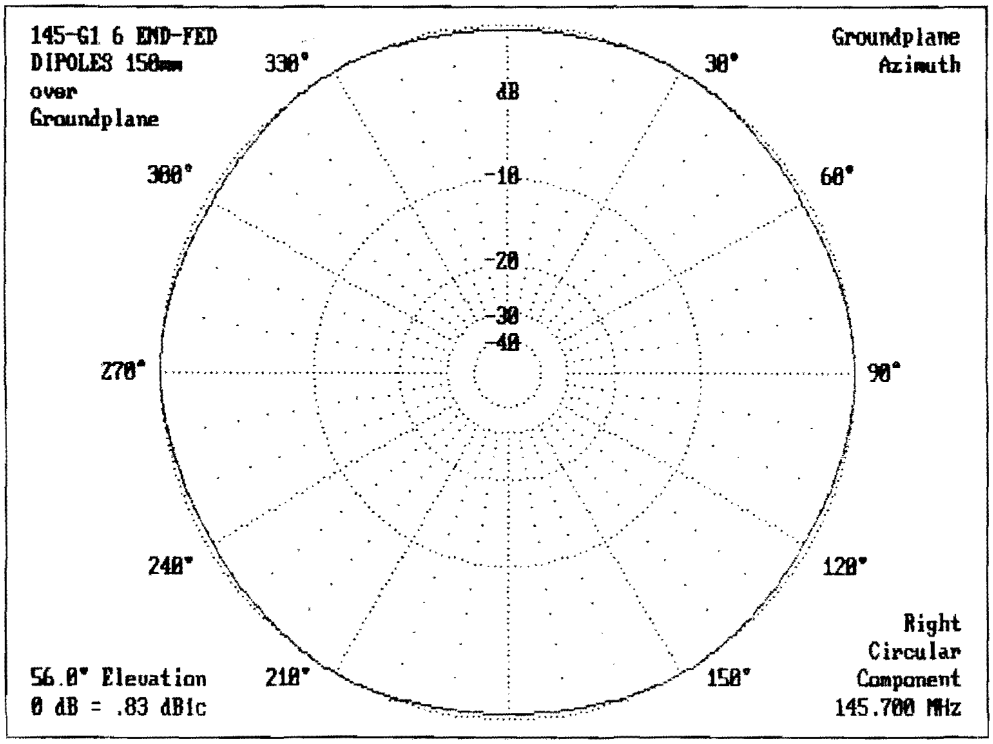

145-G1 6 END-FED
DIPOLES 150mm
over
Groundplane
Groundplane
Azimuth
330°
30°
dB
300°
-10
60°
-20
-30
-40
270°
90°
240°
120°
Right
Circular
Component
145.700 MHz
56.0° Elevation
0 dB = .83 dBic
210°
150°

Fig. 15

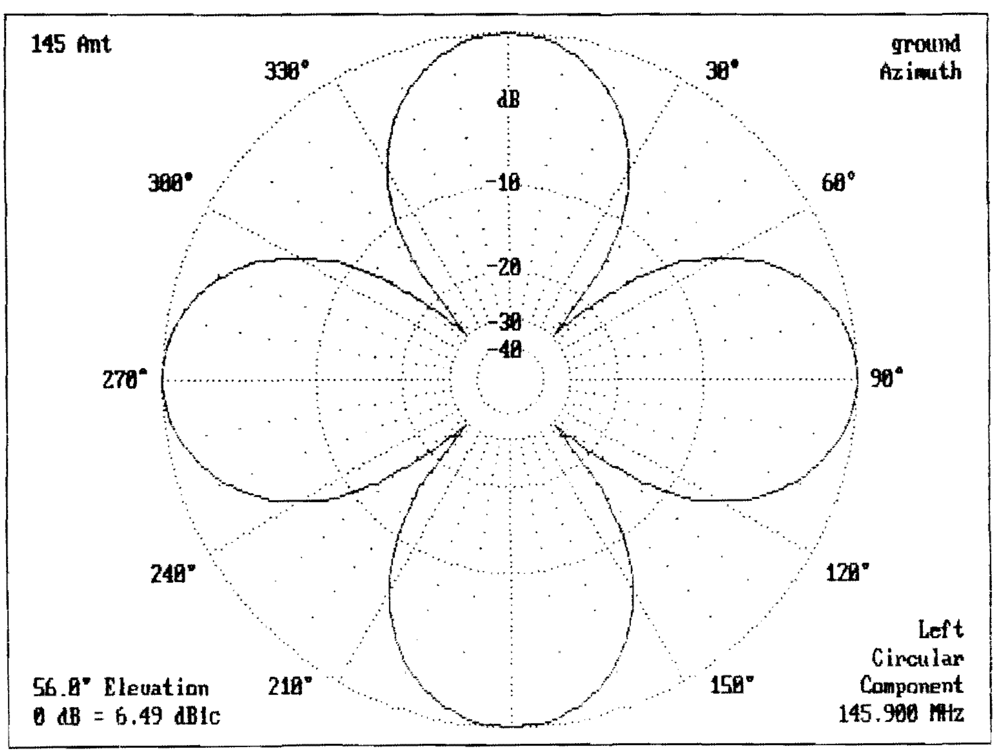

145 Ant
ground
Azimuth
330°
30°
dB
300°
-10
60°
-20
-30
-40
270°
90°
240°
120°
Left
Circular
Component
145.900 MHz
56.0° Elevation
0 dB = 6.49 dBic
210°
150°

Fig. 16

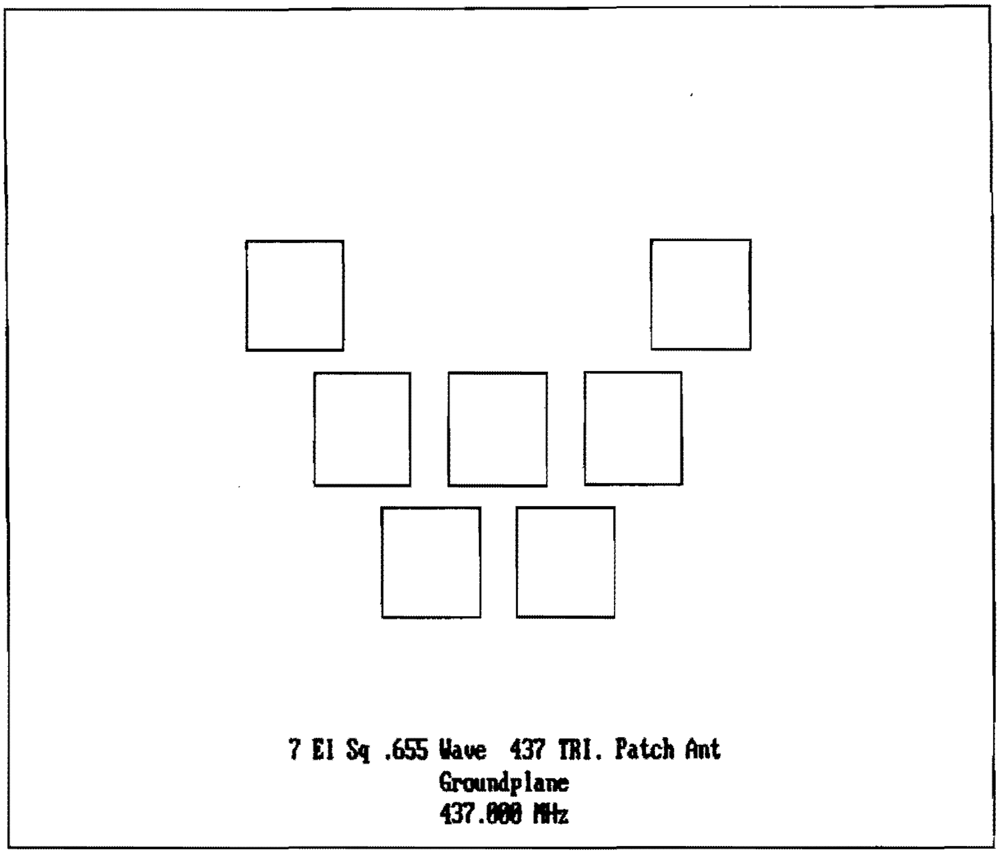

7 El Sq .655 Wave 437 TRI. Patch Ant
Groundplane
437.000 MHz

Fig. 17

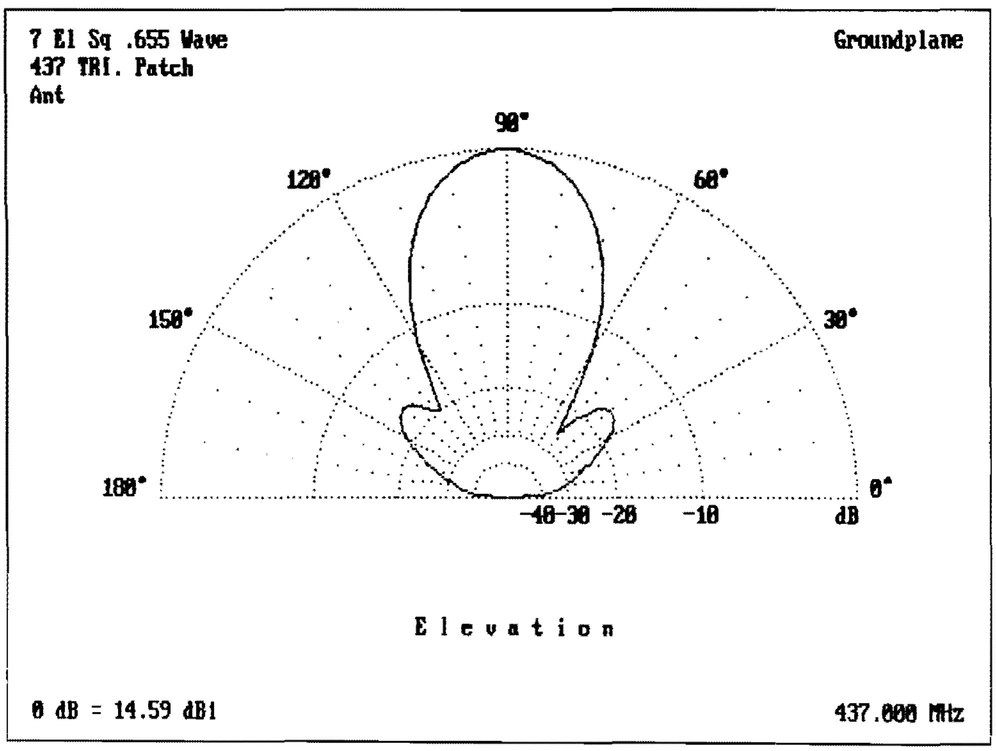

7 El Sq .655 Wave
437 TRI. Patch
Ant
Groundplane
90°
120°
60°
150°
30°
180°
0°
-40-30 -20
-10
dB
Elevation
0 dB = 14.59 dBi
437.000 MHz

Fig. 18

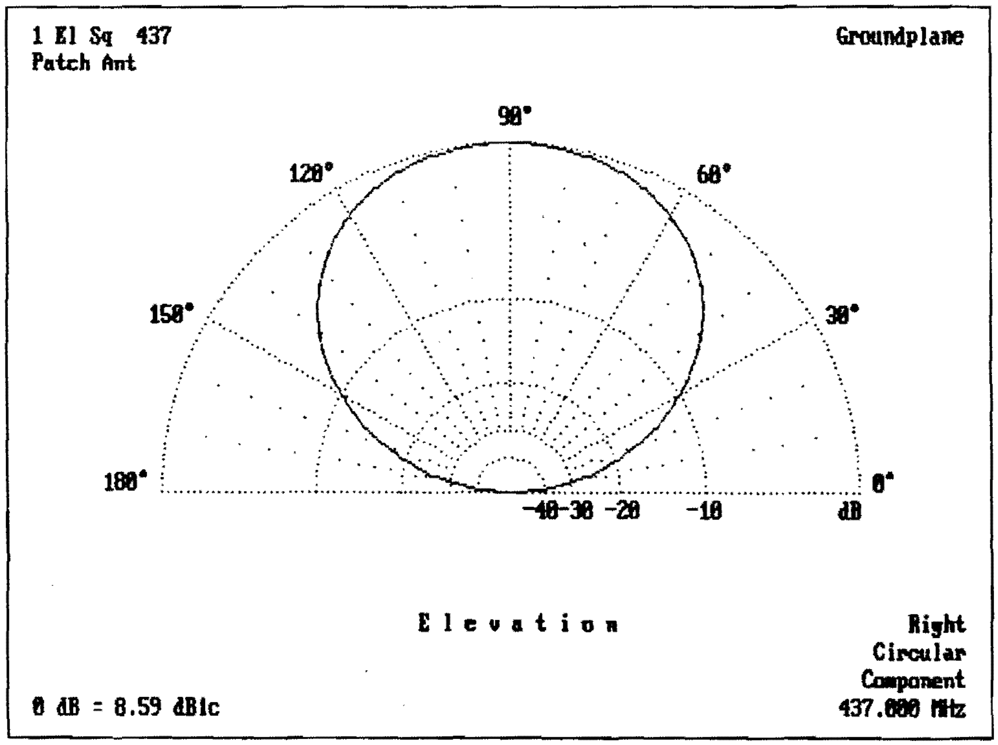

1 El Sq 437
Patch Ant
Groundplane
90°
120°
60°
150°
30°
180°
0°
-40-30 -20 -10 dB
Elevation
Right
Circular
Component
437.000 MHz
0 dB = 8.59 dBic

Fig. 19

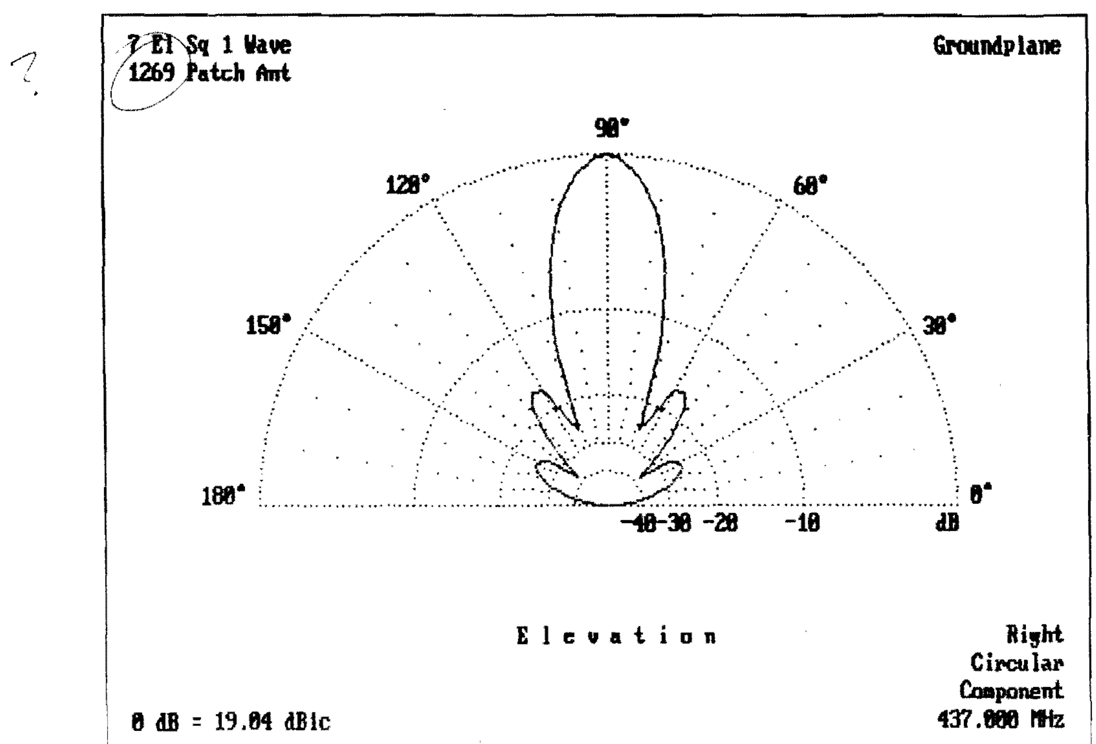
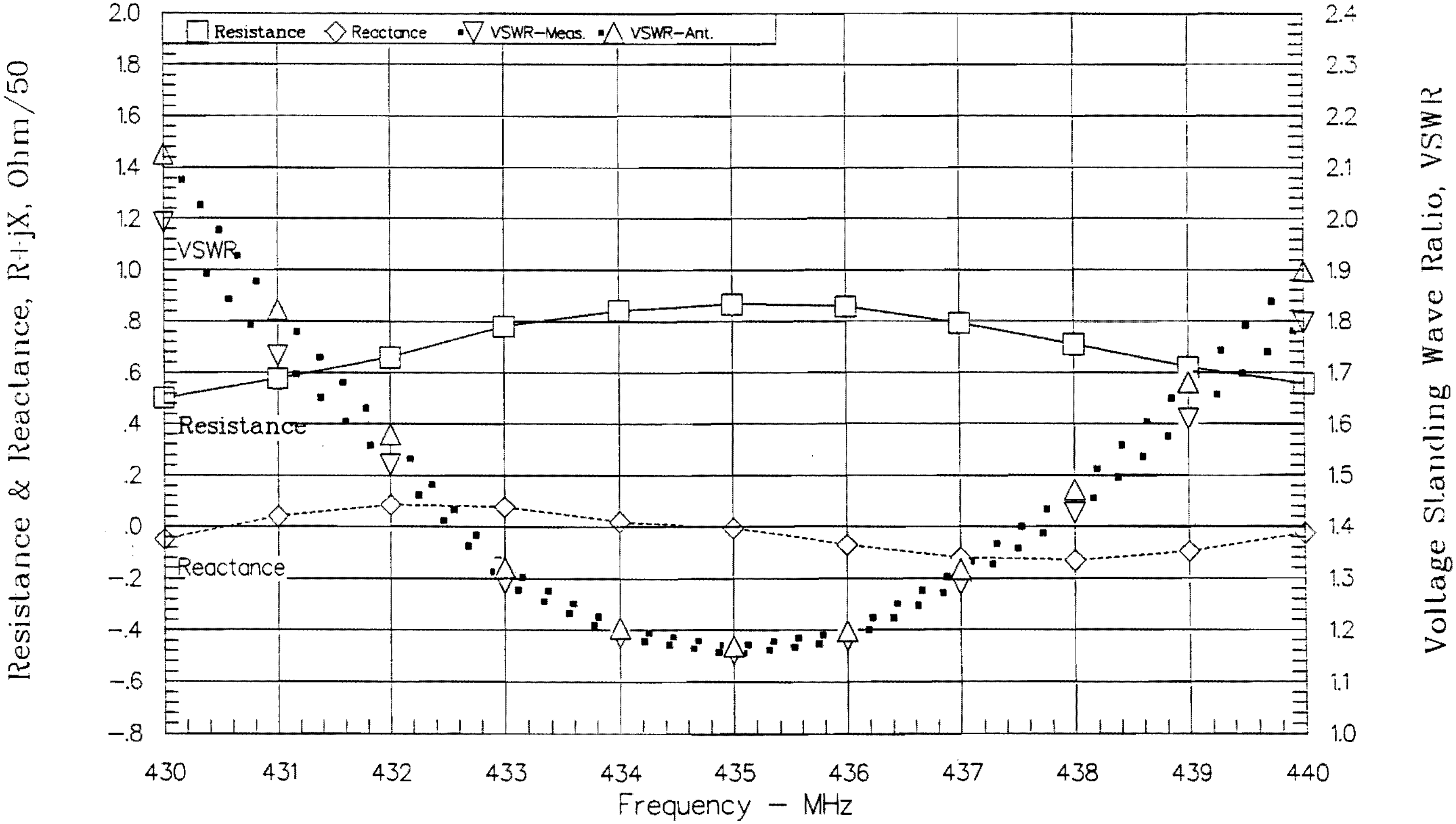

7 El Sq 1 Wave
1269 Patch Ant
Groundplane
90°
120°
60°
150°
30°
180°
0°
-40-30 -20 -10 dB
Elevation
Right
Circular
Component
437.000 MHz
0 dB = 19.04 dBic

Fig.20

Phase 3D 70cm Spacecraft Antenna
Circular Space Dielectric Patch Antenna
Spacing, 12.5mm



HP–803A VHF Bridge Measurement
9.0ft. Ferrite Loaded Cable, Measurement to Sky
07 February 1992

Fig. 21

DSP and the Average Satellite Operator

Gould Smith, WA4SXM

Digital Signal Processing (DSP) technology is no longer solely the domain of the advanced experimenter/engineer. It is now available and affordable to the average satellite operator. The main benefit of DSP to amateur operators is the inherent versatility of the units that utilize this technology. In the past many new, more efficient modulating techniques or protocols were not chosen for satellite or terrestrial operation because of the effort needed to create a base of encoding/decoding hardware for these transmissions. Each of these modes or protocol techniques necessitated new hardware design, board design, software coding and building. If it became a commercial product, then manuals, technical support, case design and advertising were a consideration. In addition these new units would take up more space and require additional cabling into the ham's operating station. DSP units need only a software upgrade and the original unit will be operational using the new modulating technique and/or protocol easily and in a much shorter period of time.

Most of the non-specialized DSP units have an open architecture. This provides the opportunity for a wide base of people to generate more applications quickly. Beside the ability to decode the wide array of modulations and protocols that amateur satellite telemetry transmits, the DSP units can be very useful in enhancing analog and digital signals received from satellites, ground and sky waves.

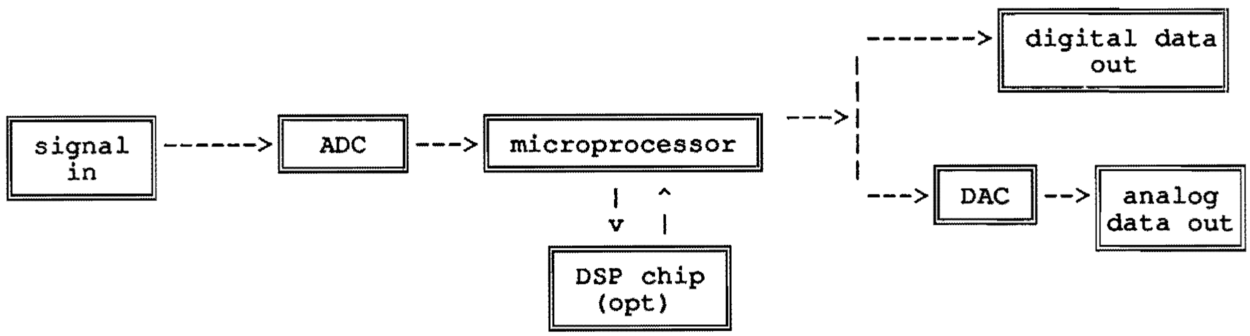
What is DSP?

Digital Signal Processing is performing mathematical operations on a digitized analog signal. These mathematical operations emulate a number of electronic functions with which amateur operators are familiar. Here are some of the uses and functions of DSP:

1. programmable filters
2. demodulating
3. image processing
4. speech processing
5. compression
6. convolution - mixing of two signals
7. correlation - comparison of two signals
8. rectification
9. amplification
10. transformation
11. experimentation
12. education/learning

The basic digital signal processing system has a device to convert an analog signal to its digital representation. This is known as an ADC (analog to digital converter or A/D). Voltage variations come in one side and binary representations of this data come out the other side. A processor then performs the mathematical operations on the binary data to extract the information or enhance the signal. Often another microprocessor specialized in mathematical operations (a DSP chip) is used to perform these operations faster. The resulting information can be further processed, normally to extract a protocol. The data is then output either in a digital or analog format. If the digital format is chosen then the data most often is output as serial data or stored as a file. If the analog format is chosen, the data must be converted to an analog signal using a DAC (digital to analog converter or D/A) for further processing by your ear, another decoding scheme or another device.

Figure 1. simplified DSP system block diagram



Although a dedicated DSP chip is used in many DSP units, digital signal processing does not require a special IC. The only requirement is to mathematically operate on digitized signal data. This can be done by a computer or microcontroller. There are a number of articles cited in the bibliography that use an external ADC board to acquire the data and use a computer to process the data. Some after the data has been stored and some in realtime. Post processing of the data is a good place to learn about digital signal processing. There are now a number of DSP function specific IC's available. Although they only do one function, they are essentially ready to go and require minimum software to implement that function.

Analog and Digital Processing

Currently the majority of our amateur radio equipment is analog in nature. They are composed mainly of resistors, capacitors, coils, diodes and transistors. These devices act in concert to filter, amplify, mix, rectify or compare a signal. The theory that is used to combine these devices for analog processing is the same one used in digital signal processing. Analog processing acts on voltage and current changes. Digital processing involves transforming the digital representation of the signal, performing mathematical operations upon it, then doing a reverse transform back to digital data. It usually is not important to the user whether the signal processing is implemented using voltage variations or complex mathematical functions. The purpose is to encode or decode information in an analog signal. Analog processing has been used for so long because discrete parts are inexpensive and readily available. The advances in solid state technology, the proliferation of microprocessors and the affordability of personal computers during the last decade has made digital processing an inexpensive alternative. The digital signal processing field is not as new as you would think. Digitized photographs were first transmitted across the Atlantic in 1921. But quantum steps were taken in the digital signal processing field by the Jet Propulsion Lab in 1964 to enhance and restore images sent from space. Since then the field has grown dramatically. Until just a few years ago, the digital processing of signals took place using stored data, and it took a 'long' period of time to perform the mathematical operations. The greatest change today has been the advancement in the speed with which signals can be digitized and the speed with which the mathematical operations can be performed. Currently for around $25, you can get integrated circuits that are fast enough to both digitize the signals and then perform the mathematical operation on them in realtime. The data can now be digitally processed as it is received or transmitted. One result of the widespread use of DSP technology is that the parts become less expensive. The experimenter can utilize the technology and then offer it to other experimenters at a hobby price.

Most of the mathematical operations concerned with digital signal processing use a summation of the results of multiplications. So a specific instruction to perform this function in the shortest amount of time is the backbone of a digital signal processing chip. Basically a DSP chip is a microprocessor with a specialized instruction set for doing mathematical operations. One of the new instructions added to the DSP microprocessor's instruction set to do this dedicated function very efficiently is called MAC for multiply and accumulate. Not only do DSP chips have specialized mathematical functions onboard, but many now include ADC and DAC functions. Some microcontrollers now have a MAC instruction included. Many of the DSP chips have multiple operations going on at the same time inside the chip, this is known as parallel processing. It is not unusual for a DSP chip to perform 12 million operations each second, often referred to as 12 MIPS (million instructions per second).

Which is better, analog or digital?

Is a sports car better than a 4-wheel drive vehicle? It depends upon the application or the problem being solved. The greatest beneficiary is the user. Now there are two choices available. Just as a car is fine for highway driving, other vehicles are better at mountain climbing or hauling. The designer must match the tool to the problem, keeping in mind the elementary design rule. GOOD, FAST, CHEAP - PICK TWO. Implementing a standard filter (high pass, low pass or band pass) can be easily done using discrete components. As the values of a resistor or capacitor are changed, the filter characteristics are changed. It requires little effort to change components while tweaking the filter on the bench and watching the results on an oscilloscope. Design and component changes are necessary to change the type of filter. As the complexity or number of the signal processing tasks increase, digital techniques become a good alternative. **DSP is flexible**. Whether it is a major change to an existing feature or a new feature, with a DSP unit, only a software change is needed. No new parts, no new board layout are called for. On the other hand, digitally processing the signal means that the designer needs to understand the device limitations and mathematical processes. New features can be added or enhanced by simply changing the software. As a user, we only need to change an EEPROM to have the new feature in the existing unit. Today the DSP designer needs to understand both the mathematical theory of electronics and be able to program well. These requirements make it more difficult for the home designer to work in the DSP field. I have placed an asterisk by the citations in the bibliography that I feel are very good introductory sources. These selections teach you by doing, not just by reading.

The answer to the question of which type of unit is better can only be answered by you. What do you want the unit to do? How reliable do you want it to be? How much are you willing to pay for it? When you answer these questions, it becomes quite easy to find the unit that satisfies your requirements - analog or digital. Alas, when we are interested in something new, most of us aren't sure what we want or need. Spend a little time, do a little research to decide what you want the device to do; i.e. what output do you want? How many modes do you want? My interests change fairly often, this usually means new equipment purchases to pursue these interests. A DSP unit is ideal for me. I have built five separate modems to collect satellite telemetry. With my new DSP unit all these functions are contained inside the one device. This means much less cabling, much less space and fewer switches. As new modes and protocols appear, my unit is just a software upgrade away from working. If you are considering doing any of the digital modes on the satellite, get a DSP unit. It may seem to be more expensive initially, but you will be ready as the modes or your interests change. The cost of all the separate modems add up to much more than one DSP unit.

Here are some of the benefits and some of the limitations to digital signal processing .

Benefits of DSP

1. consistent numerical accuracy
2. flexibility / programmability
3. stability in changing environments
4. suitability for multiplexing
5. convenience for processing the digital data

Current limitations of DSP

1. cost
2. frequency limitations
3. who can program it

All of these limitations of DSP are being addressed. Every day as the quantities of DSP chips increase the price comes down. Faster DACs and processors with faster arithmetic operations are becoming available. This will allow the sampling and processing speeds to increase. With these speed increases, the maximum frequency of the signals processed will increase. Just as high level languages developed from assembly language, the mathematical DSP functions will become available in libraries or even as language commands.

Some current DSP units for the average satellite operator

DSP has become a big marketing term lately. Don't believe that all equipment that use the DSP acronym in their advertising will give you a performance advantage. It is an excellent technology. Find out some more about DSP, find out what advantages it gives you. Analog devices will do just as well in many cases. If you want a versatile, upgradable unit seriously consider the multi-mode DSP units.

Here are descriptions of DSP units and some of the features that they can offer the average satellite operator. AMSAT-TAPR are currently working on a DSP unit that is an IBM plug-in board. There are other units available, and many more will become available to the amateur market as the technology progresses.

Today for digital satellite operation, the DSP-12 and PK-2232 units offer the ability to work all the modes with one unit. Both interface to a computer via the serial port, so they can work with any computer with serial capabilities. The Digital Interactive unit specializes in processing speaker audio. The Motorola system is an excellent package for learning about DSP techniques.

DSP-12

The DSP-12 offers a flexible platform for digital communication modes and terminal interfaces. Figure 2 shows the main menu selection with the currently available modes. New modes become available every few months. Upgrades can be run from internal RAM or by simply changing three EEPROMs. Three ports labeled HF, VHF & UHF can be individually selected for transmit and receive. The unit has an open architecture and encourages customers to develop new modems or terminal interfaces. A Developer's Toolkit is offered with schematics and source code for the V40 microprocessor. The DSP chip used is the Motorola 56001. A Debugger is included to assist the user in developing applications. CompuServe and the DIRG BBS are used to exchange ideas, to pose questions, to post new applications and to get upgrades. Users can switch from one application to another without going through the main menu.

Figure 2. LL Grace DSP-12 main menu screen (7/92)

```
****************************************************************************
*                        Main Menu                       07/29/92  00:02:00 *
****************************** GCE Version 1.99 ******************************
<A> HF         Packet     <U>  75  BPSK Packet         <H> RTTY: Baudot
<B> VHF        Packet     <Y> 100  BPSK Packet         <I> RTTY: ASCII
<E> FO-20      Packet     <X> 150  BPSK Packet         <J> RTTY: Extra RTTY 1
<P> PACSAT     Packet     <T> 300  BPSK Packet         <K> RTTY: Extra RTTY 2
<F> UO-22      Packet     <S> 600  BPSK Packet         <L> RTTY: Extra RTTY 3
<N> HAPN       Packet     <D> 1200 BPSK Packet         <W> NOAA APT*
<G> AO-13    Telemetry    <Z> Audio Sample/Play/Pipe <V> ACARS
<R> UO-11    Telemetry*   <M> AMTOR*                   <9> Setup

Enter your selection...f
 ** UO-22 PKT Mode **

 ** Use $03 (^C) to enter Command mode **

 ** Use the DIsplay command to see all parameter settings **

<UO-22 PKT> cmd:
```

* *

DSP-1232/2232

The DSP-1232 and -2232 are two models of this multi-mode DSP data controller. Both models have two ports, the 2232 can run two ports simultaneously. Figure 3 shows the main menu of the DSP-2232, illustrating the multitude of available modes. Upgrades are made by simply replacing a factory EPROM or downloading a file from the BBS and burning your own. The Motorola 56001 DSP is used together with a Zilog HD64180 microprocessor. Much of the protocol conversion is done in hardware. These units have a two line LCD display to provide status information to the user. CompuServe has an AEA forum for user's to pose questions and exchange ideas. The p1 and p2 in Figure 3 refer to port 1 and port 2.

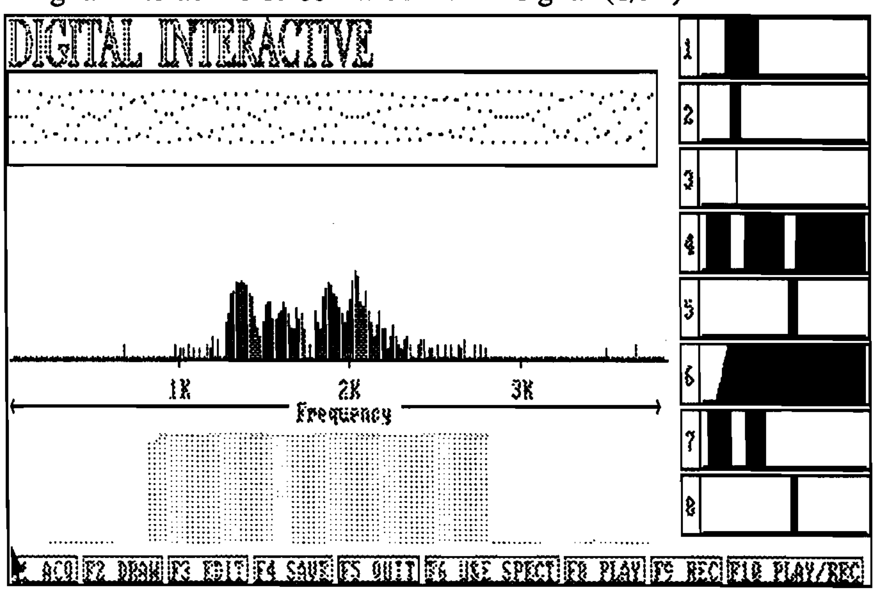
Figure 3. AEA DSP-2232 main menu screen (7/92)

```
.  1: RTTY/TOR 170: 2125/2295              2: RTTY/TOR 170: 1445/1275
.  3: RTTY/TOR 425: 2125/2550              4: RTTY/TOR 850: 2125/2975
. 10: p1 Packet 300 bps HF 2110/2310      11: p1 Packet 300 bps HF 1460/1260
. 12: p1 Packet 1200 bps VHF              13: p1 Packet 1200 bps PACSAT
. 14: p1 Packet 1200 bps PSK              15: p1 Packet 2400 bps V.26B
. 16: p1 Packet 4800 bps PACSAT           17: p1 Packet 4800 bps PSK
. 18: p1 Packet 9600 bps FSK K9NG/G3RUH   20: p2 Packet 300 bps HF 2110/2310
. 22: p2 Packet 1200 bps VHF              23: p2 Packet 1200 bps PACSAT
. 25: p2 Packet 2400 bps V.26B            28: p2 Packet 9600 bps FSK K9NG/G3RUH
. 30: RTTY/TOR 170: 2125/2295; p2 Packet 300 bps HF 2110/2310
. 31: RTTY/TOR 170: 2125/2295; p2 Packet 1200 bps VHF
. 33: p1 Packet 300 bps HF 2110/2310; p2 Packet 1200 bps VHF
. 35: p1 Packet 1200 bps VHF; p2 Packet 1200 bps VHF
. 40: Morse 750 Hz                        41: Analog FAX HF
. 42: Analog FAX APT                      43: Analog SSTV
. 44: DSP data 400 bps OSCAR-13           45: RTTY/TOR 1200 bps ASCII OSCAR-11
. 46: DSP data Spectrum                   50: p1 Packet 1200 bps MSK
. 51: p1 Packet 2400 bps MSK              52: p1 Packet 9600 bps G3RUH UO22 eq
. 60: p2 Packet 1200 bps MSK              61: p2 Packet 2400 bps MSK
```

Digital Interactive

The Digital Interactive unit is a very good example of both the configurability and power of DSP. This device provides a simultaneous time domain (oscilloscope) display, frequency domain (spectrum analyzer) display, and the currently selected filter display of a voice band signal. An IBM class of personal computer is necessary to operate the unit. Speaker audio is introduced; its characteristics displayed on the screen; and the filtered audio is output to a headphone compatible jack. The input audio can be stored, and the user can experiment with different filters on the same signal. A snapshot of the signal can be taken and then used to design a filter around the specific characteristics of that signal. This unit graphically shows the versatility of DSP techniques. This is a very nice tool to use in audio filter experiments and to view the relationship between the time and frequency components of a signal.

Figure 4. main Digital Interactive screen with RTTY signal (6/92)



Motorola M68HC16Z1EVB evaluation system

This unit is an outstanding system in which to learn DSP design and programming. The unit was promoted for a short time at a very reasonable price, even today it is still a good value if you are interested in learning about DSP operation and programming. The heart of the system is the new 16-bit M68HC16 CPU that includes MAC commands. The system includes:

1) an evaluation board with ADC, RAM, ROM, DAC and auxiliary connectors;
2) an assembler;
3) data sheets and data books;
4) a well-written, introductory book on DSP theory;
5) an auxiliary board with LED displays; and
6) a workbook for a project using the unit to design and code a five band audio spectrum display.

Digital Signal Processing has arrived on the amateur radio scene. Learn to use this exciting technology and take advantage of the many benefits it offers.

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The TAPR/AMSAT DSP 1 Project

by Lyle Johnson, WA7GXD

ABSTRACT

The TAPR/AMSAT DSP 1 project history is presented. This is followed by a discussion of the hardware currently in Beta testing.

DSP BACKGROUND

Digital Signal Processing (DSP) is a means of manipulating signals by converting them to digital information, executing some algorithms in software on this information, then (optionally) converting the signal back to an analog waveform.

Such functions as audio filters, oscillators, mixers, limiters, adaptive filters, modulators, demodulators and the like are all possible.

Until a few years ago, computers possessing sufficient power to perform these kinds of manipulations in real-time were not economically available to amateur experimenters. What was needed was a microprocessor-chip approach to specialized processors capable of performing the computationally intense, but limited, repertoire of instructions needed to handle signal processing efficiently.

In 1981, Intel introduced the 7920 single-chip DSP. This chip was too limited in performance, however, and it vanished from the marketplace in a year or two.

In 1983, Texas Instruments introduced the TMS32010 DSP microprocessor. This single chip device was capable of executing a specialized instruction set at rates of 5,000,000 instructions per second, or a cycle time of 200 nSec. (Around the same time, NEC introduced a DSP chip which grew into the 7720 family.) The TMS32010 rapidly established itself as a cost-effective processor for modems, filters, and other general DSP applications.

In 1986, the TMS32020 family was introduced, offering a much better instruction set and execution rates of 10,000,000 instructions/second. 1989 saw the third generation TMS320C30 while the TMS32050 family was introduced in 1991.

In 1988, Motorola joined the fray with their DSP56000 series, followed in 1990 by the 96000 series.

DSP is now an established commercial reality, with numerous chips offered by the above US producers, as well as NEC and OKI in Japan.

DSP, of course, has wide application in Amateur radio for digital communications, enhanced filters for transmitters and receivers (represented by the Kenwood TS-850 and

TS-950 transceivers) and satellites (including KITSAT-A and the DSP experiment RUDAK-2 on AO-21.).

PROJECT BACKGROUND

In 1986, Tom Clark, W3IWI and Bob McGwier, N4HY, began working with a digital signal processing (DSP) board based on the Texas Instruments (TI) TMS32010 chip. Several amateurs became interested in their work, and a special purchase was arranged to obtain the Dalanco Spry Model 10. A number of experiments were performed and in 1987 a special hardware development project began. The intent of this project was to create a low cost, standalone digital communications device. Tucson Amateur Packet Radio (TAPR) and AMSAT-NA joined forces to produce this project.

The original project was based on a pair of TMS320C15 chips, a NEC V40 processor for digital communications modes, a power supply board and a motherboard to tie them all together. Prototypes of all but the V40 board were built by late 1987.

In December, 1987, the MicroSat project was announced and the hardware and software people involved in the DSP project became intensely involved in MicroSat. As a result, the DSP project languished.

In February, 1990, the MicroSats having successfully been launched, the DSP project was reviewed and a new approach taken. The remainder of this paper describes the new project in terms of its hardware.

DSP 1 PC DESCRIPTION

The DSP 1 is now configured as a plug-in card for the IBM PC and bus-compatible computers. This was done in order to facilitate software development and reduce the cost of the project from a device that would sell for about $700 to one that should sell for $300 to $350. The cost reduction is possible by using the PC's case, power supply, and processor.

The DSP 1 is based on a TMS320C25 second-generation CMOS DSP chip running at a clock speed of 32 MHz and executing instructions at a rate of 8,000,000/second (125 nSec instruction cycle). This chip, which cost nearly $100 at the time of the original DSP 1 project, is now available for just under $20 and that price is expected to continue to drop!

The 320C25 can address up to 64k words of program memory and 64k words of data memory. It uses a modified Harvard architecture, allowing it to access data and program memory simultaneously as long as one or both of the memory areas are on-chip. If both are off-chip, two memory accesses are required, slowing down operation. 544 words of memory are contained within the 320C25, mappable to program or data space in 256 word chunks. The pin-compatible 320C26, possessing 1024 words of internal memory, is now available and will plug into the DSP chip socket on the DSP 1 PC board.

The default configuration of the DSP 1 includes 4k words of program memory and 4k words of data memory. The board is able to accept up to 64k words of program and 64k words of data memory, using 32k-by-8 28-pin "skinny DIP" memory devices. The board requires 35 nSec or faster memories to be employed.

The 320C25 can access up to 16 words of I/O space that do not impact the memory map. 8 words of I/O space are mapped on the PC board.

A 16-bit handshaking port is available to allow the DSP chip to send data to the PC and determine when the PC has read the data. Likewise, the PC can write a word of data to the DSP chip through this port and determine when the DSP chip has read it.

An 82C54 three-channel timer chip is mapped into the DSP I/O space as well. This allows the DSP chip to control the clock rate of the switched capacitor anti-aliasing filters used between the analog I/O connectors on the board and the A/D and D/A convertor chip. The anti-aliasing filters are MF4-50s, providing a 4-pole butterworth response whose corner frequency is controlled by setting the output rate of channel 2 of the timer chip.

Channel 0 of the timer chip is normally used to control the sample rate of the A/D-D/A chip, while channel 1 is used to phase-shift the sample clock under the control the DSP chip.

The Beta board's analog I/O is handled by an Analog Devices AD7569. This chip includes a sample-and-hold input and an 8-bit A/D convertor. In practical terms, this limits the board to about 40 dB of dynamic range. An on-chip reference is used to set the input range to +/- 2.5 volts. The A/D is clocked from the 32 MHz crystal oscillator, keeping everything phase-locked to the DSP chip. The AD7569 also includes an 8-bit D/A channel. The maximum rate this chip can be sampled on the DSP 1 board is about 400 kHz.

Faster sample rates allow applications beyond normal audio processing. The downside is less time between samples to do useful things, like filters or modems. Slower sample rates can be used if they can be adjusted to track variations in the input signal. The advantage is more time to process the data, but this is offset by the disadvantage of having to constantly re-load the sample clock timer.

DSP 1 gets around this by allowing a second sample clock value to be loaded into the timer chip. For example, let's say you wanted to sample an incoming signal every 100 μSec. However, to get away with this low sampling rate, you might need to adjust the phase of your sample clock to prevent unwanted aliasing. You could load your phase shift clock with a value of perhaps 110 μSec. Whenever you detected the phase of your incoming signal to be drifting, you issue a phase shift command. The clock chip finishes the current sample, then enables timer channel 1 for a single cycle, after which it automatically changes back to channel 0 to resume the 100 μSec sample rate. Likewise, the phase-shift channel could be used to run a faster sample rate if the signal were drifting in the opposite direction.

Due to the limitation of using a single A/D-D/A chip, the phase shift of the clock would also affect the D/A output. This is to prevent attempting to access the A/D and D/A at the same time.

Finally, the clock can be switched off and the sample command issued directly by the DSP chip based on software timing rather than hardware timers for special applications.

The next (final?) PC boards will incorporate 12-bit A/D and D/A chips to allow greater dynamic range. The maximum sample rate will be limited to about 30 kHz, so the phase-shift capability of the sampling system will be even more important.

A parallel port is included to allow the DSP chip to issue output commands to the radio port (such as tune up or tune down to track satellite doppler from a PSK modem being used on PACSAT) as well as read some external inputs.

So far, the DSP 1 description is not unlike many other DSP cards available for the PC, except for the phase-shifting clock which we believe to be unique.

The DSP 1 also contains an 85C30 SCC chip, suitable for HDLC (packet) communications and other serial communication modes. One channel of this two-channel chip is buffered to RS232 levels and available for external use. The other channel is connected to the DSP through another I/O port so the DSP chip can directly read the TXD pin and control the RXD pin. The DSP chip can also control the DCD pin, and provide or read TX and/or RX clocks. This allows the DSP to become a modem to the 85C30 and to control it for applications such as AMTOR or other modes.

The RTS pin of the 85C30 is connected through a non-retriggerable one-shot watchdog timer to the PTT pin on the radio connector. This allows the DSP 1 to key up the radio while protecting the channel from a runaway processor. The one-shot can be rapidly reset for long-transmission modes, such as RTTY, such that the attached HF transceiver is unable to react to the brief pause in PTT. Thus, the watchdog doesn't limit the modes available.

A second 82C54/71054 is connected to the PC bus and interfaced to the 85C30 to provide necessary timing clocks for the 85C30 and also provide a timed interrupt to the PC for protocol timing if needed.

The PC bus interface is very flexible. The DSP 1 PC can be mapped to any 16-bit I/O boundary in the range of 000 to 0FC0 in the PC's I/O space. It can occupy an 8-bit or 16-bit slot, and can automatically configure itself to the slot, or be forced into 8-bit mode in any slot. The unit does not occupy any other address space in the PC.

A control register allows halting and resetting the DSP chip by the PC, as well as controlling access to data or program memory. Control of an up-down address counter's direction is also done though this port, along with setting a bit on an expansion connector and setting the BIO pin of the processor.

A status register tells the DSP chip's state, allows reading the XF pin of the processor, and clears an interrupt to the PC from the DSP while revealing the source of the interrupt.

A 16-bit counter may be loaded by the PC and will then point into the data or program memory of the DSP. After every access (read or write) the counter will auto-increment or auto-decrement, based on the control register contents. This allows rapid loading or reading of the DSP memory area without requiring direct mapping into the PC's memory space. Direct mapping could be a real problem with a fully populated board (256k bytes)!

A very careful design allows an 8-bit or 16-bit PC to read or write the DSP memory while the DSP is running. The impact on the DSP is a single wait-state per word read or written. A wait-state in this case costs 125 nSec. This means that the DSP could interrupt the PC to read out a block of memory for data to display (say, an enhanced color SSTV image) and the PC could do so transparently to the DSP with minimal effect on the DSP chip's processing of new signals.

This wait state is only inserted if the there is contention between the DSP and the PC for the memory array. If the DSP is accessing internal memory or I/O at the time, the wait-state will not occur.

CURRENT STATE OF THE PROJECT

Alpha hardware was completed in July, 1990. This hardware was fully functional in November, 1990 and the Beta PCB layout began. Beta PCBs were available in late December, 1990, and testing began in January of 1991. By mid-1991, nine Beta boards had been distributed and software applications were being ported to them.

At the TAPR 10th Anniversary Annual Meeting in March, 1992, Jon Bloom, KE3Z, demonstrated RTTY, AMTOR, packet and audio filter applications on a Beta board. Franklin Antonio, N6NKF, demonstrated an enhanced version of his Spectrum Analyzer application.

Sufficient applications have now been ported to the board to verify the hardware design. Several bugs are present, and once the final resolution is made as to their cause (there is ONE remaining!) the board layout will be tweaked and final pre-production boards will be started.

We make no predictions as to when production units might become available, as this project has taken far longer than any of us ever anticipated!

Hardware design of the board is by Lyle Johnson, WA7GXD, Chuck Green, NØADI, and Mike Brock, WB6HHV with inputs from numerous others including Dan Morrison, KV7B and Franklin Antonio, N6NKF.

Initial applications software is being done by Dan Morrison, KV7B, Jon Bloom, KE3Z, Franklin Antonio, N6NKF and others.

Shuttle Amateur Radio Experiment (SAREX) Hardware Configurations and Flight Operations Support

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and
Louis M. McFadin, W5DID

Abstract

The highly visible, successful Shuttle Amateur Radio Experiment (SAREX) program has entered a second phase in its evolutionary development during 1992. It has progressed from its beginnings as pure experiment, where the unexpected was to be expected and flights were uncertain and somewhat rare, to an operational mid-deck Shuttle payload with an envious frequent flyer status. This paper describes the current SAREX hardware flight configurations and highlights the significant efforts expended by the SAREX team before, during, and after a flight to ensure mission success. In addition, a summary of potential future SAREX upgrades is described.

Introduction

SAREX is a mid-deck Space Shuttle payload sponsored by the Radio Amateur Satellite Corporation (AMSAT), the American Radio Relay League (ARRL) and the National Aeronautics and Space Administration (NASA). The primary goal of SAREX is to spark students interest in the science, technology, and communications fields by allowing them to talk to Space Shuttle astronauts using amateur radio. In addition, SAREX provides increased public awareness of NASA's manned space program by permitting radio amateurs worldwide to talk with the Shuttle astronauts. Literally thousands of hams and students have directly participated in the SAREX program, and many have been rewarded with the opportunity of talking directly with hams on the Space Shuttle.

Amateur radio on the Space Shuttle made its debut on the STS-9 mission with Owen Garriott, W5LFL, in November 1983. In the eight years following this first flight, SAREX flew as a mid-deck payload four times. These early amateur radio flights required a significant amount of volunteer overhead. Completing the documentation required to fly SAREX on the Shuttle was, in some cases, a full time job. In addition, significant constant lobbying efforts were required by high profile individuals like Roy Neal, K6DUE, to get NASA backing of the amateur radio experiment. During the two year Shuttle flight standdown after the Challenger accident, the SAREX team made a concerted effort to significantly improve this situation. First, the paperwork required for SAREX was streamlined to cover nearly all the future SAREX missions. Payload sponsorship from the NASA headquarters office of Education has also given SAREX a significant boost as an educational payload. In addition, members of the Johnson Space Center Radio Club initiated a successful amateur radio licensing program which has resulted in a large influx of astronauts obtaining their amateur radio licenses. This year, the fruit of these efforts has rewarded the SAREX team with an envious frequent flyer status on the Shuttle. Beginning with the STS-45 flight in March 1992 almost half of the planned Shuttle flights manifested for 1992 and 1993 will have SAREX on-board. The SAREX payload has, therefore, entered a new phase in its development. It has progressed from a pure experimental payload to an operational payload whose main goal is education.

Station Configurations

The SAREX payload can be flown in one of five distinct configurations. Selection of a specific configuration for a Shuttle flight is determined by various criteria including crew availability for attended operations, the number of ham astronauts on-board, Shuttle power constraints, Shuttle weight and balance considerations, and mid-deck locker availability.

Extremely power limited or weight critical missions usually will fly configuration B. See figure 1. Configuration B is battery operated, 2 meter FM voice using the side window mounted antenna and the 2 meter FM Motorola MX-360 HT. STS-45, launched in March 1992, flew SAREX in this configuration. A variation of this configuration (with an overhead window antenna) also flew on the first ham in space mission, STS-9, in November 1983.

Flights with severe weight and balance constraints, mid-deck locker storage problems or crew members with little "free" time for attended operations usually will fly configuration C. See figure 2. This configuration includes 2 meter voice via the Motorola HT and a robot packet radio capability using the Heathkit HK-21 TNC. Packet radio operations can be performed interactively using the Shuttle Grid laptop computer or in an unattended robot mode. Internal to the packet module is a 12 V DC power supply which interfaces with the Shuttle power to provide battery-free SAREX operation. This configuration was flown during the STS-35 mission in December 1990 and is manifested on the STS-47 mission which is scheduled for launch in September 1992.

When power, Shuttle weight and balance, and mid-deck locker space are not severely constrained, configuration A (figure 3) configuration D (figure 4) or configuration E (figure 5) is usually manifested. Configuration A allows the Shuttle crew to operate SSTV, Voice and Packet. For Configuration A the TNC and 12V power supply are mounted in a special housing that includes the Robot 1200C SSTV scan converter. A Panasonic VCR/Monitor is also provided to allow the crew to view the SSTV video. Configuration A has not flown on a specific Shuttle mission, but a variation of this configuration (minus the packet radio TNC and using the overhead window antenna) flew on STS-51F in July 1985.

Configuration D is virtually identical to Configuration A with the addition of 432 MHz FSTV uplink (receive only) capability. The ATV uplink module for this configuration was developed by Andy Bachler, N9AB. Configuration D flew on STS-37 in April 1991. For Configuration E, the Panasonic VCR/Monitor is replaced with a Shuttle provided Video Interface Unit (VIU). In this configuration, video from the FSTV or SSTV is viewed on color monitor in the orbiter. This modification results in a 50% reduction in SAREX payload weight. Configuration E was flown on STS-50 in June 1992.

Scheduled Contact Selection

Once SAREX is manifested on a specific Shuttle flight and a flight crew is chosen, the prearranged contact selection process can begin. This process usually starts approximately 6 months prior to launch and continues until about T-3 months. At T-3 months the scheduled contacts are incorporated in the Shuttle flight plan and only small modifications can be made via the Shuttle teleprinter FAX machine after launch.

The pre-arranged contact selection process is one of the most complex aspects of the mission planning process; primarily because there are so many hurdles that need to be overcome to successfully incorporate the contact in the Shuttle timeline. First, a tentative pool of international school groups and other stations of interest are selected based on requests from the flight crew, unique experiments which require crew/ground intervention, and school group proposals received by the ARRL and AMSAT. Approximately 8-20 scheduled contacts are planned for each shuttle mission. The number of scheduled contacts varies widely from mission to mission and is primarily dictated by the crew member's availability to support scheduled contacts. Most of the scheduled contacts are school group contacts; however, the ATV uplinks made on STS-37 and STS-50 were pre-arranged and crew family contacts are, in most cases, scheduled prior to flight.

Once a preliminary number of planned contacts are determined by the crew, a Keplerian element set is then generated by Gil Carman, WA5NOM, based on the planned liftoff time and mission orbit. Shuttle rise and set times for each station are then calculated and orbits of opportunity are selected. Orbits of opportunity are selected based on a minimum elevation criteria at the Earth station (usually 10-15 degrees) and times when the Earth station ham and the ham on-board the shuttle are both awake.

Any third party agreement concerns, requiring IARU inputs or waivers, are also initiated by the ARRL at this time. Rosalie White, WA1STO, coordinates this effort. Next, a meeting is held with the Shuttle flight scheduling office and the ARRL representative at the Johnson Space Center. The ARRL representative for SAREX is John Nickel, WD5EEV. If the proposed Earth station's windows of opportunity can be accommodated in the crew timeline, the prime and backup times, as well as relevant Earth station information, are incorporated in the mission timeline.

Pre-Launch Preparations

Several activities are performed concurrently prior to launch to ensure that the SAREX hardware, the flight crew, and the ground operations personnel are ready for flight. Months prior to each flight, the SAREX hardware is inspected, tested and refurbished (if necessary). Once the pre-flight checkout of the hardware is complete, the hardware is delivered to the appropriate NASA personnel for storage in the Shuttle mid-deck locker. Lou McFadin, W5DID and his crew at the JSC ARC coordinate this effort.

A great deal of paperwork is generated prior to a SAREX flight to demonstrate flight worthiness of the payload to NASA. Two large documents, mechanical and electrical drawings and several certification memorandums comprise the package of materials required by NASA. The Payload Integration Plan (PIP) and the Payload Data Package Annex are the two lengthy documents (nearly 100 pages total) which represent the bulk of the SAREX paperwork. These describe the SAREX payload in detail, including power, weight and volume requirements for all five configurations. Shuttle interfaces, including power receptacle requirements and window antenna dimensions are also included. For each SAREX mission, changes to these documents are noted and a special weight certification memorandum is required. The ARRL representative at JSC, John Nickel, WD5EEV, is responsible for coordinating this monumental task. In addition to the paperwork, several formal safety reviews and flight readiness reviews are held throughout the course of the Shuttle mission integration process.

Crew training is another facet of the pre-launch activities. The crew members must learn the proper operation of the SAREX radios and some of the idiosyncrasies of the window-mounted antenna system. Using the flight or flight spare SAREX equipment, the astronauts make 2-way contacts in all operating modes to simulate on-orbit flight operations. This training is performed at the JSC club station, W5RRR. In addition, pile-up operating skills are honed at W5RRR, by encouraging the astronauts to work hams on the H.F. bands; particularly DX pile-up stations. If required, newly licensed crew members are given additional training support on any band or operating mode. Gerry Creager, N5JXS, of the JSC ARC is responsible for astronaut crew training.

Communications waivers are, in many cases, required to ensure that the SAREX station and crew observe the FCC and IARU communication rules. The current statutes require all amateur radio operators in space to carry an extra class license. To date, none of the Shuttle hams have met this requirement. A special waiver must, therefore, be obtained prior to flight. In addition, reciprocal licensing paperwork for the international crew members and third party waivers, for scheduled international schools must also be completed prior to the flight. Rosalie White from the ARRL coordinates this task.

Post Launch Station Checkout

Once launch operations are completed and the Shuttle is safely in orbit, mission operations begin. Approximately 3-10 hours after liftoff, depending on the crew timeline, the SAREX equipment is configured for on-orbit operations and initial checkout. Prior to the flight, an engineering checkout contact is scheduled with the JSC Amateur Radio Club, W5RRR. This contact is of vital importance since reliable 2-way SAREX communications have been shown to be sensitive to the specific window the SAREX antenna is mounted in, the antenna set-up, and Shuttle orientation with respect to the Earth.

The above sensitivity issue was clearly demonstrated during the STS-50 mission in June of 1992. For this mission, the antenna was mounted in a different window which appears to have very different impedance characteristics than the other windows. (The Shuttle windows have a lead coating to protect the crew from excess radiation effects.) Somewhat unreliable communications during the early part of the mission caused some real-time experimentation and modifications of the antenna configuration on-orbit to significantly improve Space-to-Earth communications.

Once a successful contact is made with W5RRR and the Shuttle-to Earth acquisition-of-signal and loss-of-signal properties of the SAREX station are understood, the SAREX station is deemed ready for flight operations.

Mission Control Support

SAREX is an official shuttle mid-deck payload. As such, the SAREX team must provide real-time support in the Mission Control Customer Support Room (CSR) for the entire mission. Duties in the CSR include informing the mission control personnel of any problems with SAREX, scheduled contact successes (and failures), unscheduled contact highlights, and providing real time support to the Mission Control team. In addition, the SAREX team provides a summary of the day's events 2-3 times a day and generates SAREX-related teleprinter messages which are uplinked to the crew. The members of the JSC ARC and other selected individuals volunteer their time to maintain a 24 hour-a-day presence in the Customer Support Room from launch until landing.

Getting the Word Out

Information dissemination during time critical events such as Space Shuttle missions is always a challenge. Fortunately, we hams have stepped up to this challenge and have developed an outstanding backbone network to accomplish this task. Several bulletin stations are available, some around-the-clock, to provide up-to-the-minute SAREX information. These include the Goddard Space Flight Center ARC, WA3NAN, in Greenbelt Maryland, the Johnson Space Center ARC, W5RRR, in Houston Texas, the Jet Propulsion Laboratory ARC, W6VIO, in Pasadena California and the American Radio Relay League Station, W1AW in Newington Connecticut. W1AW broadcasts SAREX bulletins as part of its normal daily bulletin service. WA3NAN operates around the clock during all SAREX missions, providing Keplerian Elements, SAREX operating schedules, frequency reminders, and other general SAREX information. In addition, WA3NAN broadcasts Live Space Shuttle air-to-ground audio throughout the mission. W5RRR and W6VIO provide SAREX bulletins and interactive dialog sessions with hams on HF during the SAREX mission when station operators are available.

During the mission, updated orbit parameters can be obtained from SAREX team members via packet radio, through the Goddard Amateur Radio Club's Shuttle Retransmissions and through bulletins from the ARRL's W1AW station, the JSC Radio Club Station, W5RRR and through the JPL Radio Club, W6VIO. Shuttle orbit parameters are typically updated once a day during the SAREX mission. The SAREX team has received numerous requests for more frequent Keplerian updates. However, once the Shuttle attains its nominal orbit, updates more frequent than once a day are unnecessary. If a major thruster firing is required to modify the orbit, the team provides a special Keplerian update bulletin after the new orbit has been determined.

School Contacts

Direct Contacts

School groups can make SAREX contacts either directly, via a satellite station at the school, or through the international network of telebridge stations which are coordinated by AMSAT. School groups that possess the expertise and equipment to make satellite QSO's and that are directly below the orbiter flight path are typically chosen for a direct contact with the Shuttle crew.

Once a school group is selected for a direct contact, they are informed as such and asked to start mission preparations. The school group is usually informed approximately 3 months prior to launch. Pre-flight preparations by the school group includes setting up the SAREX ground station (if there isn't a satellite station at the school already), selecting the students to talk to the astronauts, selecting the questions to be asked by the students, informing the press and preparing the students for the big day. Well prepared schools usually perform numerous SAREX operations drills with the students. In addition, verification of reliable satellite communication through the SAREX station is highly encouraged and is expected to become a requirement for school groups participating in future flights. Minimum station criteria for SAREX direct contacts includes a 2 meter FM radio with 50 watts of output power fed into a high gain 2 meter beam (preferably circularly polarized). The beam should be mounted on a rotor system which can be articulated along the azimuth and elevation axes. Other accessories highly recommended include a 2 meter pre-amp and a computer controlled interface to the antenna azimuth and elevation axes via an orbit prediction program. In addition, the SAREX ground station should include sufficient redundancy (e.g. an extra independent satellite station) to maximize the success for a contact with the Shuttle crew.

Approximately two weeks prior to launch, the school group control operator is called by the SAREX team to determine if the school group and station are ready for their SAREX contact. Several key topics are reviewed with the school group including operating frequencies, operations procedures, station set up and student participation plans. After launch, the school group provides the SAREX team one last verification that they are ready for the contact through a FAX message which is sent to the Johnson Space Center one day prior to the scheduled contact.

Approximately 45 minutes before Shuttle acquisition of signal, a telephone link is established between the SAREX team in the Mission Control Customer Support Room and the school. Once established, vital last minute information is shared with the school and station operations procedures are verified one last time. During the Shuttle pass, this phone link is used by the SAREX team to determine, first hand, the success or failure of the school group contact. This information is then communicated to Mission Control at the end of the pass. If the contact is successful, pertinent archival information is obtained from the school group and SAREX operations with this school group is complete. If the contact was not successful, backup contact information (if it exists) is shared with the school. A SAREX school contact is usually unsuccessful for one or more of the following reasons: 1) A hardware failure occurred at the school with no backup capability, 2) The school group made an operations (frequency, or antenna pointing) mistake, 3) The Shuttle crew was busy solving a primary payload issue (remember-- SAREX is a Secondary payload) or 4) A sub-optimal Shuttle orientation precluded reliable communications from being established. If a backup contact is required, the backup contact is nearly always successful.

Telebridge Operations

The telebridge system is used when direct Shuttle communications is impractical, either due to a low inclination orbit, lack of satellite operations experience at the school, or due to rise/set time scheduling conflicts between the school group and the Shuttle crew. The telebridge system consists of an international network of Shuttle ground stations which can be linked to school groups using a telephone conferencing system. See figures 6 and 7. This system is similar to NASA's system of tracking stations which were used extensively during the 1960's, 1970's and early 1980's to track the manned space flights. Several school groups can be interactively connected to the bridge with several ground stations providing a direct link to the Shuttle for periods of up to 20 minutes. The school groups usually talk to the astronauts through a local radio or repeater which is patched to the telebridge. If this is not practical, a speaker phone can be used; however this is not encouraged since it is not in the spirit of an amateur radio activity.

The telebridge system was developed initially for the STS-35 ASTRO-1 mission to allow student groups to talk to crew member Ron Parise, WA4SIR. Without the telebridge, U.S. school group participation for this mission would have been virtually impossible due to the fact that the Shuttle was launched in a low, 28.5 degree inclination orbit at night. The night launch resulted in many of the U.S. passes occurring late at night when most school students are asleep. In addition, the low inclination orbit, precluded reliable, high elevation passes for schools located above a 40 degree latitude. Therefore, the telebridge gave student groups in the U.S. the only opportunity to communicate with Dr. Parise during the mission.

Figure 7 depicts the telebridge communications links for a hypothetical school group in Seattle, Washington. As shown, the primary bridging service is graciously donated by Darome Telecommunications in Chicago, Illinois. During the contact, an AMSAT bridge coordinator is on-line with the technical staff at Darome to ensure that the voice levels are appropriate and that the bridge is working well. In addition, a bridge moderator, also usually an AMSAT member, is on the primary voice circuit to coordinate the bridge activity with the crew, ground station(s) and school group(s). Other groups tied into the bridge as listen-only participants are the JSC Radio Club team in the Customer Support Room, school groups that want to hear the SAREX contact and any backup ground stations required for this pass.

Prior to the SAREX flight, the ground stations required for the mission are determined and checked out. Approximately 30-45 minutes prior to the pass, the bridge system, including all the above described groups, are brought on-line. Now, the activities for the telebridge contact parallel those performed for the direct contacts except that the international ground station initiates the contact. After SAREX loss-of-signal, the bridge coordinator obtains any pertinent archival information from the school group and the bridge is shut down.

For simplicity and to maximize the chances of success, the SAREX team has recently opted to schedule one school group with one ground station as the prime uplink vehicle. If the contact fails, a second ground station, several minutes past the prime station, can be brought on-line while the failure issues are worked in real time. This operations procedure worked quite well during STS-50; the last mission to use the telebridge. For this mission, the prime ground station was in Honolulu, Hawaii with a backup station located in Corpus Christi, Texas, 7 minutes after loss of signal in Hawaii. The SAREX team would like to thank its international crew of ground stations and Darome Telecommunications for the outstanding telebridge support they have provided on the STS-35, 37 and 50 missions.

General QSO's

As time permits, members of the SAREX flight crew make random QSO contacts with hams on the ground. These are made using packet, SSTV or voice. The preferred mode of operation for interactive QSOs, both on the Shuttle and on the ground, is voice. The frequencies for general voice QSOs are shown in Table 1. The Shuttle downlink frequency for all random voice contacts is 145.55 MHz. Split uplink/downlink frequencies have been baselined for SAREX missions. As shown in Table 1, three different uplink frequencies are provided to choose from. Since the Astronauts do not favor any of the uplink frequencies, the ability to make contact with the crew is somewhat the "luck of the draw". Also, different uplink frequencies are provided for Europe to better coincide with their band plan. On the past two SAREX missions, STS-45 and STS-50, a significant number of ground based hams were fortunate to work the crew. During these missions up to 100 QSOs per day were made resulting in nearly 1000 SAREX random QSOs on each flight.

Phoning Home

SAREX has opened a new door to the flight crew; the ability to talk directly with their families. This facet of SAREX appears to be quite rewarding from the crew and family's perspective. Shuttle missions have now reached two weeks in duration and 3 week missions are soon to follow. The ability to talk directly with family members during these long flights is expected to be a significant morale booster for both the crew member and the family on the ground.

The family contact is normally prearranged before launch. At the specified time, the contact is initiated. The procedure for making the family contact is identical to that used for a school group direct contact. The only exception is that a phone patch is used to linkup the family with the crew. When the pass reaches the expected loss-of-signal time, the families wrap up their communications with the crew and the family contact is complete.

Storage, Landing and Post-landing Checkout

Approximately 8-14 hours prior to landing, the SAREX station is disassembled and stored in its mid-deck locker. The window mounted antenna is too large to fit in the mid-deck locker. Therefore, it is stored in a special compartment which also holds numerous filters and shades for the shuttle windows.

Any on-orbit anomalies, or problems, with the SAREX equipment are noted by the crew and the ground support team. After landing, the equipment is returned to the Johnson Space Center where it is thoroughly tested and any specific hardware problems are corrected. The hardware is then prepared for the next flight and delivered to the appropriate JSC personnel.

Proposed System Upgrades

Several upgrades to the SAREX hardware and flight operations have been proposed by members of the SAREX team, shuttle crew, and the amateur radio community. A number of these improvements are being considered for future implementation. The following represents some of the improvements that are currently being discussed. Please understand that since these require NASA, AMSAT and ARRL approval, the team is always uncertain as to whether they can be fully implemented.

The highest priority change is the installation of a payload bay mounted antenna. This antenna is expected to significantly improve the ability to communicate through SAREX and in some cases could double the length of a SAREX communication pass. An additional hardware enhancement considered is the flight qualification of new radios to operate SAREX on different modes and amateur bands. This equipment will help alleviate the severe crowding the SAREX team has experienced on 2 meter FM. Sideband operation and operation on 10 meters and 70 cm are capabilities that are likely to be pursued.

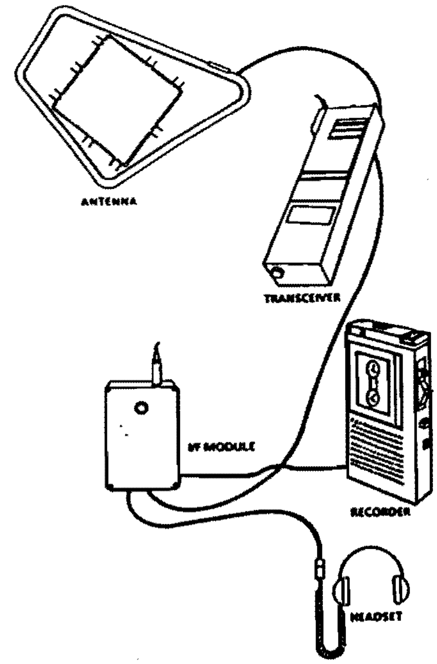
Previous student involvement activities on SAREX have been limited to on-orbit question and answer sessions with the astronauts. One concept being discussed to enhance SAREX is to extend the school group involvement to include carefully planned science or engineering projects with crew-student interaction. Using packet radio, SSTV or voice, the crew can provide downlink data to the students. This data can then be used as a key input to the project. After landing, the school groups can share the results of their projects either directly with the crew or with other students and teachers through papers they write for an educational symposium.

Acknowledgments

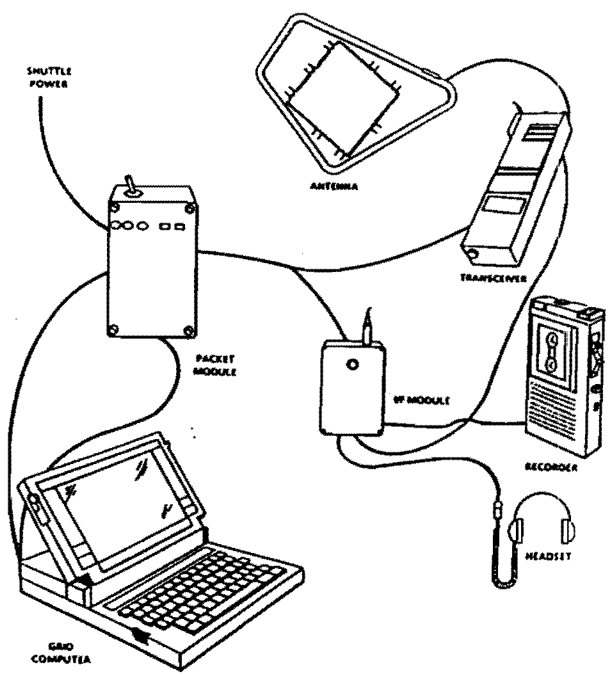
Taking on a volunteer project that must meet the stringent requirements of a U.S. manned space mission is a monumental task, to say the least. Literally hundreds of volunteers from numerous organizations have helped to make SAREX the outstanding success that it has become. It is impossible, in this short paper, to acknowledge all that have contributed to SAREX individually; however, we would like to thank all of you---and you know who you are---for a job well done. Your support, encouragement and constructive criticism is appreciated. The success of SAREX is, and will continue to be, predicated on the dedication and sacrifices made by those have a desire to share amateur radio and NASA's manned space program with the general public.

Area	Downlink	Uplink
U.S., Africa,	145.55 MHz	144.95 MHz
South America,	145.55 MHz	144.97 MHz
& Asia	145.55 MHz	144.91 MHz
Europe	145.55 MHz	144.80 MHz
	145.55 MHz	144.70 MHz
	145.55 MHz	144.75 MHz

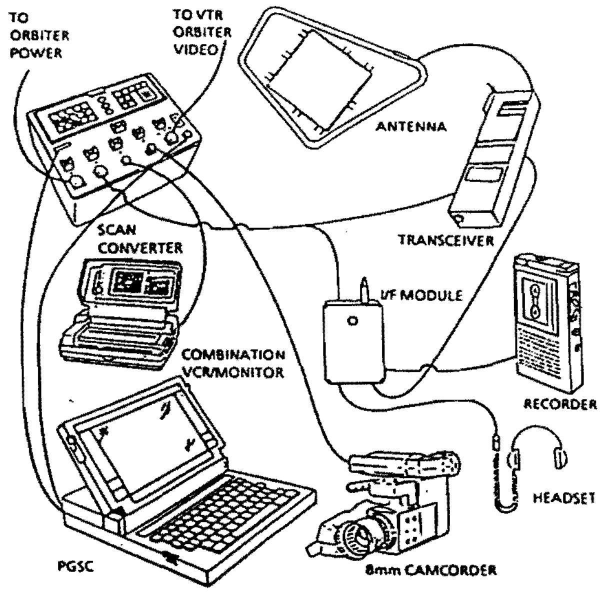
SAREX Voice Frequencies
Table 1



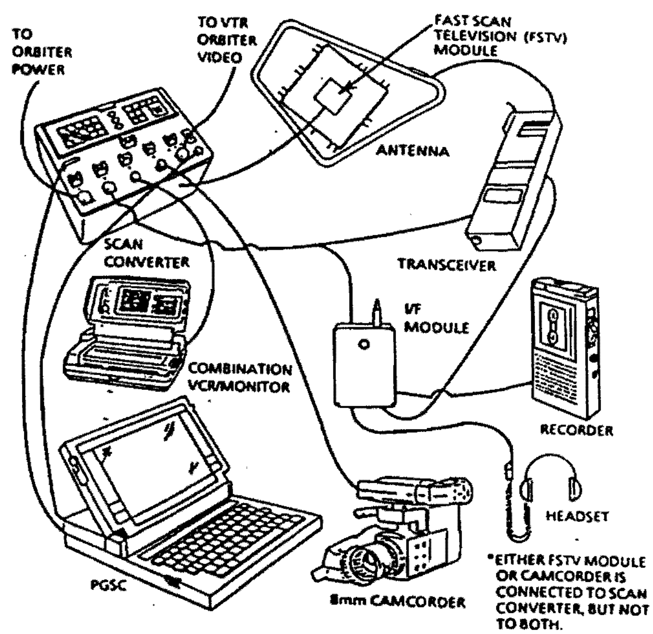
SAREX Configuration B
Figure 1



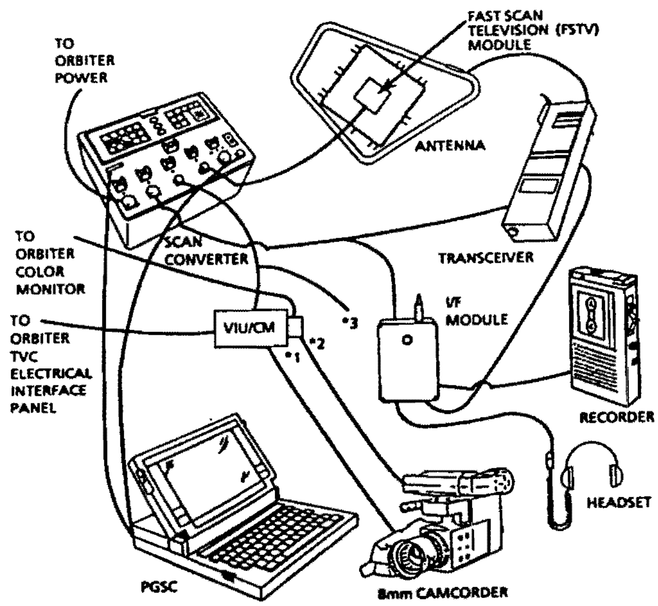
SAREX Configuration C
Figure 2



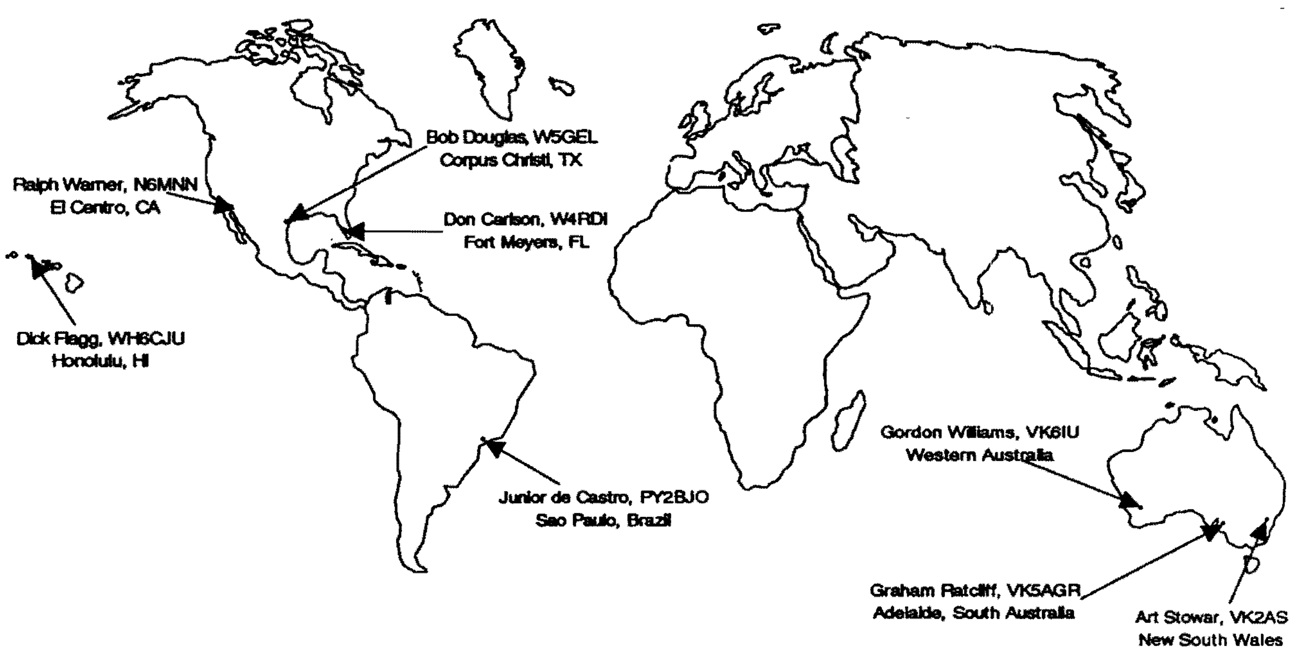
SAREX Configuration A
Figure 3



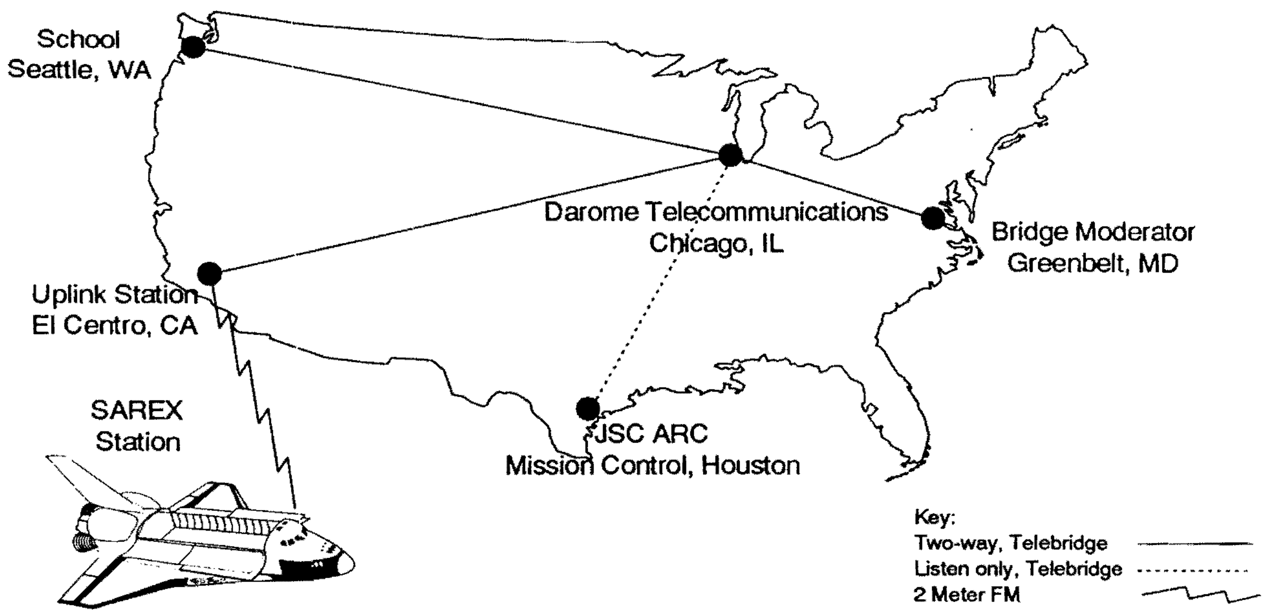
SAREX Configuration D
Figure 4



SAREX Configuration E
Figure 5



SAREX Telebridge Ground Stations
Figure 6



Telebridge Communications Links
Figure 7

DIGITAL SATELLITE AUTOMATION: GATEWAYS AND GATEWAY NODES

by John A. Hansen WAØPTV

It's hard to believe how far digital satellite communication has come in under two years. Setting aside for a moment the pioneering work of the Fuji satellites, two years ago most of us were using Pacsat and Lusat as digipeters. Now these satellites, along with UoSat 22, contain fully functional bulletin boards that are automatically accessed by stations around the world on a daily basis. It constantly amazes me that I can send a message to, say, ZL2AMD in the evening and often have a reply on the next morning's pass. I don't get this speedy a response from most of the local users of my own bbs. So now physical distance means virtually nothing; the limiting factor in response time is more how long it takes for the other fellow to get around to reading your message and responding to it.

Since before these digital satellites were launched I had envisioned setting up an automated gateway system to provide users of my bbs who did not have satellite equipment the capability to use the satellites in pretty much the same way that they could if they had their own satellite stations. A fully functional gateway, it seemed to me should be able to:

- Allow forwarding of personal messages over great distances by satellite rather than by VHF or HF links.
- Allow BBS users to obtain recent directories of what is on the satellites.
- Allow BBS users to automatically download desired files (both text and binary data) from the satellites.
- Allow BBS users to automatically upload desired files (both text and binary data) to the satellites.

All of these operations should ideally occur on a routine basis with no system operator intervention. They should include error trapping so that correctable errors can be fixed and uncorrectable errors do not crash the system. And to the greatest extent possible, they should be seamlessly integrated with the BBS itself.

We are now well on our way to achieving these four goals. The satellite gateway system has focused on the first goal while the remaining three goals are currently be achieved through the newer satellite gateway nodes system. This paper will describe both of these systems in sufficient detail to provide readers with a basic understanding of how they work and how to use them. The software needed to operate these types of systems is available from the author.[1]

SATELLITE GATEWAYS

History

The satellite gateway system was initiated almost two years ago by Dave Medley, KI6QE and John Lawson, NL7NC as a method of forwarding bbs messages between the West Coast and Alaska. It was inspired by two events. First, solar disruption of HF paths at high latitudes had become so severe that little traffic was moving in or out of Alaska. Secondly, there was some concern that if another major earthquake or other natural disaster were to strike Alaska, an alternative means of moving large quantities of emergency and health and welfare traffic would be necessary. The system soon expanded to handle traffic on a regular basis to most parts of the world. In a recent typical seven week period the gateway system handled about 10,000 messages totally about 11 megabytes of data. Figure 1 shows a listing of the currently active members of the satellite gateway system.

While it seems unlikely that the satellite gateway system will totally replace HF and other methods of long distance forwarding, satellite gateways do offer some distinct advantages. First, they routinely handle longer messages than other means of forwarding. Because the data moves at 9600 baud, and because all of the messages are compressed before forwarding, messages of 10k or even more provide no real problems for gateway forwarding. A 10K message will typically compress to 5K. Forwarding time on the uplink for a message of this size is generally under 25 seconds. Downlink time is even less; generally on the order of 6 seconds. A second advantage of satellite forwarding is that messages generally reach their destinations very quickly. Messages generally go anywhere in the world within 24 hours, and the trip from the U.S. to Europe has occasionally be completed in under 2 hours.

For the first six months to a year that this system was running, virtually all of the traffic handling was done manually with gateway sysops manually preparing the traffic for uploading, manually uploading and downloading and manually importing the messages into their bbs's. Each sysop was required to commit to being present for at least one satellite pass a day. The time commitment involved turned out to be on the order of 1-2 hours a day. It wasn't too long before it drove us all nuts.

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[1] The author would like to express his gratitude to the following stations for beta testing and providing helpful comments in developing the Gateway Node software: ON4KVI, ZL2AMD, G8TZJ, ZL2UFW, JA6FTL, VK3JAV. In addition the author would like to especially thank KF5OJ who provided some initial insight into the construction of the SLIST.DAT file and who has provided substantially programming experience to the project.

Several different members of the group began working on automation schemes to lighten the load. At the same time, the UoSat team that was involved in groundstation software development made great strides in building "hooks" into their software that those of us struggling toward automation could use. A specialized version of Phil Karn's Net program was developed by PE1CHL which also aided some automation efforts. Several different automation schemes resulted, depending on the type of bbs and groundstation software in use, but the all share common characteristics. This paper describes the system in place at WA0PTV.

Satellite gateway automation involves 3 basic parts: automating the link to the satellite, uploading, and downloading.

The Link to the Satellite

Having a satellite station operate with no one in attendance requires that the groundstation radio be automatically tuned to adjust for doppler shift and that the antennas be automatically pointed (assuming directional antennas are used). Most stations handle antenna tracking and radio tuning by using either the Kansas City Tracker or the JAMSAT/TAPR trackbox, though a few stations have "rolled their own". Generally it has been found that to use the Kansas City Tracker/Tuner board to do the tuning in this type of installation it is necessary to run it out of a separate computer than the machine which is running the bbs and gateway software.

Generally speaking some sort of microprocessor intelligence is required to do the radio tuning because in addition to following the doppler shift on the signal from the satellite, the tuner must also be able to reposition the radio's receiver back up at the frequency that will begin the next pass.

Tuning is a critical element of an automated groundstation and one of two reasons that most gateway traffic now moves on UoSat 22, rather than the microsats. Because the satellite downlink on UoSat is FM (rather than sideband as used on the microsats) tuning for the doppler shift is much less critical. In addition, data flows at a rate of 9600 baud on UoSat 22, compared with 1200 baud on the PSK satellites.

Automated Uploading

To upload, the bbs software should have the capability to forward to a file. The majority of groundstations are using either the F6FBB or AA4RE bbs software. Both of these packages are capable of forwarding to files. Generally then, the bbs takes all the files that are going to each destination gateway and forwards them out to a file which can then be prepared for uploading. In the case of my station, a program called OUT.EXE then takes each of these files, compresses it, and installs a file header that is necessary to provide the satellite with information about the file (To, from, subject, etc.). These files are then automatically uploaded by the groundstation program PG using the -U -Q parameters.

Automated Downloading

The groundstation program PB has the capability to automatically request all the files from the satellite that are destined for each station. So all files addressed to WA0PTV are automatically downloaded by WA0PTV's groundstation. Then a batch file, called INMESS.BAT is run to process the downloaded files. The file headers are stripped off and those files that are compressed are decompressed. Of the resulting files, those which have the extension .in are assumed to be gateway files (this is now standard practice for gateways). All the .in files are run through a program called SIFT which corrects many of the errors that would otherwise cause the system to crash if they were imported as is. This program also identifies files that are not gateway files (but have the .in extension anyway) and sets them aside. Then it puts all the resulting traffic in one large file to be imported into the bbs. Nearly all of the bbs programs have IMPORT commands that can automatically take a file full of messages and convert them into bbs messages.

Putting It All Together

For most gateway stations the gateway software runs on a computer that is also running the bbs software. This requires a multitasker of some sort and the one most commonly used is DESQview. It is also possible to take down the bbs while the satellite passes are going on and then put it back up when the passes are over, but most stations have at least 386SX machines that allow them to run both programs together. The bbs software runs in one DESQview window, while in another window a batch file called AUTO.BAT is constantly running. This batch file begins by processing any outgoing files using OUT.EXE. Then it runs the groundstation program PG to upload any files going up (the program is often in this state because when it hits this point in the loop it waits to hear the satellite before uploading).

When it automatically exits PG it then runs the groundstation program PB to get a directory from the satellite and download any needed files. In the configuration file for PG there is a line that says EXITAFTER 60 which causes PB to exit after it has heard nothing from the satellite for 60 minutes. This is set as a high value so the computer won't be constantly cycling between the two programs when there is nothing to upload. Then the INMESS.BAT file is run to process the files received. The program then cycles back up to the top.

In this way messages flow between the gateway and the bbs automatically without any operator intervention. I have, on occasion, left my gateway running when I've been out of town for five days and returned to find it functioning well.

User Notes

Local BBS users need do nothing special to access the satellite gateway. All messages that arrive at the satellite gateway bbs destined for distant points are automatically sent via satellite. In addition, to the extent that remote bbs's automatically forward their long distance messages to the satellite gateway bbs, the users of those bbs's need to do nothing special to access the satellite gateway system.

However, sometimes an individual may wish to be certain that a message travels via satellite rather than HF, and he or she is located so far from the gateway that the sysop of at least one of the intervening bbs's forwards its long distance mail via a service other than the satellite gateway system. In this case, a user can generally use a facility called REQSAT to ensure that the traffic goes via satellite.[2]

To use REQSAT at the WA0PTV bbs, for example, long distance users send a message to REQSAT:

SP REQSAT @ WA0PTV

the subject of the message is the actual subject as the user wishes it to appear on the distant bbs. The first line of the text of the message must be a line addressing the message of the form:

SP TOCALL @ BBSCALL

where tocall is the call sign of the actual station to receive the message and BBSCALL is the bbs that is local to the destination station. The rest of the text proceeds normally with a cntl-Z at the end. The gateway bbs then automatically processes this message and readdresses it to the proper party.

GATEWAY NODES

More recently, a mechanism has been developed to give bbs users more direct access to the satellite. Users can now get their own satellite directories, mark their own files for downloading from the satellite and upload messages to other satellite users. This concept has been called a "satellite gateway node". The goal is to give all users of the groundstation bbs the same kind of access to the satellite that anyone with their own satellite station has. As mentioned above, this involves three processes: getting a directory, uploading, and downloading.

Getting a Directory

Uo22's directory is always maintained on each of the groundstations computers, so the main problem is extracting it from the format used by the satellite (files of the form PB_####.PFH where #### is an integer) and putting it into an ascii format that can be imported into the bbs. Three programs, GETDIR.EXE, READPFH.EXE, and SATDIR.EXE

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[2]Not all satellite gateways are currently set up to handle REQSAT messages. It is best to send a message to the sysop first and ask if he has this capability.

currently do that job, though I expect they will soon be combined into a single program. These programs take the most recent directory entries, filter out all the gateway traffic files and a number of extraneous satellite system files, and write the rest into a table that can be imported into the bbs. Optionally, the sysop can also specify that files above a specified size be filtered out. Then the import feature of the bbs is used to present the directory to bbs users as a standard bbs message. BBS users read the directory and thereby obtain a copy from which they can decide which messages they should download.

Downloading

To download a message bbs users can send a message to GWMARK @ GWMARK, using the command: SP GWMARK @ GWMARK. The title to the message is an empty field and the text consists of a list of message numbers that the user wants to have downloaded. The bulletin board then forwards these GWMARK messages as part of the forwarding process to a file called MARK.GWN. A program called SLISTALT.EXE then alters the groundstation file that tells the satellite which messages to download (SLIST.DAT) so that the appropriate messages will be downloaded. On the next satellite pass PB grabs these files and INMESS puts them in a directory that is accessible to the BBS users. The user comes back later and downloads the files from the BBS.

Uploading

If a user wants to send a message to be posted on Uo22, that is possible as well. He uses the standard SP or SB command with GWNODE in the @ field. For example to send a message to ALL he would type: SB ALL @ GWNODE.

The bbs then forwards all messages to GWNODE to a file called GWNODE.MSG. Here a program called GWNODE.EXE processes the individual messages putting the bbs user's call sign in the FROM field and the subject as listed on the bbs in the subject field on the satellite. Thus they appear on the satellite directory exactly as they would if they had been uploaded by the bbs users themselves.

At the time of this writing there is no mechanism for BBS users to upload nontext files (pictures, voice mail, programs, etc), but I am expecting that this will be added in the near future.

Putting It All Together

In the case of gateway nodes that are also gateways, the same AUTO.BAT file controls the action for both functions. After the OUT.EXE program is run to process outgoing gateway traffic, the GWNODE.EXE program is run to process gateway node traffic. Downloaded files are processed by INMESS.BAT at the same time the incoming gateway files are processed. The programs that create the directory to be imported into the bbs are run after each pass is completed (when PB is exited) right after INMESS is run. Thus in stations that are both gateways and gateway nodes the programs work in tandem. Stations that are only gateway nodes work in a similar fashion, though they have somewhat simpler auto.exe files.

WHERE DO WE GO FROM HERE?

The focus of the gateway community is largely been on trying to achieve greater efficiency in the utilization of satellite resources. In addition, one of the real drawbacks to using satellites for message forwarding rather than traditional U/VHF or HF links is that with the traditional methods each station in the chain confirms to the previous station that the message has been received before it is deleted. No such mechanism exists in the case of satellite gateways. When my station uploads a file to the west coast, I assume that KI6QE will be along later in the day to pick it up. This is one of the reasons that care has been exercised in selecting gateway stations. The only assurance that I have that KI6QE actually downloaded and forwarded the message is my knowledge that Dave is a reliable fellow. Some type of "return receipt" would be desirable so that in the event that messages are not received they could be automatically resent.

The gateway nodes system is very new and developments occur almost daily. Features that either will be added by time this is published, or shortly thereafter, include:

o The ability for bbs users to upload binary files.

o The ability to automatically download messages addressed to local bbs users and notify them that the messages have been downloaded.

o The ability to convert all automatically downloaded text messages into appropriately formatted bbs messages and import them into the bbs.

o The ability for users of nearby bbs's to use the gateway node system.

o The ability to download files through a G8BPQ switch without actually logging onto the bbs.

It is hoped that the gateway and gateway nodes systems will greatly expand the number of people who are able to use the satellites that are launched amateur organizations and thereby significantly expand the potential funding base for the development of additional satellites.

TABLE 1
SATELLITE GATEWAY SYSTEM STATIONS

Call	@BBS	LOCATION	Service Area
NORTH AMERICA			
KI6QE	KI6QE	Los Osos	NOCAL,CENCA,OR,WA,ID,NV,AZ,VE6-8
AA6QN	AA6QN	San Diego	SOCA,MEX
NL7NC	KL7AA	Anchorage	AK
VE8DX	VE8DX	Baffin Is	Baffin Island only
WA0PTV	WA0PTV	Fredonia	NY,NH,RI,VT,MA,ME,VE1,2,3
KF4WQ	KF4WQ	Lumberton	NC,SC
W0SL	K0PFX	Manchester	KS,MO,IL,IA,TN
NU9H	WV9O	La Porte	IN,IL,MI
NR3U	NR3U	Selinsgrove	PA,NJ,OH,MD,VA
N0GIB	N0GIB	Sioux Falls	SD,ND,WY,NE,MN,MT,UT,WI
W5ERO	W5ERO	Lubbock	TX,NM,OK,AR
KG4TM	KG4TM	Guantanamo	Guantanamo,Caribbean area
WH6AQ	WH6AQ	Honolulu	US Possessions. Pac Area.
W7LUS	W7LUS	Ft Lauderdale	FL GA KY Central America
KF5OJ	KF5OJ	Alexandria	LA AL
EUROPE			
ON4KVI	ON4KVI	Vielsalm	Western Europe
EI6EH	EI6EH	Kells	Ireland, Denmark
EA3RAC	EA3RAC	Barcelona	Spain,Portugal,France,Italy
OH6KG	OH6RDW	Karleby	Finland Sweden Norway
GB7LAN	GB7LAN	Lancaster	UK
SV8RV	SV8RV	Zakynthos	Eastern Europe,USSR
OCEANIA			
ZL2AMD	ZL2AMD	Napier	New Zealand, South Pacific
VK5ZK	VK5ZK	Adelaide	SA,WA
VK8SO	VK8SO	Alice Springs	Alice Springs
FO5LQ	FO5LQ	Tahiti	French Polynesia
VK4BBS	VK4BBS	Brisbane	QLD,NSW,TAS,ACT,NT,PHL
VK3JAV	VK3JAV	Mernoo	VIC
ELSEWHERE			
4X1AS	4X1RU	Tel Aviv	Israel
JA6FTL	JA6FTL	Kagoshima	JA,DU,VS6,BV,YB
ZS1ABM	ZS1ABM		South Africa
LU8DYF	LU8DYF	Olivos	CX,CP,OA,CE,PY,YV,LU/LW
LU1ESY	LU1ESY		CX,CP,OA,CE,PY,YV,LU/LW
LU7ABF	LU7ABF		CX,CP,OA,CE,PY,YV,LU/LW

RUDAK-II on AMSAT OSCAR-21
Full System Overview,
Current activities and future planning

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Introduction

On 29 January 1991 the first international Orbiting Satellite Carrying Amateur Radio (OSCAR) in which radio amateurs from the Soviet Union worked together with radio amateurs from Germany was successfully launched.

The official name of the project was RM1, which stands for "RADIO M-1". The digital transponder RUDAK-2 is part of RM1.

After the launch from the Northern Cosmodrome in Plesetsk, USSR the satellite was named as AMSAT-OSCAR 21, to emphasize that the spacecraft was built by, and for, Radio Amateurs around the world.

Background

OSCAR-21 (RS-14) is a joint project between AMSAT-U and AMSAT-DL. The idea of a joint effort between the two groups, one in the USSR and the second, in Germany first appeared in the spring 1989. The discussions about what and how things had to be done lasted till the meeting of the representatives of the two groups in Surrey in July 1989 when the preliminary agreement about the cooperation was signed. The final version of the cooperation agreement was later signed in the autumn of 1989 after much of the work already had been started.

According to the mutual agreement, AMSAT-U-ORBITA developed and made the linear transponder, receiver, transmitter, command radio link, telemetry system, power supply system and decided all the problems with the official and other government organizations about the location of the equipment and launching.

The RUDAK group of AMSAT-DL developed and made the digital part, called RUDAK-2 which contains a digipeater and an AX.25 mailbox. It also provides other possibilities for experiments in transmitting of information using modern digital methods. It also contains its own RF input and output circuits on IF level.

The ground command station was developed by the AMSAT-U-ORBITA and AMSAT-U-SPUTNIK groups. The RUDAK group however provided some special digital part for it.

Command stations for RM1 are situated in Molodechno at UC1CWA and in Moscow at RK3KP. The ground command stations for Rudak-2 only will be situated in Munich at DG2CV and near Hannover, at DB2OS.

The final agreement was signed on behalf of AMSAT-U-ORBITA by the technical director of project "RADIO-M1" - V.Chepyzhenko, RC2CA; and on behalf of AMSAT-DL, by their president, K. Meinzer, DJ4ZC. The Project Manager for the RUDAK-2 is Hanspeter Kuhlen, DK1YQ. The coordinators for the project are P.Guelzow, DB2OS and L. Labutin, UA3CR.

The Mission

AMSAT OSCAR-21 is an attached secondary payload (Piggy-back) aboard the USSR geological research satellite "INFORMATOR-1" and provides an Mode B communications transponder in low earth orbit and an orbiting experimental digital communications payload, called RUDAK.

The Launch and Orbit

The Launch was originally scheduled for early 1990, but due to some delays on the launcher and the primary payload it was delayed until early 1991. The successful launch on 7 January 1991 placed the satellite into a slightly elliptical polar orbit with about 1000 km height at an inclination of 83 degrees. The period of the orbit is 105 minutes.

Specifications of the Satellite

Dimension and shape: Cylinder of height about 4 meters and diameter 1.8 meters

System configuration: Professional geological research equipment, telemetry system, command link equipment, transponders and power supply, thermal control. Amateur linear and digital transponders, telemetry system, command link equipment, power supply.

Attitude control: Satellite attitude will be maintained using a gravity gradient approach in the form of a rod 9 meters long pointing away from the earth.

Planned service life: 3 years.

OSCAR-21 System specifications

System configuration

Two sets of the equipment are installed aboard the satellite: Linear transponder #1 is Mode B and the RUDAK-2 with subsystems, and a Linear transponder #2 mode B with subsystems. Transponder #2 does not have any links to the RUDAK-2 subsystem. The Primary transponder is Linear Transponder #1, the second one is a spare which can be put into operation in the event of a failure of the primary system.

Transponder and Beacon Data

The Transponder RF Frequency Assignments and Beacon Data for the Primary Payload are shown in Table 1, those of the backup system in Table 2. The 1100 bps is not a misprint, it is real. Apparently this data rate is used by a popular PC tape cassette interface in the Soviet

Union. Because this PC is simple and cheap for the Hams in the USSR, the AMSAT-U-ORBITA team decided to use it on this spacecraft.

Table 1 Primary Payload

Beacons and telemetry #1

CW telemetry 8 channels	145.822 MHz	0.2 Watts
Digital telemetry 30 channels	145.952 MHz	0.4 Watts
	1100 bps, PSK/FM, deviation 2kHz	
Digital telemetry Rudak-2	145.983 MHz	3.0 Watts
	BPSK 1200 bps AX.25 (like FO-20)	

Transponders #1

Linear transponder: inversely heterodyned translator

Uplink passband	435.102 to 435.022 MHz
Downlink passband	145.852 to 145.932 MHz
Transmitter output max	10 Watts
Bandwidth (3db)	80 KHz
Uplink EIRP required about	100 Watts

(2) Digital transponder Rudak-2: digipeater and store & forward packet communication (AX.25), telecommunications experiment with digital signal processing up to nearly 20 KHz, 1 MByte RAM disc, four separate uplink channels.

Uplink frequencies:

RX-1 435.016 MHz 1200bps,FSK,NRZIC/Biphase-M
RX-2 435.155 MHz (AFC) 2400 bps,BPSK, Biphase-S
RX-3a 435.193 MHz (AFC) 4800 bps,RSM
RX-3b 435.193 MHz (AFC) 9600 bps,RSM
RX-4 435.041 MHz (digital AFC) RX for RTX-DSP

Downlink frequency: 145.983 MHz 3 Watts

The downlink can be switched to the following operating modes:

Mode 1: 1200 bps, BPSK, NRZI,(NRZ-S) (like FO-20)
Mode 2: 400 bps, BPSK, Biphase-S (Like AO-13 beacon)
Mode 3: 2400 bps, BPSK, Biphase-S
Mode 4: 4800 bps, RSM, NRZIC (Biphase-M) (like 4800 bps uplink)
Mode 5: 9600 bps, RSM, NRZI (NRZ-S) +Scrambler (like 9600 bps uplink)
Mode 6: CW keying (only for special events)
Mode 7: FSK (F1 or F2B),e.g. RTTY, SSTV, FAX, etc. (for special events)
Mode 8: FM modulated by D/A signals from DSP-RISC processor (speech)

Table 2 Secondary Payload

Beacons and telemetry #2		
CW telemetry 8 channels	145.948 MHz	0.2 Watts
Digital telemetry 30 channels	145.838 MHz	0.4 Watts
	1100 bps,BPSK/FM, deviation 2 kHz	
Digital telemetry 30 channels	145.800 MHz	2.0 Watts
	1100 bps BPSK/FM, deviation 2 kHz	

Transponder #2

Linear transponder: inversely heterodyned translator	
Uplink passband	435.123 to 435.043 MHz
Downlink frequencies	145.866 to 145.946 MHz
Transmitter output max	10 Watt max.
Bandwidth (3db)	80 KHz
Uplink EIRP required about	100 Watts

Antennas

The 435 MHz receiving antenna which is shared by the analog and digital modes is a Helix with up to +3 db gain using Right Hand circular Polarization. The 145 MHz transmitting antenna is a Half wave dipole. Antennas are always earth-pointing due to the satellites gravity gradient attitude stabilization.

The Telemetry

OSCAR-21 transmits Morse code (CW) and digital telemetry. It will be transmitted on 145.822 MHz when transponder #1 is in use or on 145.948 MHz if transponder #2 is in operation. A CW Morse-Code telemetry frame consists of the call RS14 and 8 channels of four digits in the following format:

RS14 S0AB
S1AB
S2AB
S3AB
S4AB
S5AB
S6AB
S7AB

Channels 0 to 6 contain analog telemetry data. Channel 7 contains engineering calibration parameters.

The first digit (S) identifies some special status information for the command stations.

The second digit (0 to 7) are the numbers of the line (channel).

The remaining digits (A and B) are the analog telemetry data which can be decoded according to the equations shown in Table 3.

Table 3 CW Telemetry decoding parameters

Channel (line)	Parameter	Formula	Unit
0	Transponder power output	0.05N	Watt
1	Transponder PA Temperature	N	Deg. C
2	+24 V Regulated	N	Volt
3	+16 V Regulated	N	Volt
4	+9 V Regulated	N	Volt
5	Service	N	*
6	Service	N	*
7	Service	N	*

For example, a typical frame and its meaning are shown below.

RS14	7059	- 2.95 Watt HF
	7124	- 24 deg. Celsius PA temp.
	7224	- 24 Volt Power Supply Voltage
	7316	- 16 Volt " " "
	7410	- 9 Volt " " "
	7500	- internal status
	7600	- " "
	77PP	- " "

Digital Telemetry (RM1)

The Digital telemetry consists of 30 parameters monitoring on-board conditions and 2 calibration verification points. It is generated by the transponder payload and command system and not by the RUDAK-2 system. The transmission baud rate is 1100 Bit/s with FM/PSK Modulation. The beacon frequency is 145.952 MHz for transponder #1 and 145.838 MHz for transponder #2. If transponder #2 passband is off, then the digital telemetry beacon operates on 145.800 MHz.

The RUDAK-2 digital communications payload

The Computers

RUDAK-2 contains two computers. The first, called R1, is a slightly modified version of the RUDAK computer originally developed for OSCAR-13 in which mainly digipeater operation had been intended requiring relatively little memory capacity. For that reason the computer was only equipped with 56 KByte of RAM. On account of the low orbital altitude of OSCAR-21, mere digipeater operation is not particularly exciting, thus leading to the decision to support mailbox and store & forward operation also. However, since the 56 KBytes of memory are not sufficient to store the entire software, RUDAK-2 also has a 1 MByte memory expansion which is serially accessible in 256 byte blocks via an 8-bit port. Since it is operated similar to a disk drive, it is called a RAM disk. This system, although functionally complete already, was extended further by the addition of a second computer. The design of R1 is approximately five years old and thus no longer corresponds to the current state of technology. A more modern computer concept was developed in order to provide for a certain degree of redundancy and also to allow the evaluation of newer more exciting techniques particularly in view of Phase 3D. The name "RUDAK Technology Experiment" (RTX) reflects the experimental character of this system. The most interesting aspect will probably be the unprecedented use of digital signal processing. In addition to two or four phase PSK, other modulation types such as rectangular spectrum modulation (RSM), minimum shift keying (MSK) or even FSK could be tried out. Furthermore, it is conceivable to improve the signal to noise ratio by use of encoded modulation types such as "folding codes" in conjunction with Viterbi AND/OR soft decision decoding.

The entire system was so conceived that a failure of any one of the three subsystems (R1, RAMDISK, RTX) would still permit acceptable operation.

The R1 Computer

R1 is a typical representative of the 8-bit microcomputer generation. A 65SC02 CPU clocked at 819.2 KHz, serial (84C40 SIO) and parallel (65SC22 VIA) interface components, as well as seven 8-KByte CMOS RAM's (4464 with 6 transistor cells) and one 8-KByte CMOS PROM (6616) constitute the nucleus of this computer. Along with all other necessary logic components, the total count of IC's is a mere 22. Since a standby reserve had been allocated during the development of the RUDAK processor for OSCAR-13, this second board could thus be used directly in RUDAK-2. Only the parallel port needed modification to support bidirectional operation of the RAM disk.

The RTX Computer

To a certain degree, this computer originated from the goal of evaluating as many alternatives to the R1 concept as possible. Since reliable operation is possible even without a second computer, lower safety margins were accepted than for R1. The RTX employs the 16-bit RISC CPU RTX-2000 from Harris. It can be run optionally at 9.8 MHz or 6.5 MHz with one memory access per clock cycle. At the faster rate, it reaches a throughput of typically 10 to 15 MIPS (millions of instructions per second), with a maximum of 40 MIPS. The architecture of the CPU diverges significantly from that of conventional microprocessors and corresponds to the virtual CPU of the programming language FORTH. For a number of reasons, the CPU is particularly suitable for our intended application:

- o The FORTH architecture supports the implementation of IPS, i.e. the CPU uses IPS essentially as its machine language, thus permitting extensions to the available IPS software, but at execution speeds higher by at least factor 100.
- o The short execution times for instructions (1 or 2 clock cycles, no pipeline) allows very rapid interrupt processing.
- o The rapid multiplier simplifies digital signal processing (DSP).

However, at the beginning of development, there was no practical experience with this relatively new CPU. The main memory of the computer consists of 128 KBytes of RAM (65536 16-bit words). Static CMOS RAM's with access times of 35 ns were chosen due to the high access speeds required. In contrast to R1, this memory is equipped with a 1-bit error correction logic in order to catch any probable soft errors. The error correction logic requires an additional 65 KBytes overhead so that a total of 192 KBytes of memory is installed. The RTX computer contains no fixed program storage (PROM) since this may have been the cause of the failure of RUDAK-1. The operational software is loaded via direct memory access (DMA) in the same manner as for the onboard computer of the Phase 3 satellites (IHU).

The input/output section constitutes a significant portion of the system. VLSI components such as a SIO were not chosen since most standard IC's cannot handle the high bus speeds. These functions were shifted to the software.

All 14 digital inputs are connected to the receivers and diverse telemetry signals. Four digital outputs control the transmitter and the RAM disk. Two bidirectional 8 bit ports provide the link to R1 and the RAM disk. If the RTX is switched off, this 8 bit port goes transparent so that R1 and the RAM disk can communicate. In all, there are 16 inputs and 2 outputs in the analog interface of the computer. Two of the inputs receive the demodulated orthogonal components I and Q from the receiver Rx-4. One output drives the VCO of this receiver. In this way, various coherent and of course non-coherent demodulators are possible using digital signal processing. Limits are set only by the computational capacity of the CPU and the IF bandwidth in the receiver.

An additional input gets the discriminator output from Rx-1 and thus supports demodulation of FM signals or the evaluation of analog signals such as speech. The remaining analog inputs get analog telemetry signals. The second output allows analog frequency modulation of the downlink.

The circuit consisting of 63 IC's in all was laid out on a four layer circuit board, two for power and two for signals. The relatively large number of IC's is due in part to the discrete construction of the I/O section and the lack of "trick circuits", which were avoided because of the tight time schedule with 3½ weeks for circuit design, 2 weeks for board layout, and 2 weeks for board construction, so that no prototype could be built. It was thus indeed a big relief when the circuit, which had been developed entirely on paper and computer monitor, functioned perfectly right off.

The power consumption of the computer during operation is around 1.5 Watt, most of which is needed by the fast RAM's.

The RAM Disk

The memory expansion for the mailbox contains 31 static 32 KByte CMOS RAM's without error correction. If it should prove to be necessary, error correction can be implemented in software. In place of the 32nd RAM, an EPROM was installed, half of which programmed at "fast" and half at "normal" rates. Due to the increased radiation in orbit, the EPROM should be erased more or less quickly. The goal of this experiment is to measure this lifetime in conjunction with the programming algorithm.

The RAM disk is not mapped into the main memory, but is accessed as a peripheral device via the parallel port. The memory is divided into blocks or sectors of 256 bytes each, similar to disk devices. The data within a block can thus only be read or written as a whole. Although the RAM disk should primarily serve the mailbox, other applications are also conceivable, such as intermediate storage of programs or digitized analog data. The power consumption of the RAM disk is a mere 30 mW.

The Transmitter and Receiver

The transmitter was so designed that, in addition to the "old" data rate of 400 bits/s PSK, it can be operated with data rates up to 9600 bits/s. However, the normal mode of operation will be 1200 bits/s and the 400 bits/s will likely only be used during initial testing and startup. Furthermore, the possibility of generating frequency modulation was provided so that even FSK or Analog FM can be transmitted.

Four receivers are provided for reception of signals from ground stations: Rx-1 receives 1200 bits/s FSK and Rx-2 receives 2400 bits/s PSK. These two receivers support the routine operation of RUDAK-2. The two other receivers are more of an experimental nature. Rx-3 receives 4800 bits/s or 9600 bits/s RSM. Rx-4 is similar in design to Rx-3, but the necessary filters are implemented in software for a special processor, the RTX, which will be operated as a signal processor. Thus it will be possible to receive virtually any type of modulation for experimentation.

For the first time, RUDAK-2 provides the opportunity to evaluate RSM in outer space in anticipation of Phase 3D. At 1200 bits/s FSK, transmitter power of 10 W is required with 5 dBi Antenna gain. At 9600 bits/s RSM the necessary power increases to 20 W. Naturally, antennas with higher gain could also be used, reducing the needed power correspondingly.

First experience

The RUDAK-II payload was successfully switched ON for the first time nearly one month after the launch of OSCAR-21 on 22 February 1991. The RUDAK-Beacon on 145.983 MHz started transmitting 400 bit/s PSK Telemetry, while the CW Beacon on 145.822 MHz were transmitting morse telemetry. Both beacons could be copied with very strong signals. After initial tests, the IPS kernal was loaded into the RUDAK R1 system and later the beacon was switched to 1200 bit/s PSK AX.25 format, which is compatible to FUJI, PACSAT etc.

Within a few days the RUDAK ground commandstation was able to complete all system tests, including Digipeater-, Robot- and Mailbox Mode. On 24 February 1992 the first in-orbit demonstration of the RUDAK-RTX Digital Signal Processing (DSP) capabilities took place with the first Digital Voice/Speech Experiment.

The words "I'm completely operational and all my circuits are functioning perfectly.." could be even copied with a handheld transceiver surprising many listeners.

Unfortunately only 1 week later in early March 91 a malfunction occurred and the RUDAK beacon was found to be permanently switched Off and could not be turned on again by any commands from the ground, although high uplink power was used.

This happened when a -12dB attenuator in the RM1 receiver section was turned off and the receiver probably started to self-oscillate. However, all attempts to recover RUDAK-II were unsuccessful and there was also no more access to the RM1 command system. Using RUDAK command channels, there is only a limited control over the RM1 command system, i.e. the RUDAK Beacon can be turned ON/OFF by inverting the RM1/INFORMATOR-1 command lines.

OSCAR-21 can also be controlled using the INFORMATOR-1 command system and on 21 May 1992 the backup transponder #2 could be activated. Transponder #2 worked as expected, with very strong downlink signals and an outstanding receiver sensitivity.

In July 91 another effort was undertaken to recover transponder #1 using a special schedule and by switching periodically between transponder #1 and transponder #2, including the -12dB attenuator. But no progress was made at this time and RUDAK still remained off.

In August 91 efforts were concentrating to build up another commandstation at AMSAT-DL command station facilities to get control and improved over the RM1 command system by using higher uplink power. However, all attempts to send commands to the RM1 system and to switch the transponders did not had any success. It must be concluded that parts of the RM1 command system failed, since no commands could be uplinked from the AMSAT-U or AMSAT-DL groundstations.

At the same time the world saw the dramatic changes in the former USSR, which also did not stopped at the command center of the INFORMATOR-1 Satellite. One must know, that all military and civilian USSR satellites were controlled only by the big General Command Center (GCC) near Moscow, which also has some control and tracking stations all over the country. The

Ministry of Geology and Science of the former USSR, which owns INFORMATOR-1, was no more able to pay for the control of the satellite and for financial reasons the GCC refused any commanding of the satellite and was on "strike". This does indeed affected the OSCAR-21 payload in INFORMATOR-1 and for several month not any commands were uplinked to the satellite and most systems were simply turned off.

Fortunately, AMSAT-U and the Adventure Club in Moscow could make a contract with the GCC, that they will again send commands to turn on the AO-21 and RUDAK-II payload. The command access via the INFORMATOR-1 was still functioning and in late 1991, early 1992 the complete OSCAR-21 payload was turned OFF and ON again for a full power down reset. There were more and other problems, which hampered the commissioning of RUDAK-II, but in May 1992 a big break-through was made.

The Problems and the Solutions

It was discovered that due to self-switching in the RM1 command system the RUDAK Beacon was often switched off or into different modes, like ranging mode. Fortunately the RUDAK command system itself can read the status of those self-switching command lines and has the ability to simply logically invert the commands. A special so-called "Watch&Bite" Software was written for the RTX-2000 computer and this problem could be completely solved.

Another problem was identified in a DC/DC Converter of a Power Supply for the RUDAK System. This Power Supply, which is not part of RUDAK-II, has it's own "electronic fuse" to protect for short circuits. Unfortunately the current limit was only set about 10% higher than the nominal RUDAK power consumption. Like any CMOS parts and computer components, the power consumption is in direct relation to the processor speed and program execution. There might be current spikes above this limit, causing the electronic fuse to switch off the power supply. By reducing the processor speed of the RTX-2000 computer and turning of the R1 computer, the current consumption could be markedly reduced. It was also found, that the current fuse of the DC/DC may be very sensitive to a BUS over-voltage. Therefor a special program from the GCC was installed to better control and regulate (reduce) the BUS voltage in case of over-voltage.

This in fact was completed in late May 1992 and since than RUDAK-II was in continuous operation. In the weeks before, the RUDAK system was often after only a few days suddenly completely switched off and could only turned on by resetting the "electronic fuse". This was simply done by turning the main power relay off and on.

However there are still some more problems. The receiver sensitivity is sometimes very high, but sometimes much uplink power is necessary. It is unclear if this effect is due to a -12dB attenuator relay in the RM1 Receiver or due to some interference with onboard transmitters or high power transmitters from ground. It is planned to periodically switch On/Off the attenuator to verify it's function. The new 70cm high power Pave *Pawn* radar recently installed in the UK gives additional problems while uploading large portions of software into the computer and it also hampers commanding. This Radar does also give much trouble with commanding AMSAT OSCAR-13 on 70cm.

Current Activities

After RUDAK-II was successfully recovered from his hibernation in May 1992, all systems were again completely checked-out. The RUDAK Hardware Command Decoder with it's RM1 Bypass was a great help, since the loss of the RM1 command system.

The RUDAK R1 Computer was found to be 100% operational, but it's use will be discontinued because this system is no much more interesting due to it's old technology. The R1 computer was originally designed for and flown on AMSAT OSCAR-13. It now has only backup functions on OSCAR-21. This includes the RUDAK Mailbox, which was also active for a few weeks. However, the software may be later ported to the RUDAK RTX computer. The 1 MB RAMDISK and the EPROM experiment is also still 100% functioning. The RAMDISK will now be used from the RTX2000 only. The RTX2000 DSP Hardware & Software itself is also working as expected and fully operational. In addition to Digipeater, Mailbox and Robot mode, a new type of Digital Voice & Sound generation was successfully demonstrated for the first time on an OSCAR satellite. In addition to the HAL Voice generation, we have heard the Beep Beep signals from the famous SPUTNIK-1 satellite again coming from Space from it's original Soundtrack! Another milestone was a realtime FM Repeater using DSP, which means that uplink and downlink are not simply connected together, but everything was done by software. AMSAT OSCAR-21 is the first Amateur Radio Satellite with such DSP capabilities. The FM Mode is continuously in use for more than two month now and it's primary purpose was to directly study the Uplink and receiver sensitivity characteristics. However, it was a great surprise to the builders, that the FM Mode was used by so many peoples with greatest fun. AO-21 is easy to receive, even with a handheld and many stations find this high flying FM repeater for the first time, when the 2m scanner stopped at 145.987 MHz.

Many Hams who are not yet active on satellites and even do not have any SSB equipment, did now get their first feeling with satellites. Some of them may later join the linear transponders (indeed in SSB) as well. In August a new Software was loaded with 6 Minutes of FM Mode, 3 Minutes of Digital Voice and 1 Minute of 400 Bit/s PSK Telemetry. This time RUDAK-II is talking in russian language and in between the FM repeater can be used.

The Future

Since RUDAK-II is now running continuously for more than 2 months, it gave a new motivation to the RUDAK team and some more work on the Software will now be done. The RUDAK-II equipment must be regarded as basically a flying test-bed for techniques to be used on Phase-3D. There are still techniques and experiments to be performed however such as: 4800/9600bps RSM; other modulation (MSK, QPSK); voice and other sounds; voice mail; spoken telemetry and bulletins; other DSP/modem experiments such as SSTV and FAX. There are already plans for a RUDAK-III system on the next AMSAT Phase 3D Satellite to be launched in 1995/96.

Although the discussion is not yet finished, first ideas suggest using the RTX-2000 processor in conjunction with some other processor hardware. The primary tasks for the RTX will be in the

DSP Modem techniques, were other CPU's may be responsible for the communication protocols and data handling with various onboard experiments, like the SCOPE Camera Systems.

RUDAK-III should have as many receive channels as possible (only limited by volume and power) and encompass low-speed (1200 bps psk) through to high-speed (64K rsm) capabilities using several protocols (DAMA, FTL0, BROADCAST).

RUDAK-III will handle low and medium speed Store&Forward traffic and a large mass memory (RAMDISK) in the area of 50 MB or more is also intended. High Speed Gateway traffic will be done in near realtime, were RUDAK-III does work like a Digipeater or Autorouter to other Gateways.

Developing and constructing the RUDAK-III hardware and software will start very soon now, but the project group is still open to everyone who would like to participate.

Special thanks are to Leonid Labutin UA3CR for his tremendous efforts to coordinate the commanding activities with the General Command Center (GCC). Also special thanks to Gerhard Metz, DG2CV who spent so many nights and who did not give up in getting again new software uploaded to OSCAR-21.

Microsat Engineering Test Results
August, 1992

By Jim White (WDØE), Bruce Rahn (WB9ANQ) and Paul Williamson (KB5MU)

INTRODUCTION

Beginning with the turnover of AO-16 to the command team in early 1991, we have been tending to its care and feeding and occasionally that of the other microsats. Among other tasks this includes gathering and analyzing telemetry for the purpose of watching over the health of the spacecraft bus. During the past several months we have greatly increased our understanding of the spacecraft systems. However there were a few things that we were never able to understand to our satisfaction. The crash of the file server software on 27 July provided the opportunity to review spacecraft performance and systems and answer a few of those bothersome questions. It turned out that we learned much more than anticipated. This paper discuses the analysis methods used, the results of that analysis and the expected effects on microsat users.

BACKGROUND

The four microsats (AO-16, DO-17, WO-18, LO-19) were launched in January 1990. Operational control of LO-19 transferred to the Argentine group who sponsored and funded it a few months later. Control of WO-18 was assumed by the Center for Aerospace Technology at Weber State University at about the same time. Control of AO-16 was gradually assumed by a command team led by Bruce Rahn, WB9ANQ. The first year was a period of intense software development and a parallel effort to collect and analyze large amounts of telemetry that led to a fairly through characterization of the spacecraft systems. During that time Bruce, Jim White, WDØE, Courtney Duncan, N5BF, and (after Courtney's departure from the team) Paul Williamson, KB5MU, learned a great deal about the operational characteristics of AO-16. However at the time the file server software became operational some questions remained. Since the bulk of the downlink channel time was being used by file exchanges it was difficult to collect telemetry at a fast enough rate to allow detailed analysis. While some work continued, such as characterization of seasonal temperatures and power generation cycles, other efforts were put on hold. By July of 1992 several months had gone by with little activity of this nature.

When the file server software crashed (probably because of a double bit error in the EDAC memory) it had been operating continuously for 316 days without a problem. At that point the server software developers were a few days away from making the latest version available for AO-16. The new release contains several enhancements including the directory broadcast feature which will greatly increase throughput. The team decided we would not load the old software only to reload the newer version a few days later. Rather, we would wait for the new code and take the opportunity to run higher speed telemetry and possibly even Whole Orbit Data (WOD) for a few days. Hopefully this would allow us to answer several questions. The puzzle list looked something like this:

- Some of the data from some telemetry channels had never been completely understood. The results did not match expectations. These were not particularly important channels (or so we thought) so we had not been too concerned about the funny results. These were temperature channels and generally indicated the design targets had been met even though some patterns in the data were puzzling. But Bruce recently had begun to suspect two or more of these channels were reversed or otherwise incorrectly labeled.

- We had received reports that the AO-16 PSK transmitter was hard to copy. Bob Diersing, N5AHD, had measured the bit error rate (BER) from AO-16 several months before and found it quite acceptable, so these reports were puzzling. However, some of us had experienced the problem ourselves so it appeared as though this would be worth looking into.

- We wanted to know how much the space environment had reduced the output of the solar arrays. Whole orbit data is necessary to make this determination.

- Reports of phase noise or jitter on various microsat transmitters (especially from James Miller) caused us some concern. Preliminary observations had indicated that there was indeed more than we would have liked.

- We were looking for ways to tune up the power control software in the spacecraft to improve the downlink signal margins, which is an continuous effort.

We felt all or most of these questions could be answered with a few days of high speed telemetry from the spacecraft and a few experiments. Of course it took longer than expected, but we found out more than we anticipated. During this period of engineering tests we concentrated on AO-16, but did some work with WO-18 and LO-19 as well, in cooperation with their respective command groups.

It might be worth reviewing why answering these questions was important.

- It's always desirable to do a detailed validation that spacecraft systems are working correctly from time to time so you can watch for long term trends that might not show up in routine coarser observations. Catching these can sometimes allow corrective action to be taken before a problem becomes serious. Validations are valuable to spacecraft designers and builders because they show what worked well and what can be improved in future satellites. With at least two more spacecraft of the microsat design in the works results can be applied during construction and hopefully contribute to an improved spacecraft.

- It was necessary to determine why the AO-16 PSK transmitter was difficult to copy before corrective action or adjustment could be considered. The ideal result would be a better signal and more usable satellite. This is especially important for ground stations using omni-directional antennas, for whom any degradation in signal could mean the difference between acceptable and unusable down-link signals.

- Clearing up the confusion over the temperature telemetry channels was not considered to be particularly important since it was clear that the temperatures were well within design specifications and were not a threat to the batteries or other spacecraft systems. We did not realize how important this issue would become.

- Lastly, and certainly of lesser importance to the amateur satellite user, the command team just can't stand it when we don't understand something.

METHODS

Bruce and Jim collected and analyzed telemetry from their own locations and from several other AMSAT members and microsat users who were kind enough to respond to their requests for data from various other locations. Internet electronic mail and telephone discussion and consultation took place between the command team members and with Dick Jansson, WD4FAB, Jan King, W3GEY, and Harold Price, NK6K. In about three weeks we gathered and dissected over 1 megabyte of telemetry, exchanged several hundred thousand bytes of email and ran up our phone bills considerably with brain storming sessions well into the night. The primary method of telemetry analysis was to gather the data, often while commanding changes in various spacecraft parameters, then drop the calculated engineering values into spreadsheets and graph or otherwise manipulate the results. This activity peeked with several hours of observations and analysis on August 8.

On that day Jim took a car load of equipment to Jan King's OSC lab in Boulder. A few hours of preparation went into setting up lab quality equipment to observe in real time and make photographs or plotter charts of spectrum displays, phase jitter, and eye patterns of the microsat transmitter signals. As passes took place for the remainder of the day conference calls were established with other team members. Often one member would command changes to transmitter power or other parameters and observe and report on telemetry while another would transmit special test files and Jan, Jim, and Greg Hein, WTØM, would observe and record the results.

By special arrangement with the LO-19 command team that satellite was transmitting a test file to enable spectrum analyzer measurements. A great deal was accomplished during a few short passes thanks to the close cooperation and flexibility of the entire team. It is worth mentioning that no prior arrangements had been made with Weber State University, but Bob Argyle noted what we were doing on the other microsats and did exactly what was needed to WO-18 while we were observing it. Further coordination was then accomplished on the phone. Special thanks to Bob for being so observant and responding to the situation.

RESULTS

As of this writing (mid August) the following issues have been resolved by the work that led up to the August 8 effort and the analysis which has followed. More work remains and further results will be reported in the AMSAT-NA Journal.

The AO-16 PSK transmitter carrier suppression has deteriorated to the point where it is essentially 0 when cold, and is only about 5 to 6 dB when warm. Figures 1, 2 and 3 are spectrum analyzer displays of the AO-16 PSK transmitter before launch, on August 8 when cold, and the same day when warm respectively. Carrier suppression can be determined by measuring the vertical distance between top of the carrier signal and the modulation peaks in the plots. Please note in these and the figures which follow that the horizontal and vertical scales of the plots are not all the same. The TAPR PSK modems in use at OSC and at WB9ANQ were able to copy data reliably at power levels of 1W and 1.3W when suppression was measured at 6.7 dB and were able to copy only occasional packets at a power level of 3.2W when suppression was measured at 5.3 dB. It appears that when carrier suppression is 5 dB most current PSK modems are unable to properly recover the data. This carrier suppression problem probably results from transmitter component values drifting slightly with time. The Q of these stages may be high enough that they are overly sensitive to small component value changes that have occurred in orbit. It is not likely this will get better for the life of the mission. One option for the continuation of the mission was to operate the PSK transmitter at no more than about 1 Watt and dump the rest of the power into the batteries. This would lead to over charging, which was a concern. While this option might result in a usable signal for a while, there was the distinct possibility that the carrier suppression problem would get worse because of further component drift, rendering the signal useless at any power level. The other option was to switch to the raised cosine (RC) transmitter. There were several mitigating factors considered regarding the RC option.

The power amplifier transistor (HPA) in the RC transmitter was replaced at the last minute in the lab prior to shipment to Kourou because the original was damaged. The new one was the most efficient of the entire set of devices purchased for the project, but was inadvertently tuned into a bad load during repair. Additionally, there was no time to re-calibrate the RC transmitter power output telemetry channel. So we have a very efficient device less than optimally tuned and an uncalibrated power output telemetry channel. However it was Jan's judgment that there was little risk in operating this transmitter full time and it would seem we can live with the telemetry calibration question. The team concluded that the PSK transmitter should be removed from service and the RC transmitter used for routine operations.

The AO-16 RC transmitter carrier suppression was measured at between 18 and 20 dB and was essentially insensitive to power level, which is excellent. Figure 4 is the RC transmitter spectrum prior to launch and figure 5 is the same display captured during these tests. Additionally the phase jitter or phase noise was examined. The jitter (or deviation from exactly 0 and 180 degrees of phase shift) was approximately 20 degrees and about 5 degrees asymmetrical. It will probably be worth attempting to adjust the modulator in order to reduce the jitter and/or make the shift more symmetrical. However even in its current state this transmitter should perform quite well. (The best microsat transmitter observed had about 15 degrees of jitter and was symmetrical.) The advantages of RC over PSK have been discussed in previous papers and articles. However we should also note that we confirmed Jim's hypothesis of a few months ago that the second sideband product of the RC transmitters is about as strong as the same sideband on a straight PSK transmitter - even though remaining sideband energy is very low. With very large link margins this may make it easier to achieve false lock when receiving an RC transmitter.

- The WO-18 straight PSK transmitter was known to be bad from tests conducted immediately after launch. During the August 8 tests the phase jitter was in excess of 45 degrees at 1.4W output power. Figure 7 is an oscilloscope display showing the phase deviation from 0 and 180. A perfect PSK transmitter would create a display with tight circle traces at the top and bottom of a vertical line. The angle from the center line to the edge of those circles is the amount, in degrees, the phase shift varies from 0 and 180 degrees. In figure 7 it can be seen that this transmitter is producing so much phase noise that it would be very difficult for any demodulator to recover the data. We did not look at the WO-18 PSK transmitter spectrum because of time constraints. The jitter observations were useful as comparisons to properly operating transmitters.

- The WO-18 RC transmitter has a carrier suppression of about 7.5 dB at power level of 1.4W (figure 8), and the phase jitter is about 15 degrees and quite symmetrical. Figure 6 is a spectrum display of this transmitter prior to launch. The phase jitter is equal to the best microsat transmitter at this time. There is probably be little to be gained from adjusting the modulator except for observing the effect of those adjustments on a properly operating transmitter.

- Figure 9 shows the LO-19 RC transmitter carrier suppression prior to launch. During the tests we measured it's carrier suppression at 12dB as can be seen in figure 10.

- No observations were made of the LO-19 PSK transmitter, but a carrier suppression observation may be made at some future date.

TELEMETRY CHANNELS

The following conclusions were reached after a couple of hours of examination of WOD, single pass telemetry, Jim and Bruce's earlier test results, and records made during design and construction.

- Conflicting notes exist in the available documentation as to which of the thermistors is connected to each AART (Asynchronous Addressable Receiver Transmitter) multiplexer input. Only sketchy information is available that directly relates AART addresses to thermistor locations. However in every case CH 36 is related to the +Y (originally -Y in some data) thermistor. After examination of telemetry data we concluded channels 34 through 37 were actually connected as shown in the chart below. It can be clearly seen in figures 12 and 13 that channel 36 is actually the +Y panel temperature. This cleared up a long term question about the behavior of that channel. Now that we understood this channel to be the temperature of a side panel the reasons for the 10 to 15 degree swings during the illuminated portion of the orbit were clear. The side panels warm and cool as the sun angle on them changes. CH 35 has been used to obtain the +Y panel temperature for the array-side power management software. We have been using a channel (CH 35) that at times is up to 15 degrees different from the actual side panel temperature.

- It is likely that these channel assignments are the same in all four spacecraft because the thermistors were physically connected to the same points on the AART boards in each. However this could not be verified from the available data. Further testing is planned to substantiate this.

- We determined CH 14 "Rx Temp" and CH 15 "+X (RX) Temp" channels are probably reversed (figure 14).

- The makeup of the panel sandwich for the side and top surfaces was verified. The team has ask Dick Jansson to check his thermal conductivity study of these panels so we may be able to more closely adjust the +Y and +Z temperature measurements and calculations.

- Some quick calculations indicate for every 5 degrees of improved accuracy in measured panel temperature we will gain .15W at the output of the Battery Charge Regulator (BCR). That is .45W for the 15 degree improved accuracy that will occur during portions of each orbit. An additional 1 Watt may be produced for short periods once all software tuning is completed. It remains to be seen how much this will impact power generation over an entire orbit. However, even a small improvement will have a positive impact in the microsat power system because it has an overall orbit average power production of only 6 Watts.

Temperature telemetry channel corrections for AO-16:

CH NUMBER	OLD DESIGNATION	CORRECT DESIGNATION
CH 14	RX Temp	+X (Rx) Temp
CH 15	+X (Rx) Temp	RX Temp
CH 34	PSK TX HPA Temp	RC PSK BP Temp
CH 35	+Y Array Temp	RC PSK HPA Temp
CH 36	RC PSK HPA Temp	+Y Array Temp
CH 37	RC PSK BP Temp	PSK TX HPA Temp

SUMMARY

Several improvements to microsat operations and future microsat designs will result from these tests and investigations. We have already switched to the RC transmitter on AO-16 which will provide a downlink signal that most stations will find easier to reliably decode. Expected or proper operation of several other microsat transmitters has been verified. Power control programming will be modified to correctly sample and calculate the temperature of the panels providing the majority of current to the battery charge regulator. This will allow the transmitter to be run at higher power which will improve downlink signal strength. Additional operating time for the AO-16 and DO-17 S-Band transmitters may also be possible. A great deal of information about the quality of the system design(s) was gathered and documented for future satellite builders.

As of this writing several tests and measurements remain to be done. Bob Diersing is gathering data in order to determine downlink bit error rates while the RC transmitter is in use. We have not yet loaded whole orbit data gathering software so we can measure panel power output deterioration (however glimpses of portions of orbits confirm our expectation that little reduction has taken place since about the end of 1990). We would like to look at the spectrum of the LO-19 PSK transmitter and both of the transmitters aboard DO-17.

Thanks those who assisted during these tests, and especially to the microsat user community for their patience while AO-16 has been out of service. With luck the changes noted in this paper will be implemented shortly and the AO-16 file serve back on line with improved signal levels and quality. Improvements will be implemented in the other microsats as operations allow.

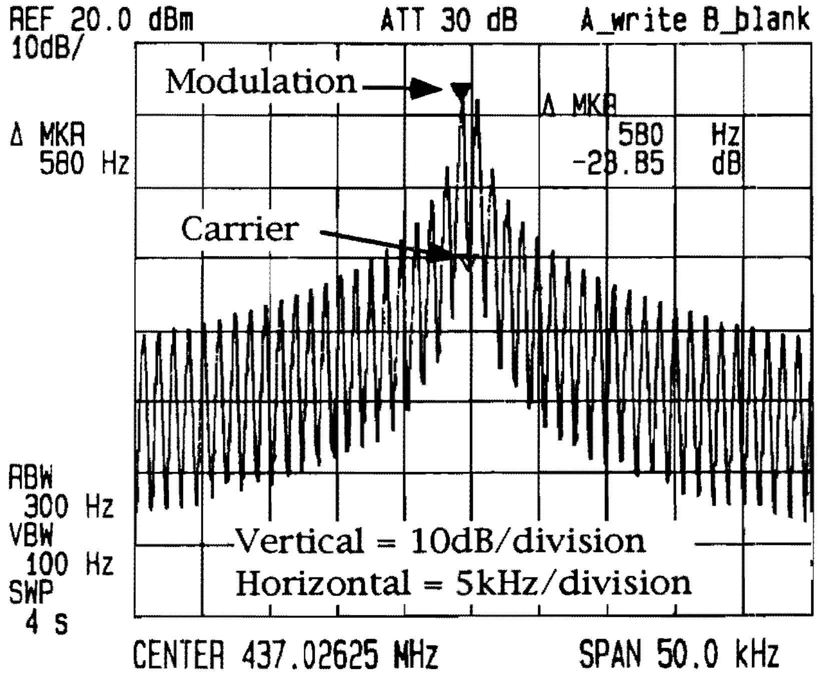

Figure 1: AO-16 PSK Transmitter spectrum before launch

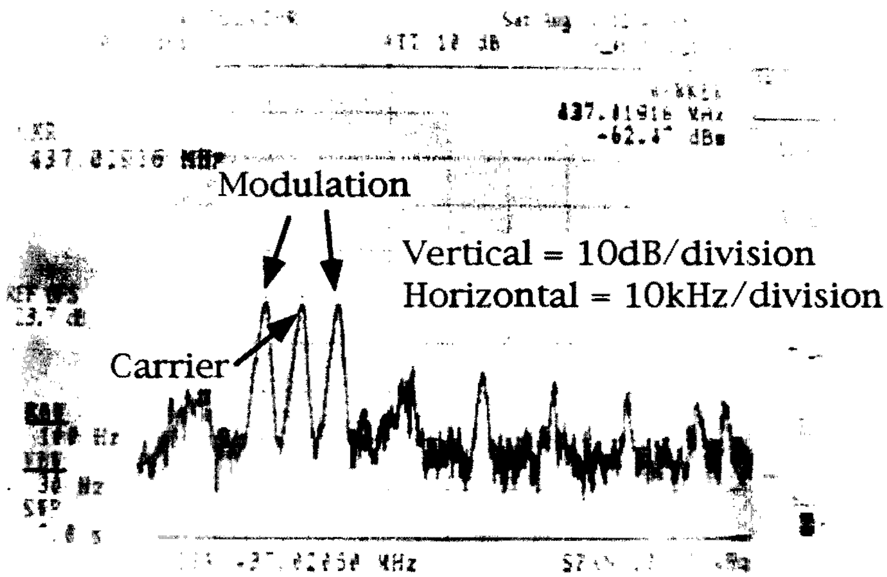

Figure 2: AO-16 PSK Transmitter spectrum on 8/8/92, cold

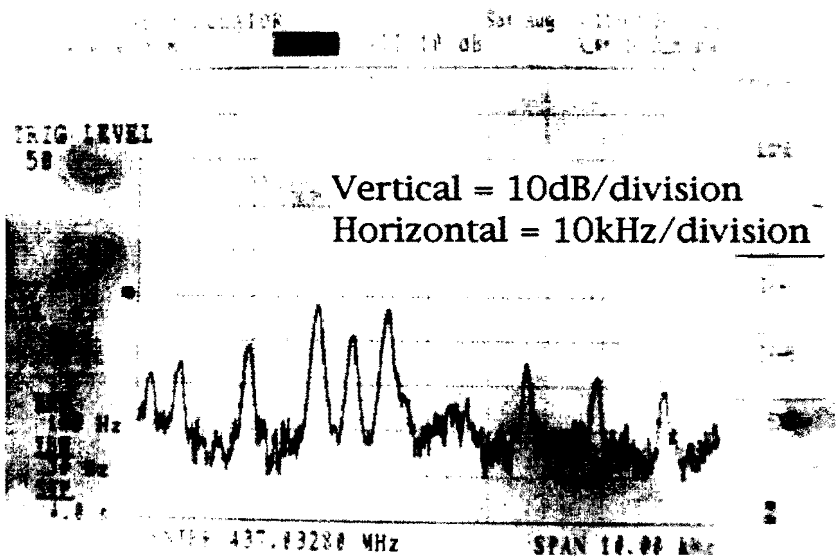

Figure 3: AO-16 PSK Transmitter spectrum on 8/8/92, warm

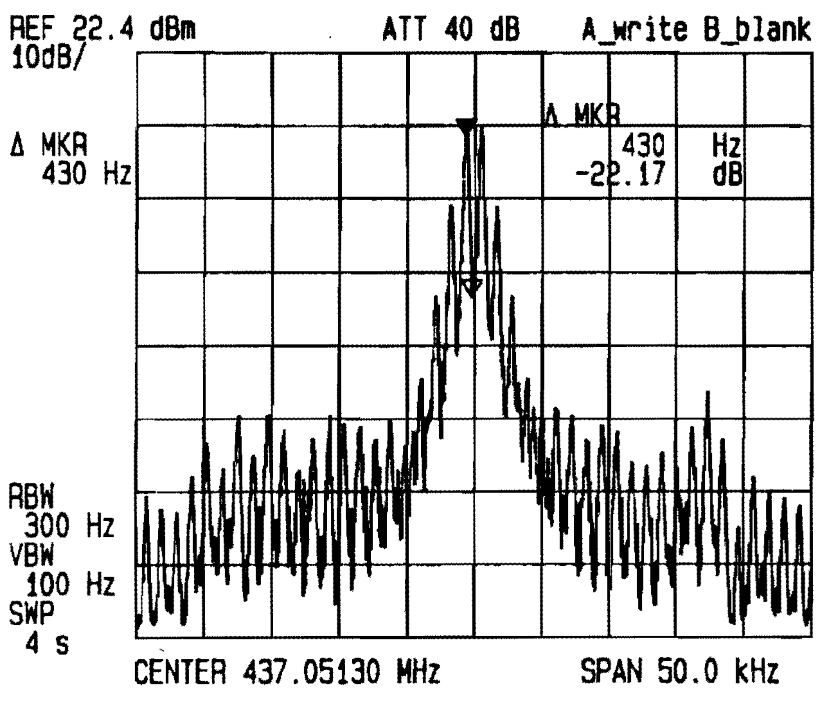

Figure 4: AO-16 RC Transmitter spectrum before launch

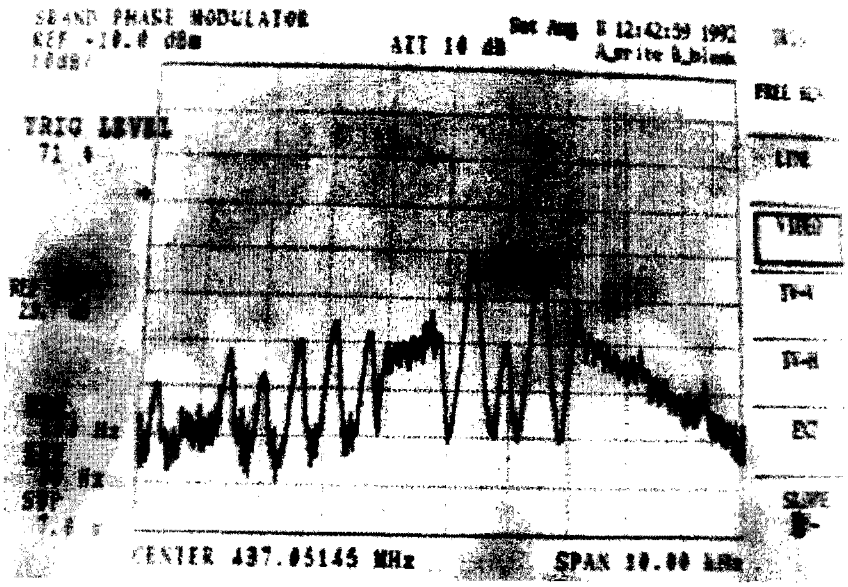

Figure 5: AO-16 RC Transmitter spectrum on 8/8/92

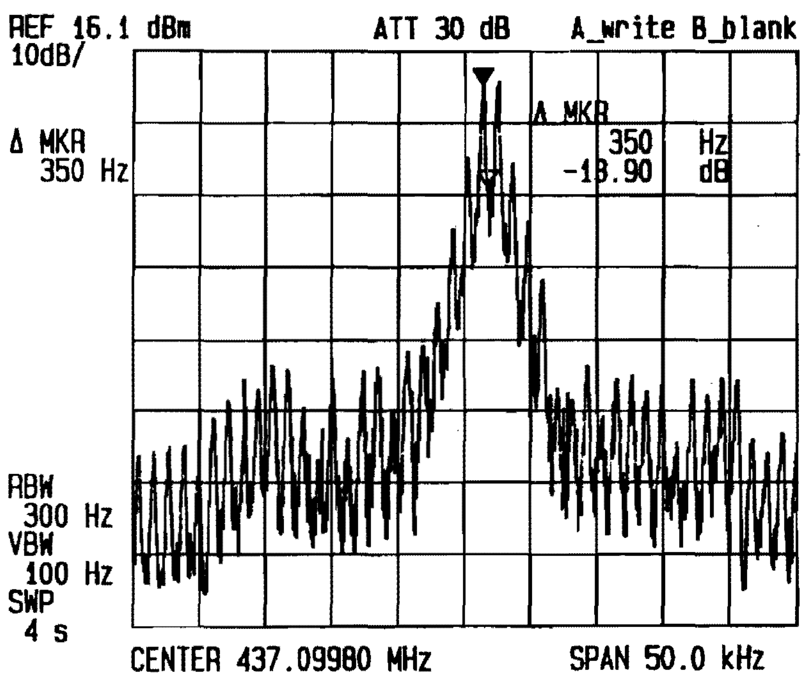

Figure 6: WO-18 RC Transmitter spectrum before launch

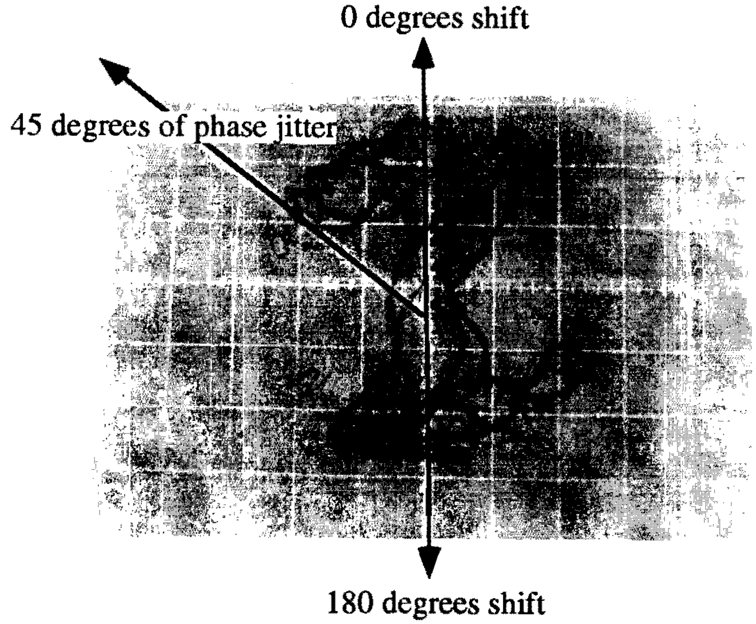

Figure 7: WO-18 PSK Transmitter phase jitter/noise

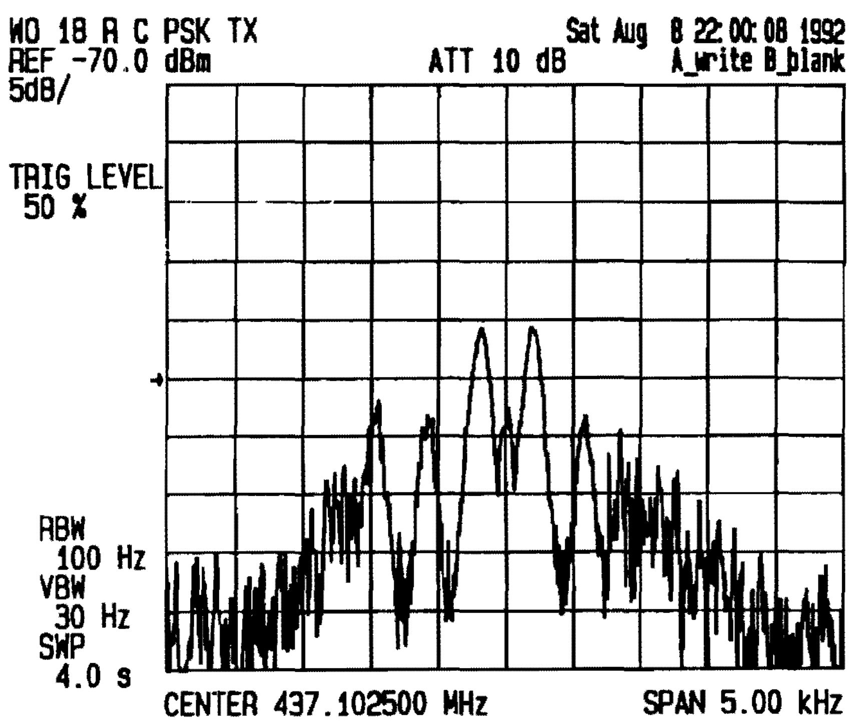

Figure 8: WO-18 RC Transmitter spectrum on 8/8/92

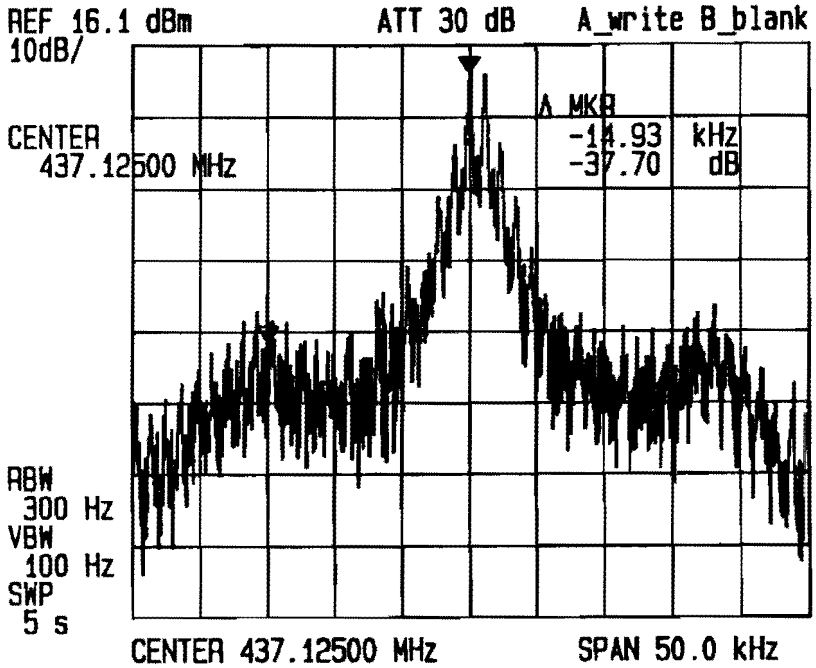

Figure 9: LO-19 RC Transmitter spectrum before launch

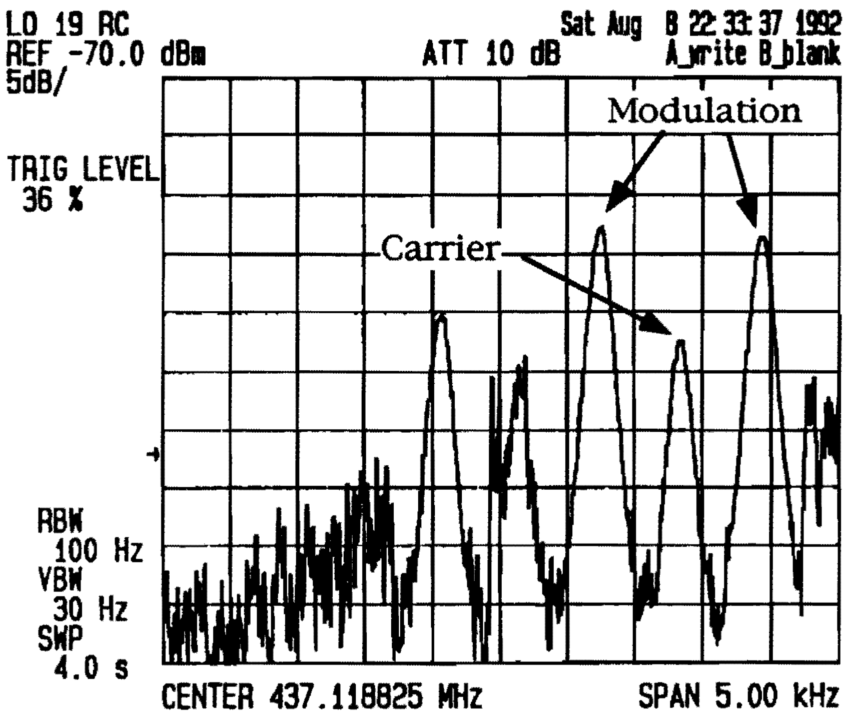

Figure 10: LO-19 RC Transmitter spectrum on 8/8/92

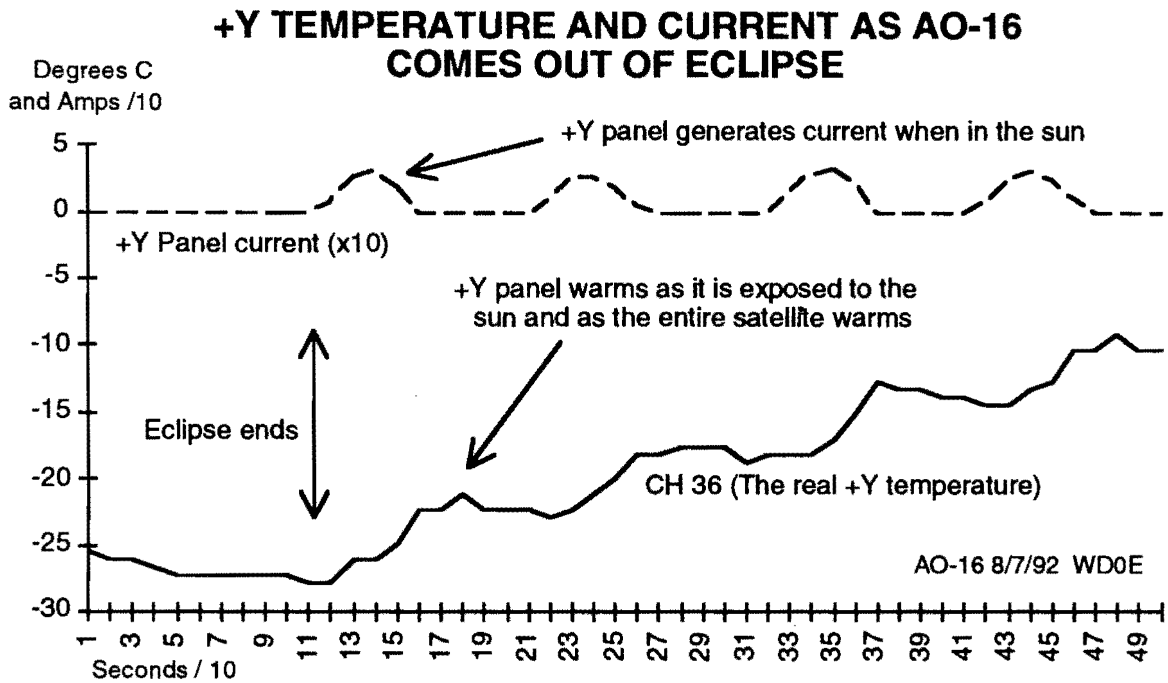

Figure 12: AO-16 CH 36 (+Y temp) and +Y current correlation

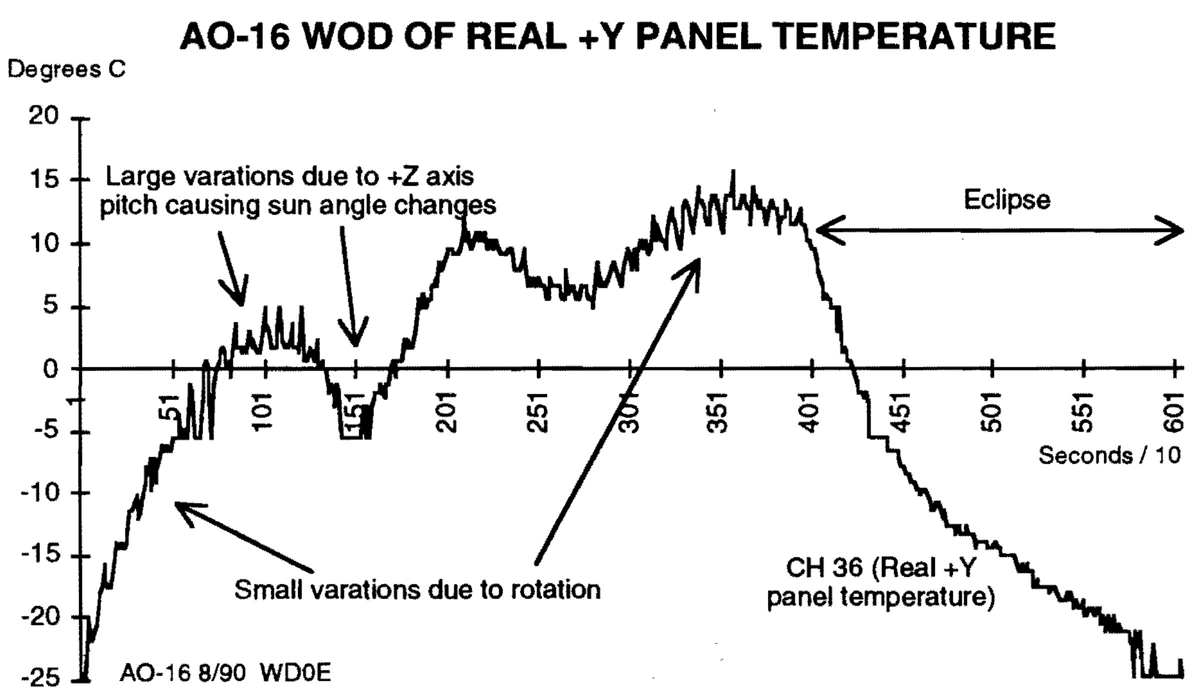

Figure 13: AO-16 CH 36 (+Y temp) whole orbit data

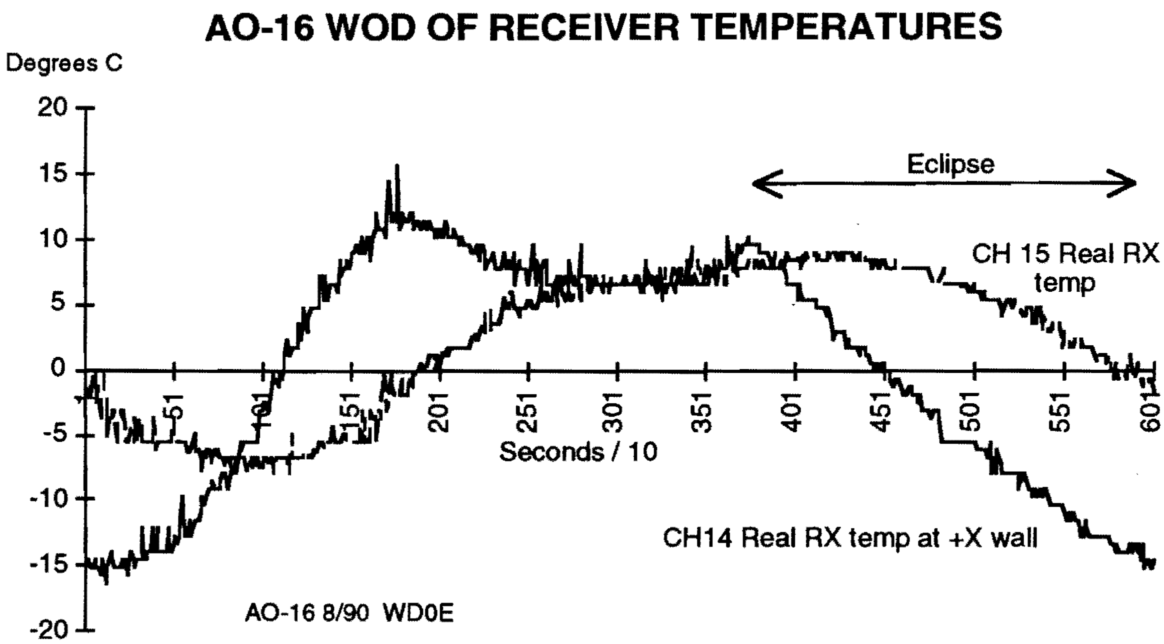

Figure 14: AO-16 Receiver temperatures

AN EXAMINATION OF PACSAT-1 DOWNLINK ERROR RATES AND FILE SERVER OPERATION

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ABSTRACT

This paper documents the current status of ongoing monitoring of PACSAT-1 downlink data and operations and focuses on three primary areas: (1) determination of an estimate of the downlink bit error probability that might be encountered by the typical PACSAT-1 user station; (2) determination of a downlink efficiency factor for file server operations; and (3) a characterization of the downlink traffic mixture. An estimate of the bit error probability is made based on block errors encountered during telemetry frame reception in the absence of any uplink traffic. The downlink efficiency factor, which is the ratio of bytes or frames transmitted only once to total bytes or frames transmitted for a particular user, is determined for two cases--a single station downloading fairly large files and for a large group of users engaged in all types of connected more activity.

INTRODUCTION

In a few months PACSAT-1 will complete three years of operation. In late 1990, the first broadcast and file server operations commenced. Improvements to ground station software and software aboard the satellite have continued throughout 1991 and 1992. As this paper is being written (August, 1992), programming to support the file and directory broadcasting features already operating on UO-22 is being prepared for PACSAT-1. This author has followed the evolution of the PACSAT-1 system since its launch and has been engaged in various analyses of telemetry, file broadcast, and file server traffic appearing on the downlink.

There are four major parts to the following presentation. The first is a description of the equipment and software used to collect and analyze the data reported later. Next, estimates of the downlink bit error rate are given for several different time periods and operating conditions. Third, measurements of the downlink frame retransmission rate for file server traffic are developed. Finally, a long-term characterization of PACSAT-1 traffic is given.

HARDWARE AND SOFTWARE CONFIGURATION

Figure 1 shows the equipment configuration used during the tests reported here. Two computer/radio systems were employed--one for two-way communication or monitoring (System No. 1) and one for monitoring only (System No. 2). Each radio system has its own antenna system and a single computer controls the antenna position for both systems. Equipment specifications shown in Figure 1 are those published by the manufacturers.

During the tests the equipment was operated in one of two modes. For some of the downlink error rate determination tests, both computer/radio systems were operated in monitor mode. This allowed two independently captured data samples to be obtained during the same satellite visibility period. During some of the downlink bit error rate tests, the audio from the System No. 1 receiver was connected to both modems. The same procedure was used during the file downloading tests. This allowed one computer system to be engaged in the downloading process while the other system captured all the data on the downlink.

DETERMINATION OF DOWNLINK BLOCK AND BIT ERROR RATES

Since the performance of any digital communications system is affected by the block error rate, and since an LEO satellite system is subject to additional factors which can introduce errors, several error rate observations have been carried out.

There are times when the satellite telemetry system is transmitting a fixed and recurring sequence of frames with no other traffic on the downlink. This situation usually occurs between the time the housekeeping and telemetry system software is loaded and the loading of the file server system. Since the number and type of frames that should appear can be determined, it is only necessary to compare what should have been received with what was actually received and then compute a block or bit error probability. The result should be a fairly accurate estimate of what can be expected given the downlink frequency, Doppler shift encountered, and the requirement to track the satellite.

During the past year or so, downlink data has been collected under the conditions described above on three occasions and estimates have been made of the downlink bit error rates. The first data set was collected during the time period from July 21 through July 26, 1991 while the standard PSK transmitter was in use. The second data set was collected between July 28 and August 7, 1992. This period coincides with the reloading of the housekeeping and telemetry system after the onboard computer crash of July 26, 1992 and the switch to the raised cosine PSK transmitter. All observations in this sample were recorded while the standard PSK transmitter was in use. The third sample was

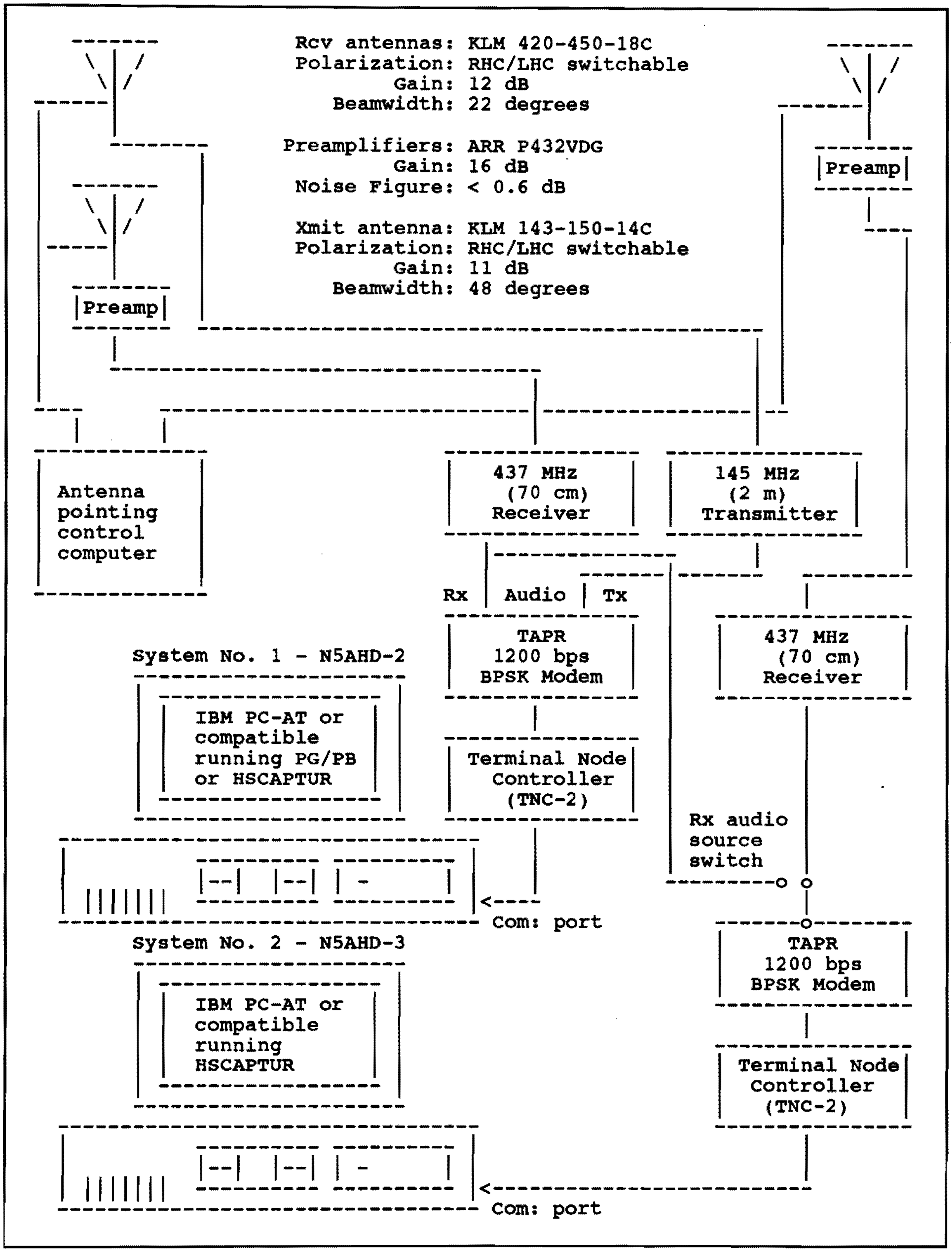

Figure 1. Equipment configuration for PACSAT-1 downlink signal strength and error measurements.

taken beginning August 10, 1992. All observations in this sample are from the raised cosine PSK transmitter.

During all three collection periods, data from many more orbits were captured than appears in the summary tables. This is because only those visibility periods free of uplink traffic were used in the final analyses. There are times in the software reloading process where the digipeater service is available to ground station users. If the digipeater is used, the telemetry rate is reduced from 10-second intervals to 60-second intervals. Rather than trying to compute what the rate should have been in any given interval, visibility periods with any user activity at all were discarded. Data from passes with less than a 5 degree elevation angle and those that caused the azimuth rotator to pass through 180 degrees were also discarded.

The same general procedure has been employed in the analysis of data from each sample period. First, the block error probability for each telemetry frame type is computed for each orbit in the sample. Next, the average block error probability for each frame type for the entire sample is computed. From the average block error probability a bit error probability is computed by solving Eq. 1 for Pe_{block}, giving Eq. 2, where n is the block (frame) size in bits (control bits plus information bits). The result is a bit error probability that would have produced the observed average block error probability for the block length of interest. Finally, an overall average bit error probability is computed by weighting the bit error probability for each frame type by the frame length. It should be noted that Eq. 1 and 2 assume that bit errors are independent. For a discussion of why the independence assumption does not always apply to real world systems, see [2].

$$Pe_{block} = 1 - (1 - Pe_{bit})^n \quad (1)$$

$$Pe_{bit} = 1 - (1 - Pe_{block})^{\frac{1}{n}} \quad (2)$$

Table 1 shows the block error probabilities by frame type for each visibility period contained in the July 1991 data sample. Applying the procedure described above results in the bit error probabilities by frame type and the weighted average bit error probability given in Table 2. Similar data and computations are given in Tables 3 and 4 for the July 1992 data from the standard PSK transmitter and in Tables 5 and 6 for the July/August 1992 data from the raised cosine PSK transmitter.

In Tables 1, 3, and 5, the -1 and -2 suffix on the orbit numbers refers to the receiving system used to capture the data

(See Figure 1). For the data in Table 1, the two receiving systems were operating completely independently. For the data in Tables 3 and 5, the audio from receiver no. 1 was fed to both modems. Thus, for these two samples, differences in block error probabilities are caused by differences in the demodulation capabilities of the two modems.

There are some interesting observations that can be made in Tables 1, 3, and 5. Notice in Tables 1 and 3 that there are very few block error probabilities above 0.1, while in Table 5 there are quite a few which are near or above 0.1. Also, in Table 5, there are many more cases where both modems correctly demodulated the same number of a given frame type. This can be seen by comparing the block error probabilities for the -1 and -2 suffix entries for the same orbit number. It is especially interesting with respect to Table 3 because the observations in both Table 3 and 5 were made with the same receiver audio connected to both modems. Furthermore, there is less than one week difference in the data collection time between the two samples. The only difference is that the satellite was using the standard PSK transmitter when the data in Table 3 was collected while the raised cosine transmitter was in use when the data in Table 5 was collected.

Table 7 shows the block and bit error probabilities that result from combining all data into a single sample. Since the raised cosine transmitter is now in use permanently, the data in Table 5 will be extended as much as possible before the return to file server operations.

DETERMINATION OF THE FRAME RETRANSMISSION RATE

Since this author is one of several stations downloading activity log files for the AMSAT-NA data archive, a procedure was developed for determining the count of retransmitted information frames on a per-user basis for file server transactions. It is important to note that these retransmissions can occur for one of two reasons: (1) the ground station received the frame and the acknowledgement sent to the satellite was lost; or (2) the ground station didn't receive the frame at all and therefore never acknowledged it. Although there has been no attempt made to identify the cause of the retransmissions, most of the retransmissions counted are probably the result of lost acknowledgements. It is also important to remember that the receiving system recording the downlink traffic could fail to receive a frame causing the count of retransmitted frames to be understated.

A summary of retransmissions observed during file downloading operations at the author's station is shown in Table 8. Since PACSAT-1 has only one outstanding frame per connected mode user (Maxframe=1), a retransmission can be identified by

Table 1
Block Error Probabilities by Frame Type
Sample No. 1 --- July 21 to July 26, 1991
Standard PSK Transmitter

Orbit Number	STATUS Blk Err	LSTAT Blk Err	TIME Blk Err	TLM Blk Err	Max Elev	Pass Duration
7794-2	0.0392	0.0588	0.0196	0.0980	9	08:34
7799-1	0.0267	0.0263	0.0263	0.0400	53	12:47
7799-2	0.0233	0.0230	0.0230	0.0233		
7807-1	0.0115	0.0115	0.0345	0.0920	36	14:38
7807-2	0.0115	0.0115	0.0341	0.0833		
7808-1	0.0127	0.0595	0.0380	0.0253	20	13:18
7808-2	0.0127	0.0000	0.0256	0.0385		
7836-1	0.0353	0.0471	0.0471	0.0357	79	14:14
7836-2	0.0471	0.0588	0.0471	0.0476		
7850-1	0.0122	0.0000	0.0247	0.0617	51	13:43
7850-2	0.0122	0.0000	0.0244	0.0617		
7865-1	0.0448	0.0294	0.0000	0.0303	27	11:19
7865-2	0.0256	0.0127	0.0000	0.0385		
Total						02:48:32
Mean	0.0242	0.0260	0.0264	0.0520		
Std Dev	0.0130	0.0221	0.0140	0.0243		
Blk Size	344	424	664	1128		

Table 2
Bit Error Probabilities Corresponding the
Observed Block Error Probabilities
Sample No. 1 ---- July 21 to July 26, 1991

Frame Type	Block Error Prob Pe_{block}	Bit Error Prob Pe_{bit}	Length L_{frame}	Weighted $L_{frame} * Pe_{bit}$
STATUS	0.0242	0.71E-4	344	0.0245
LSTAT	0.0260	0.62E-4	424	0.0264
TIME	0.0264	0.40E-4	664	0.0268
TLM	0.0520	0.47E-4	1128	0.0534
Total			2560	0.1311
Average		0.51E-4		

Table 3
Block Error Probabilities by Frame Type
Sample No. 2 --- July 28 to August 7, 1992
Standard PSK Transmitter

Orbit Number	STATUS Blk Err	LSTAT Blk Err	TIME Blk Err	TLM Blk Err	Max Elev	Time Visible
13137-1	0.0380	0.0127	0.0385	0.0253	33	13:14
13137-2	0.0370	0.0123	0.0253	0.0247		
13143-1	0.0353	0.0345	0.0345	0.0353	45	14:33
13143-2	0.0244	0.0357	0.0581	0.0595		
13150-1	0.0000	0.0484	0.0323	0.0328	8	10:39
13150-2	0.0156	0.0645	0.0645	0.0678		
13193-2	0.0833	0.0882	0.0746	0.0758	13	12:01
13194-2	0.0114	0.0115	0.0682	0.0345	49	14:43
13199-1	0.0000	0.0159	0.0769	0.1129	9	10:50
13199-2	0.0159	0.0476	0.0923	0.0968		
13265-1	0.0000	0.0000	0.0222	0.0217	4	13:11
13265-2	0.0127	0.0253	0.0385	0.0759		
Totals						02:31:38
Mean	0.0228	0.0330	0.0522	0.0553		
Std Dev	0.0226	0.0246	0.0221	0.0294		
Blk Size	344	424	664	1128		

Table 4
Bit Error Probabilities Corresponding to
Observed Block Error Probabilities
Sample No. 2 --- July 28 to August 7, 1992

Frame Type	Block Error Prob Pe_{block}	Bit Error Prob Pe_{bit}	Length L_{frame}	Weighted $L_{frame} * Pe_{bit}$
STATUS	0.0228	0.67E-4	344	0.0231
LSTAT	0.0330	0.79E-4	424	0.0336
TIME	0.0522	0.81E-4	664	0.0536
TLM	0.0553	0.50E-4	1128	0.0568
Total			2560	0.1671
Average		0.65E-4		

Table 5
Block Error Probabilities by Frame Type
Sample No. 3 --- August 10 to August 18, 1992
Raised Cosine PSK Transmitter

Orbit Number	STATUS Blk Err	LSTAT Blk Err	TIME Blk Err	TLM Blk Err	Max Elev	Time Visible
13322-1	0.0238	0.0000	0.0119	0.0361	36	14:04
13322-2	0.0238	0.0000	0.0119	0.0361		
13323-1	0.0779	0.1013	0.1154	0.0789	19	13:09
13323-2	0.0779	0.1013	0.1154	0.0921		
13328-1	0.0000	0.0732	0.0732	0.0617	26	13:44
13328-2	0.0000	0.0732	0.0732	0.0617		
13336-1	0.0259	0.0132	0.0779	0.0789	17	12:58
13336-2	0.0259	0.0132	0.0779	0.0789		
13337-1	0.0588	0.0824	0.0930	0.1928	38	14:20
13337-2	0.0588	0.0824	0.0930	0.1807		
13351-1	0.0219	0.0112	0.0777	0.1556	78	15:10
13351-2	0.0219	0.0112	0.0777	0.1556		
13379-1	0.0000	0.0122	0.0617	0.0741	24	13:42
13379-2	0.0000	0.0122	0.0493	0.0617		
Totals						03:14:14
Mean	0.0298	0.0419	0.0721	0.0960		
Std Dev	0.0268	0.0388	0.0300	0.0505		
Bl Size	344	424	664	1128		

Table 6
Bit Error Probabilities Corresponding to
Observed Block Error Probabilities
Sample no. 3 --- August 10 to August 18, 1992

Frame Type	Block Error Prob Pe_{block}	Bit Error Prob Pe_{bit}	Length L_{frame}	Weighted $L_{frame} * Pe_{bit}$
STATUS	0.0298	0.88E-4	344	0.0302
LSTAT	0.0419	1.01E-4	424	0.0428
TIME	0.0721	1.13E-4	664	0.0748
TLM	0.0960	0.90E-4	1128	0.1010
Total			2560	0.2489
Average		0.97E-4		

Table 7
Bit Error Probabilities Corresponding to Observed Block Error Probabilities All Samples Combined

Frame Type	Block Error Prob Pe_{block}	Bit Error Prob Pe_{bit}	Length L_{frame}	Weighted $L_{frame} * Pe_{bit}$
STATUS	0.0241	0.71E-4	344	0.0244
LSTAT	0.0363	0.87E-4	424	0.0369
TIME	0.0496	0.77E-4	664	0.0508
TLM	0.0713	0.66E-4	1128	0.0740
Total			2560	0.1861
Average		0.73E-4		

Table 8
Frames and Bytes Retried While Downloading Activity Log Files

	Orbit Number	Total Bytes	Total Frames	Retried Bytes	Retried Frames	Eff Fact Bytes	Eff Fact Frames
	10763	28812	109	8392	32	0.71	0.71
	10764	21019	96	7301	28	0.65	0.71
	10770	23667	92	1955	7	0.92	0.92
	10771	37223	144	2165	14	0.94	0.90
	10777	23136	96	3937	16	0.83	0.83
	10778	5773	29	337	3	0.94	0.90
	10779	18741	94	2154	11	0.89	0.88
	10785	8196	44	280	1	0.97	0.98
	10792	21660	90	6138	22	0.72	0.76
	10793	14909	60	2501	9	0.83	0.85
	10799	15768	77	1844	12	0.88	0.84
	10807	27355	111	5010	18	0.82	0.84
	10813	28848	116	5060	20	0.82	0.83
	10828	24847	100	2788	10	0.89	0.90
	10856	18177	102	5141	25	0.72	0.75
		Bytes	Frames			Bytes	Frames
Total		318131	1360		Mean	0.83	0.84
Retried		55003	228		Std Dev	0.09	0.08
Eff		0.8271	0.8324				

comparing the sequence number in consecutive information frames. If the same sequence number appears twice (or more) in succession, the second through n frames are retransmissions. Table 8 gives an "efficiency factor" computed on the basis of both frames and bytes retried. There is very little difference in the two figures because the bulk of the retried frames are full-length information frames. No attempts were made to artificially optimize the downloading tests, for example, by choosing only high elevation passes or times when user activity was light. Consequently, the data reported should represent what a user could expect over a period of time when using properly operating ground station equipment.

In contrast to the tabulation of retransmissions for a single station described above, a much larger data set was also analyzed for retransmissions. This larger data set spans the time period from April 1 through July 26, 1992 and contains data collected from approximately 95 passes. From the 95 passes, 47 with a downlink utilization greater than 60 percent were chosen for further analysis. For these 47 passes, a count of retried frames and bytes was extracted for each connected-mode user. For this tabulation, all activity for a given station during the same pass was counted as a single transaction. The data from the large sample analysis is summarized in Table 9.

The transaction records contained in the large sample summarized in Table 9 were examined to find the stations with the largest byte counts and fewest number of retries. These records are presented in Table 10 to show the operating conditions that are possible with the PACSAT-1 file server and a properly operating station and moderate loading conditions. The data presented in Table 10 results from 10 different stations. The total byte and frame counts include the retransmitted bytes and frames. The downlink utilization and total user columns are included to give some idea of the level of activity at the time the transaction was completed.

DOWNLINK TRAFFIC CHARACTERISTICS

There are two methods which may be used to collect satellite usage statistics. First, a ground station can monitor the downlink while the satellite is visible and record all traffic for later analysis. Second, an analysis of the activity log files stored on the spacecraft can be done. The activity log files (AL files) can be downloaded just as any other file kept by the file server. Monitoring the downlink provides a view of the traffic from a particular location. Analysis of the AL files provides an observation of the traffic from the viewpoint of the satellite. The former method was employed during collection of data reported in this section.

The data shown in Table 11 was collected during a nearly year-long time period and shows little variation in the mix of

Table 9
Summary of Frame Retransmission Analysis for Large Sample

Number of stations:	70		
Number of transactions:	262		
Total bytes:	1,476,340	% retransmitted bytes:	33.8
Total frames:	12,320	% retransmitted frames:	28.9
Retransmitted bytes:	499,110	Efficiency factor (bytes):	0.662
Retransmitted frames:	3,553	Efficiency factor (frames):	0.712

Table 10
File Server Transactions With More Than 10,000 Bytes of Downlink Data and Retransmission Rate Below the Mean

Orbit Number	D/L Util	Total Users	Total Bytes	Total Frames	Retried Bytes	Retried Frames	% Retry Bytes	% Retry Frames
11664	64	3	11903	61	19	1	0.2	1.6
11665	67	7	10005	62	554	2	5.5	3.2
11978	69	12	13647	64	831	3	6.1	4.7
12199	65	3	17125	68	1674	6	9.8	8.8
12808	65	6	20627	88	2238	8	10.8	9.1
12865	61	6	12206	51	1393	5	11.4	9.8
11814	89	5	11784	61	902	6	7.7	9.8
12728	65	2	13474	63	1950	7	14.5	11.1
12185	64	7	24433	101	3081	12	12.6	11.9
12193	87	8	21349	133	3699	17	17.3	12.8
12292	95	5	10432	78	1530	11	14.7	14.1
12042	76	9	14310	82	2019	16	14.1	19.5
12193	87	8	16174	71	3137	14	19.4	19.7
12192	79	9	15339	81	4623	18	30.1	22.2
12865	61	6	19374	76	4736	17	24.4	22.4
12328	89	5	14436	66	2431	15	16.8	22.7
13022	79	2	22922	85	5564	20	24.3	23.5
12342	79	4	13736	63	3443	15	25.1	23.8
12793	75	5	25637	101	6960	25	27.1	24.8
13028	65	4	11000	60	3403	15	30.9	25.0
11664	64	3	27002	107	7257	27	26.9	25.2
12542	72	5	17551	63	4449	16	25.3	25.4
12850	81	2	11619	86	4075	22	35.1	25.6
11714	72	5	11805	66	3970	18	33.6	27.3
12850	81	2	21387	95	6219	26	29.1	27.4

Table 11
Summary of Downlink Traffic Samples

	Sample No. 1 03/17/91-05/29/91	Sample No. 2 06/16/91-08/27/91	Sample No. 3 09/02/91-11/28/91
Total Bytes	3,168,924	2,107,941	5,878,189
File Server	1,353,752-42.7%	897,444-42.6%	2,376,650-40.4%
Broadcasting	1,630,643-51.4%	1,089,510-51.7%	3,123,095-53.1%
Telemetry	184,259- 5.8%	120,987- 5.7%	378,444- 6.5%

Table 12
Downlink Traffic Sample No. 3 by
Time of Day and Day of Week

	Weekdays Daytime	Weekdays Nighttime
Total Bytes	513,660	1,576,803
File Server	214,418-41.7%	680,316-43.1%
Broadcasting	268,366-52.2%	786,245-49.9%
Telemetry	30,876- 6.1%	110,242- 7.0%
Downlink Time	01:05:40	03:27:24

	Weekends Daytime	Weekends Nighttime
Total Bytes	2,177,564	1,610,162
File Server	834,598-38.3%	647.318-40.2%
Broadcasting	1,206,108-55.4%	862,376-53.6%
Telemetry	136,858- 6.3%	100,468- 6.2%
Downlink Time	05:00:20	03:50:49

file server, file broadcast, and telemetry traffic observed on the downlink. Analyses of data comprising Sample Nos. 1 and 2 have been used during the construction of a downlink traffic simulator [1]. During the previous analyses it was thought that further breakdown of a sample into weekday versus weekend and daytime versus nighttime traffic might yield additional useful parameters for the simulator. Such a breakdown for Sample No. 3 is shown in Table 12.

For the data presented in Table 12, daytime refers to the local (CST/CDT) daytime visibility periods which occur between roughly 16:00 and 19:00 UTC. Nighttime refers to visibility periods which occur between 03:00 and 06:00 UTC. The later is due to the fact that local CST/CDT evening is the next day UTC. There are considerably fewer observations in the daytime weekday category because, for the most part, work schedules did not allow monitoring during that time period. Even so, there is still very little variation in the traffic mix for the three traffic types. It should be remembered that downlink monitoring will not record file uploading traffic from ground stations since uplink traffic is not repeated on the downlink.

SUMMARY

Several aspects of PACSAT-1 operation have been examined in this paper. An estimate of the downlink bit error probability has been made based on block errors encountered during telemetry frame reception in the absence of any uplink traffic. An average bit error probability of 7.3E-5 was computed by combining observations from three downlink data samples made under different conditions. The bit error probabilities for the three individual samples ranged from 5.1E-5 to 9.4E-5. Data collection and analysis to further refine these values is still in progress.

Average downlink efficiency computations were made for the case of a single station downloading files and for a large sample of connected-mode users. The downlink efficiency is the ratio of correctly-received bytes or frames to total bytes or frames transmitted for a given user. For the single-user case, the author's station downloaded a total of 318,131 bytes in 15 sessions. Of the total bytes downloaded, 55,003 were retransmissions resulting in an efficiency factor of 0.83. In the large sample, 1,476,340 bytes destined for 70 users in 262 sessions was monitored. Of this total 499,110 were retransmissions resulting in an efficiency factor of 0.67.

Additional data has been presented which shows that the mixture of traffic types heard on the downlink did not change appreciably during much of 1991. Furthermore, the mixture did not change much with time of day or day of week. As this paper is being prepared, software supporting the enhanced directory and file broadcasting features already available on UO-22 is being readied for installation. Once the new software has been operating for a while, a new study will be done to see how the traffic mix has changed.

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Communication Systems of SEDSAT1

by

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ABSTRACT

SEDSAT1 will be an OSCAR satellite offering both the leading edge in communications services to avid satellite users while still allowing new amateurs to experience satellite communications for the first time. SEDSAT1 will offer improvements such as higher baud rates, better data compression, increased RF power, and several modes of communications. Also, an experiment package on board will allow transfer of real-time images and telemetry from numerous systems. The communication capabilities of SEDSAT1 is one of the most interesting aspect of the satellite, and also the most challenging.

The primary digital modes of communication for SEDSAT1 will be mode J. The heart of the system will be a Motorola chipset that allows digital communications at speeds of 9.6 kbits or 19.2 kbits. The modulaton techinique will be FSK, UoSat compatible. The choice of mode J is now considered typical, but the addition of mode A is one that has not been seen in quite awhile. The mode A transponder will broaden satellite coverage to more amateurs who have been interested in amateur satellites, but do not have the deep pockets to maintain a satellite station. The mode A transponder will be a 60 Khz wide linear ssb transponder. SEDSAT1 is committed to offer the beginning ham a chance to get started in amateur satellites. In fact, one of the experiments on-board will be an FM Communication Experiment (FCE). On an experimental basis, the FCE will allow a beginner with limited equipment to access the satellite via mode A.

For the experienced satellite user, SEDSAT1 has a wide variety of technological advances. Faster data transfer rates allow SEDSAT1 to be the perfect transitional satellite to phase 3-D. When first launched, SEDSAT1 will allow speeds of 9600 baud. When demand arises, the satellite can provide increased baud rates of 19,200 baud. Since most personal computers can handle transfer rates of 19.2k, the upgrade needed would only be to the modem, therefore not requiring major expense. Also, with the FCC's approval, a testing of the Motorola's chip set would allow data rates of up to 56 or 64 kilobaud. This dynamic data rate will present an ideal opportunity to gather information for phase 3-D operations.

Power needs are controlled by the on-board Command Data System. Power output will be regulated by the on-board computer for the most efficient transfer of RF energy. The RF output is expected to vary between 0.5 to 25W. The power is dependent on the number of on-going experiments as well as stored and solar power available. This greater output power is primarily due to the new technologies in NiMH batteries and improved efficiencies of solar cells combined with an intelligent power management system.

THE *SUSIE* PROJECT

Satellites for the Understanding of Space Instrumentation and Experimentation, or, Bringing Space into the Classroom

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ABSTRACT

Capturing, decoding and displaying telemetry from orbiting spacecraft in real time, in the classroom, is an excellent way of introducing space science to students. At this time there are a number of orbiting satellites carrying amateur radio (OSCAR) actually sending back telemetry. Further satellites are planned in the near future with real opportunities for true pioneering science. Signals from these spacecraft are downlinked on frequencies that can be received on regular vhf/uhf scanner radio receivers. Excluding the Personal Computer, a simple telemetry capturing ground station can be set up for less than $500.00 in equipment costs.

This paper provides an introduction as to how this can be done using readily available low cost equipment. General topics discussed cover telemetry, the spacecraft themselves. Ground station hardware topics include receiving antennas, radio receivers and modems. Software topics discussed include the software used to track the spacecraft and the software used to both decode and display the data in real time as well as that for post pass analysis.

INTRODUCTION

There is no substitute for the excitement of hands-on experience in awakening an interest in space. There are on-going programs in educational institutions[1,2] which bring signals from space into the classroom, providing students with first hand experience in receiving signals from outer space. This capability is not as difficult nor as expensive as one may think. Signals from Orbiting Satellites Carrying Amateur Radio (OSCAR) built by amateurs for educational and communications purposes are currently being received in hundreds of homes and classrooms around the world using simple low cost equipment.

The thrill of receiving a signal from space soon fades however if the data cannot be understood. Even after the data has been decoded, watching the temperatures on-board a spacecraft as it passes overhead is also of little interest, but, what can be made interesting is receiving and capturing the data over many days or even months and looking for trends and relationships. This paper concentrates on those spacecraft which downlink computer compatible telemetry. These spacecraft downlink signals in the amateur 145 MHz and 430 MHz bands modulated by means of Frequency Shift Keying (FSK), Frequency Modulation (FM) or Phase Shift Keying (PSK). Some of the characteristics of the downlinks of suitable OSCARs currently operational are shown in Table 1. UoSAT-OSCAR 2 (UO-2) and AMSAT-OSCAR 13 (AO-13) send back BAUDOT or ASCII data, SARA-OSCAR 23 (SO-23) sends back analog and digital telemetry while AMSAT-OSCAR 16 (AO-16), DOVE-OSCAR-17 (DO-17), WEBER-OSCAR 18 (WO-18), LUSAT-OSCAR 19 (LO-19) and Fuji-OSCAR 20 (FO-20) downlink packetized telemetry.

THE SPACECRAFT

Before discussing the equipment needed to receive signals from the spacecraft, a brief word about the spacecraft themselves is in order. Since these OSCARs rode into space as secondary payloads, the orbits that they are in are close to those of the primary payload and are not optimized for amateur radio communications. The exception is AO-13 which contained a motor which was used by radio amateurs to boost the spacecraft from the orbit the rocket placed it in into its operational orbit. The ones that are in low earth orbits can be received with simple equipment, but are in range for short periods of time, AO-13 in an elliptical orbit is in range for many hours each day, but needs more sophisticated receiving equipment. The orbital parameters of the OSCARs under discussion are shown in Table 2.

UO-2 which was launched March 1, 1984, is similar to and is a follow on to the now reentered UO-1. It was designed and built at the Department of Electronic and Electrical Engineering at the University of Surrey, England. UO-2 was built to develop scientific experimentation and space education. While much invaluable experience has been received by the UoSAT people, not much has been published in the general educational and radio amateur press about its on-board experiments and telemetry data formats. As such, apart from a small group of dedicated users, UO-2 seems to have been ignored by the majority of radio amateurs and educational institutions.

Table I Some of the Characteristics of OSCAR Downlinks.

SPACE-CRAFT	BEACON (MHz)	MODULATION	DATA TYPE	DATA RATE (Baud)	Note
UO-2	145.825	FM	ASCII	1200	1
UO-2	435.025	FM	ASCII	1200	1
AO-13	145.812	FSK	BAUDOT	50	1
AO-13	145.812	PSK	ASCII	400	1
AO-13	435.651	FSK	BAUDOT	50	1
AO-13	435.651	PSK	ASCII	400	1
AO-16	437.025	PSK	AX.25	1200	1,3
AO-16	437.050	PSK	AX.25	1200	1,3
DO-17	145.825	FM	AX.25	1200	1
WO-18	437.100	PSK	AX.25	1200	1,3
WO-18	437.075	PSK	AX.25	1200	1
LO-19	437.150	PSK	AX.25	1200	1,3
LO-19	437.125	PSK	AX.25	1200	1,3
FO-20	435.912	PSK	AX.25	1200	1,3
SO-23	145.955	FSK	ASCII	300	4

NOTES

1. Spacecraft also broadcasts bulletins and Various Telemetry formats.
2. Spacecraft downlink modulation is changed according to a pre-published schedule.
3. Alternate (back up) beacon frequency, may be used on Wednesdays.
4. Binary Digital Telemetry format with ASCII identification, two analog temperature and battery voltage FM subcarrier channels.

UO-2 carries four on-board experiments:- a Digital Communications Experiment, a Space Dust Experiment, a Charge Coupled Device (CCD) Video Camera Experiment and a Digitalker Experiment.

The Digital Communications Experiment demonstrated the concept of store-and-forward digital communications using spacecraft in low earth orbit. The Space Dust Experiment measures the impact of dust particles, and calculates the momentum of the particles. The CCD Video Camera Experiment takes pictures of the earth at a resolution of 384 x 256 pixels with 128 gray levels. This experiment does not seem to have returned any usable pictures. The Digitalker Experiment provides clear digitized voice using a fixed vocabulary and is switched on from time to time.

Table II Orbital Parameters of the OSCARs

SPACECRAFT	APOGEE (KM)	PERIGEE (KM)	INCLINATION (Degrees)	PERIOD (Minutes)
UO-2	699	670	98.00	98.30
AO-13	39000	770	26.10	686.65
AO-16	804	780	98.70	100.80
DO-17	804	780	98.70	100.80
WO-18	804	780	98.70	100.80
LO-19	804	780	98.70	100.80
FO-20	1745	912	99.05	112.00
SO-23	776	769	98.50	100.30

AO-13 which was launched June 15, 1988 was built as a joint venture between radio amateurs in the USA and in Germany organized as the Radio Amateur Satellite Corporation (AMSAT). AO-13 is a spin stabilized long life long range radio amateur communications satellite which provides daily intercontinental communications capability for hours at a time. It contains a number of analog and digital transponders with communications links on several frequencies. An on-board computer based on the RCA 1802 microprocessor controls the spacecraft and generates the downlink telemetry. Schedules are published in the amateur radio press which provide information as to which transponder is active at any time during the orbit. AO-13 also contains a motor which was used by radio amateurs to boost the spacecraft from the orbit the rocket placed it into its operational orbit.

AO-16 which was launched January 22, 1990 in a multiple satellite launch is designed to provide a platform for experiments with digital store-and-forward communications techniques as a follow-on to the Digital Communications Experiment of UO-2. It was built by AMSAT, occupies less than a cubic foot of space, masses 8.5 kg and contains a V40 microprocessor and 8 Megabytes of RAM. Essentially it is a loaded PC Clone in orbit. AO-16, DO-17, WO-18 and LO-19 are commonly known as Microsats and were constructed as a set by AMSAT during 1989. Each of the Microsats contains bar magnets which align them along the earth's magnetic field and is spun around that axis by photon pressure from the sun acting on the communication antennas which are painted white on one side and black on the other.

DO-17 which was launched January 22, 1990 is the second Microsat. It is sponsored by AMSAT in Brazil and is similar to AO-16 but its prime mission is to provide an easily received Digital Orbiting Voice Encoded beacon for educational and scientific use. Unfortunately a combination of two on-board hardware failures and lack of available manpower in AMSAT (a volunteer organization for all practical purposes) have kept DOVE's voice off the air. At this time DOVE only transmits packet telemetry.

WO-18 which was launched January 22, 1990 is the third Microsat. It is an engineering project of the Center for Aerospace Studies at Weber State University in Utah. It has the capability for digital communications but is not used as such. It contains an on-board video camera which has returned pictures of the earth using a non standard format picture transmission format. WO-18 also carries a number of experiments. The Spectrometer experiment is designed to observe the spectrum of sunlight reflected off the earth's atmosphere and surface. The Particle Impact Detector is a piezoelectrical crystal mounted on the side of the spacecraft which produces an output voltage each time a microparticle impact occurs. The Magnetometer Experiment contains two orthogonal flux gate magnetometers. As they were not calibrated they can only provide information about relative changes in the magnetic environment of the spacecraft. As in the case of UO-2, data about the experiments and their telemetry calibrations are lacking in the general amateur radio press.

LO-19 which was launched on January 22, 1990 is the fourth Microsat. It is sponsored by AMSAT in Argentina, and has a similar mission to that of AO-16.

FO-20 which was launched on February 7, 1990 is a communications satellite in low earth orbit providing simultaneous analog and digital communications capability. FO-20 was built in Japan for Japanese radio amateurs and is the second Japanese built OSCAR.

SO-23 which was launched on July 17, 1991 is a French Amateur Radio Astronomy satellite monitoring radio signals from Jupiter in the spectrum between 2 and 15 MHz. SO-23 downlinks the measurements on its telemetry beacon.

THE FUTURE

The Future is bright. At least eight additional spacecraft have recently been announced as being in various stages of construction in several countries[3]. A brief summary of the announced spacecraft is listed in Table 3. The most exciting spacecraft is the proposed radio amateur MARS mission. This mission can be achieved using technology already developed by radio amateurs. Other telemetry experiments are also planned for the Soviet MIR space station[4].

RECEIVING SIGNALS FROM SPACE

Consider the signals generated by the spacecraft and the equipment needed to receive their signals.

Receiving Signals from DOVE

The easiest spacecraft to receive usable signals from is DOVE (DO-17) which transmits on a frequency 145.825 MHz. This frequency is available on most hand held scanners, and signals are strong enough to be heard on nothing more than the simple antenna provided with that the scanning radio when it is purchased. However, the thrill of receiving satellite signals wears off very quickly without any means to know what those signals mean. A somewhat better system is needed for reliable regular reception of usable signals. A basic receiving system for DOVE is shown in Figure 1. DOVE's signals are strong enough that the ground station does not need a tracking antenna; an omnidirectional antenna is sufficient. The antenna can be a ground plane, a turnstile[5] or a J-pole design[6]. A preamplifier should be used to compensate for any losses in the cable between the antenna and the receiver, or any fades in the strength of the received signals. Any scanning radio which receives narrow band FM can be used as the receiver. This is the same type of modulation used on the public service channels. If the scanner can hear the police and other services and can tune to 145.825 MHz, then it is capable of receiving signals from DOVE. The digital signals from DOVE are encoded as audio tones and need a modem to convert them to the RS-232 digital signals that can be interfaced to the serial port of a PC. This type of modem is known in Radio Amateur circles as a Terminal Unit (TU).

Table III Amateur Radio Spacecraft Currently Under Development

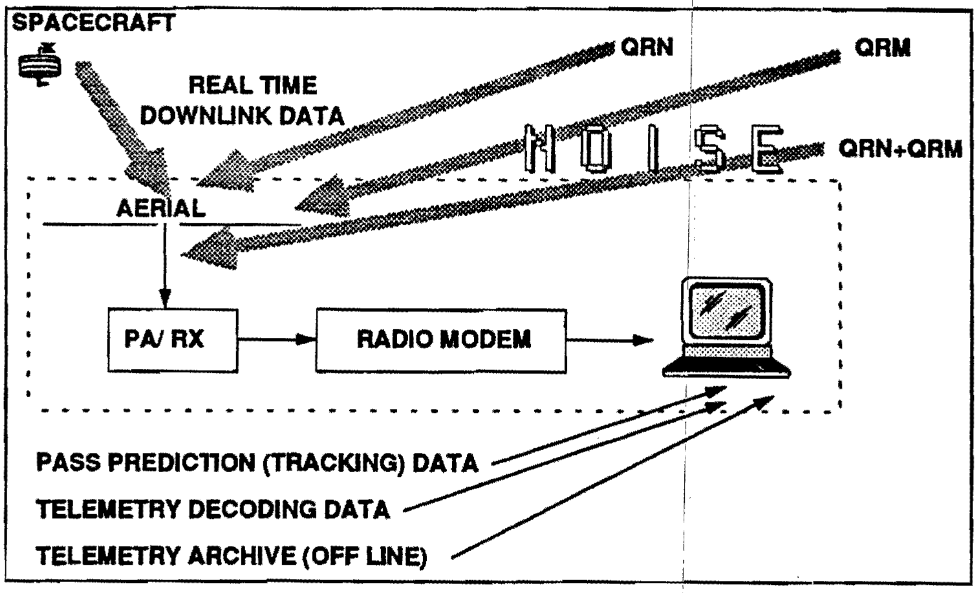
SPACECRAFT	COUNTRY	MISSION	LAUNCH DATE
ARSENE	France	Long Life Intercontinental AX.25 Communications	1992
KITSAT	Korea	Educational Construction Project	1992
SEDSAT	USA	Educational Construction Project	1993
TECHSAT	Israel	Educational Construction Project	1993
IT-AMSAT	Italy	Similar to AO-16 with science experiment.	1994
SUNSAT	S. Africa	Educational Construction Project	1994
MARS	Germany and an International Team	Interplanetary probe and long range communications relay	1995
AMSAT-PHASE 3D	Germany and an International Team	Long Life Intercontinental Communications	1995

The signals are sent as packets using a modified version of the X.25 protocol called AX.25. Radio Amateurs use this protocol for communications, and DOVE employs it for telemetry transmission purposes so that any Radio Amateur equipped for packet radio communications is also equipped for receiving signals from DOVE.

Receiving PSK Modulated Signals in the 70 CM Band

Receiving signals from AO-16, WO-18 and LO-19 as well as from FO-20 requires somewhat more complex equipment. These spacecraft transmit on downlink frequencies in the 70 cm or 430 MHz band. As they use PSK, the receiver has to be a conventional communications receiver. This can be either a communications receiver designed for that frequency range, or a conventional short wave receiver with a front end down converter. A PSK modem attached to the TU is also required.

Figure 1 Basic Receiving System for DOVE-OSCAR 17.



Receiving Signals From UO-2

The same basic radio receiving system used to receive signals from DOVE can be used to copy the telemetry from UO-2. This spacecraft however has a lower powered transmitter than that of DOVE and consequently has a weaker signal strength on the ground. This lower signal level, coupled with the fact that the modulation is plain ASCII data means that errors will be seen in the received data due to signal fades and noise bursts (interference) from local sources. Better antennas are needed for reliable reception, and antennas that track or move and always point at the spacecraft are desirable.

The TU used for UO-2 is simpler as compared with that used for DOVE due to the different data encoding (ASCII instead of AX.25).

Receiving Signals from AO-13

So far all the spacecraft considered have been low earth orbits. AO-13 however is in an elliptical orbit with a high apogee. It also downlinks telemetry as BAUDOT and ASCII data. While signals from this spacecraft can be heard on the simple DOVE type of receiving configuration with an omnidirectional receiving antenna, the signals are weak and barely audible, i.e. they are in the noise and cannot be received in usable form without a tracking antenna.

RECEIVING SYSTEM COMPONENTS

Consider the different components or building blocks that are used in the different receiving configurations.

Antennas

Antennas receive signals, and each type of antenna has some degree of directivity and polarization. When the spacecraft rises above the local horizon, the ground station experiences acquisition of signals (AOS). At this time the ground station is receiving signals coming from a particular direction (azimuth). As the spacecraft rises in the sky, the elevation angle of the received signals changes, until the spacecraft drops below the observer's horizon and the ground station experiences loss of signals (LOS). As seen from the ground, the spacecraft rises from a horizon in one direction, travels in an arc across the sky and sets at a different horizon in a different direction. Each pass for each spacecraft is different. Antennas for receiving signals from spacecraft must thus be able to receive signals coming in from almost any angle.

Antennas in this context, fall into two categories, omnidirectional and rotatable. The simple turnstile antenna is horizontally polarized and has a good response to signals arriving from high angles and can be built for about $2.00[5]. The ground plane and J Pole antennas are vertically polarized and have a good response to signals arriving from low angles. These antennas however do not have much gain. Yagi Beam Antennas however have gain with respect to the turnstile or ground plane, but only in specific directions. You can think of the gain in some directions as being moved into the direction that the antenna is pointed at. The gain of the antenna depends on the number of elements in the antenna, and the higher the gain, the narrower the area of the gain (lobe). Consequently, these beam antennas must be moved to keep the spacecraft in the main lobe of the antenna. Since the need for keeping the antenna pointed at the spacecraft depends on the beam width of the antenna, the lower the gain of the antenna the less accurate the tracking need be. Luckily the orbits help out in this respect. UO-2 is in low earth orbit, which means it is fast moving, needs only a small amount of gain, so TV style rotators can be employed to point antennas with between 2 and 4 elements, while AO-13 which is in an elliptical orbit, moves so slowly for nearly 8 of its 11 hour orbit, that again, TV style rotators can be used to point higher gain antennas with between 8 and 11 elements.

Building your own antennas is an easy and worthwhile project. Antennas for these OSCARS are simple and not very critical with respect to the materials used. They have in fact been built from recycled junk[7].

Receivers

Receivers fall into two categories, FM and linear. FM receivers are used for reception of the FM signals from DOVE, SARA and UO-2, while linear receivers are needed for reception of the FSK and PSK signals from the other spacecraft. All vhf/uhf scanner radios are FM receivers. The linear receivers need single side band (SSB) capability, something normally found in short wave communication receivers. As a result of the growing popularity of amateur satellite communications, suitable vhf/uhf transmitter-receivers (transceivers) have been on the market for several years, however these transceivers are expensive listing in the $800 to $1200 range. An alternative approach to reception is to use a short wave communications receiver listing around $500 together with a front end downconverter which lists at under $100. The short wave radio can also be used to tune in, not only the world of amateur radio, but news broadcasts from overseas; a totally different are of classroom activity.

"Expensive" is a relative term. These days, many people think nothing of spending $1000 on a stereo system or on equipment for photography or other hobbies.

Terminal Units or Modems

Digital radio links work much in the same way as digital signals are transferred over the telephone line. However in this case, instead of a phone wire, a radio link is used. Both links use modems to convert the serial input/output digital RS-232 signals of the computer to the audio tones used on the communications link.

Packet radio signals are demodulated by a radio modem known as a Terminal Node Controller (TNC). The device is connected in between the radio and the computer and provides hams with two way digital communications. A packet only TNC lists for between $120 and $200. For reception of the PSK signals from AO-16, WO-18, LO-19 and FO-20, PSK Modems are available either as addons to a regular TNC or as stand alone units, listing between $150 and $700.

The BAUDOT Radio Teletypewriter (RTTY) signals from AO-13 can be demodulated by an RTTY Terminal Unit. These devices are listed at between $100 and $300. On the other hand a multi-mode communications controller listing between $250 and $700 can be used for AO-13 as well as DOVE and the other spacecraft. AO-13 downlinks BAUDOT because that is the most commonly used digital communications mode used by radio amateurs at high frequencies (short waves).

The modem for UO-2 is a little more difficult, as its ASCII encoding is the reverse of the standard used in the USA. This is because the spacecraft was built in the UK and its use of tones to represent data reflects the encoding used in a standard audio tape interface at the time the spacecraft was built (1982-1984)[8]. Still, a do-it- yourself circuit needs a few integrated circuits, is simple to build, easy to test, and costs less than $50[9].

COMPUTERS

Any Personal Computer can be used, providing that software is available. While writing software to do the job is a good learning experience, it is nice to be able to see how someone else did the job, or have a standard to test against. Just because this paper discusses software for the IBM PC and its clones, does not mean that there is none for other machines. Two basic kinds of software are needed, orbit tracking and telemetry decoding.

TRACKING SOFTWARE

Tracking software does not actually track spacecraft. It predicts the position of the spacecraft based on Keplerian orbit elements. Various programs exist providing many different features including graphic displays, printouts of azimuth and elevation positions, control of antenna pointing positions (with suitable hardware). The most spectacular graphics from an educational point of view are provided by InstantTrack, a program available from AMSAT in return for a minimum (tax deductible) donation of $50. This program also has some displays which illustrate explanations of orbital dynamics. Much of the other software is available as share-ware, with registration costs of between $25 and $50, while commercial software lists between $50 and $350.

SATELLITE DATA FORMATS

The satellites have been built by different organizations at different times and each uses different data formats. DOVE and FO-20 use ASCII Packet format, yet while DOVE transmits the data in Hexadecimal format, FO-20 uses Decimal Format. SO-23 transmits binary digital telemetry with two analog FM subcarriers, one centered on 200Hz, the other centered on 500Hz. AO-16, WO-18 and LO-19 transmit their telemetry in pure binary format. By using packetization, the data quality is checked in the link itself and bad packets are not normally passed to the computer from the TNC. AO-13 RTTY does not have any error checking at all, so it is up to the receiving station to visually inspect the data before trying to convert it to engineering units. UO-2 also transmits its telemetry as ASCII text, but the designers of the spacecraft recognized that the downlink was prone to error and incorporated a checksum in its data format. A downlink telemetry format standard has been proposed[10] and hopefully will be adopted in the near future.

Examples of the raw UO-2, DOVE and FO-20 telemetry are shown in Figure 2. Examples of decoded display pages are shown in Figure 3.

Figure 2 Examples of Raw Telemetry.

Figure 2a Example of the Raw FO-20 Telemetry.

```
19-Apr-90 17:14:34 8J1JBS*>BEACON:
JAS1b RA 90/04/19 17:13:58
609 430 687 676 744 837 845 829 498 681
617 001 505 516 526 524 526 523 654 000
683 675 686 695 999 643 875 471 099 000
110 111 000 000 111 100 001 111 111 000
```

Figure 2b Example of Raw DOVE Telemetry.

```
23-Jan-91  02:49:23  DOVE-1*>TIME-1:
PHT: uptime is 173/00:36:26. Time is Wed Jan 23 02:47:30 1991
23-Jan-91  02:49:26  DOVE-1*>TLM:
00:59 01:59 02:87 03:31 04:59 05:5A 06:6E 07:52 08:6D 09:72 0A:A2
0B:DC 0C:E9 0D:D8 0E:02 0F:26 10:CC 11:A8 12:01 13:04 14:AD 15:94
16:98 17:94 18:96 19:98 1A:94 1B:91 1C:9B 1D:98 1E:25 1F:5F 20:BA
23-Jan-91  02:49:27  DOVE-1*>TLM:
21:95 22:82 23:24 24:1E 25:2A 26:01 27:02 28:02 29:01 2A:02 2B:02
2C:01 2D:29 2E:02 2F:9E 30:CA 31:9E 32:11 33:CE 34:C4 35:9A 36:A8
37:A6 38:B6
23-Jan-91  02:49:28  DOVE-1*>STATUS:
 80 00 00 8F 00 18 CC 02 00 B0 00 00 0C 0E 3C 05 0B 00 04 04
23-Jan-91  02:49:28  DOVE-1*>LSTAT:
I P:0x3000 o:0 l:13081 f:13081, d:0
23-Jan-91  02:49:28  DOVE-1*>WASH:
wash addr:0680:0000, edac=0xd6
```

Figure 2c Example of a Received Raw UO-2 Telemetry Data Frame

```
00519D0141370267650361400404660503;4 6019E07045608040C08036C
10519C11298312000313056114069A15529A!6188;175452185905195058
20519F21220322662223000124001725000726093E27541528564D294681
30519E31041732287C33568B34007035217236276637393D38426B39455E
40649F41117242647343061044162545000146000247444748454949422x
50456251108D52634653284p54663215000056p00357451258447A59460E
60826A615FC1625F4A63334164440265160466174267700668000E69000F
UOSAT-2              9101281004625
```

Note Reception Errors due to noise bursts.

TELEMETRY PROCESSING SOFTWARE

The telemetry decoding equations are usually published in the amateur radio press around launch time. Since those magazines are not readily available months let alone years after the launch, the equations for each of these spacecraft can be found in the documentation for WHATS-UP[11] or in other amateur radio satellite handbooks published by various individuals and organizations.

Telemetry processing software using these equations is somewhat scarce. Until DOVE was launched there wasn't very much interest. Software was thus developed, either by the command stations or by one or two individual hams who were interested in what was going on up there in the sky. Each program only processed data from one specific spacecraft and did not usually do it in real time, or provide any tools for analyzing the data.

Figure 3 Samples of Decoded Telemetry

Figure 3a Sample Decoded Page of DOVE Telemetry

PHT: uptime is 177/12:34:12. Time is Sun Jan 27 14:45:16 1991

-X Array Cur	:0.174 A	Array V	:22.829 V	Battery 1 V	: 1.330 V
+X Array Cur	:0.000 A	+Z Array V	:23.836 V	Battery 2 V	: 1.346 V
-Y Array Cur	:0.000 A	Ext Power Cur	: 0.000 A	Battery 3 V	:1.337 V
+Y Array Cur	:0.000 A	BCR Input Cur	: 0.480 A	Battery 4 V	:1.325 V
-Z Array Cur	:0.000 A	BCR Output Cur	: 0.314 A	Battery 5 V	:1.350 V
+Z Array Cur	:0.251 A	BCR Set Point	: 119	Battery 6 V	:1.431 V
IR Detector	: 56	BCR Load Cur	: 0.241 A	Battery 7 V	:1.343 V
+Z Array Temp	: 3.0 C			Battery 8 V	:1.344 V
+Y Array Temp	: 4.8 C			Bat 1 Temp	: 3.0 C
				Bat 2 Temp	: -24.8 C
+2.5V VREF	:2.506 V			TX#1 RF OUT	: 0.0 W
Ground REF	:0.020 V			TX#2 RF OUT	: 3.7 W

Figure 3b Sample Decoded Display Page from FO-20.

JAS1b RA 91/01/13 00:40:58

Solar Panel Temp #1:	15.20 Deg.C	Total Array Current:	1105.89 mA
Solar Panel Temp #2:	31.92 Deg.C	Battery Charge	: 102.87 mA
Solar Panel Temp #3:	32.68 Deg.C	Battery Voltage	: 14.806 V
Solar Panel Temp #4:	29.64 Deg.C	Battery Center	: 6.744 V
Baseplate Temp. #1 :	40.73 Deg.C	Bus Voltage	: 17.259 V
Baseplate Temp. #2 :	41.42 Deg.C	+5 V Regulator	: 5.214 V
Baseplate Temp. #3 :	40.87 Deg.C	-5 V Regulator	: 0.000 V
Baseplate Temp. #4 :	41.14 Deg.C	+10 V Regulator	: 10.471 V
Temperature Cal. #1:	1.30 V	Offset Voltage #1	: 0.000 V
Temperature Cal. #2:	1.29 V	Offset Voltage #2	: 0.000 V
Temperature Cal. #3:	1.75 V	Calibration Volt #2:	1.230 V
Battery Temp. :	45.04 Deg.C	JTA TX Output Power:	0.46 W
JTD Temperature :	42.12 Deg.C	JTD TX Output Power:	3.52 W

This type software is floating about in amateur radio circles, andsome are available on Compuserve in the HAMNET forum libraries, but the only comprehensive program is WHATS-UP written by this author[11], which provides features for both real time (during a pass) and post pass processing together with a host of customization capabilities.

WHATS-UP also contains an interface to a Kenwood communications radio transceiver to set the receiver to the correct beacon frequency, as well as to be able to read back the true frequency periodically during a pass to measure the Doppler shift on the satellite's beacon.

During a typical pass, data are captured, decoded and displayed in real time. Post pass, data from selected channels can be extracted and read into a spread sheet for analysis. Graphs can be plotted of the value of different telemetry channels through-out the pass. Data can be compared over several passes. Doppler curves can be plotted by measuring the change in the radio frequency during the pass. In fact, the whole world of the professional spacecraft data processor in miniature is present in this simple ground station. A sample Doppler curve plotted using data from a real satellite pass is shown in Figure 4. A similar example of a changing parameter is shown in Figure 5. A whole semester can be usefully spent discussing why the predicted and actual Doppler curves are different or why the UO-2 solar array current telemetry parameter changed during the pass.

Figure 4 Doppler Curve for WO-18

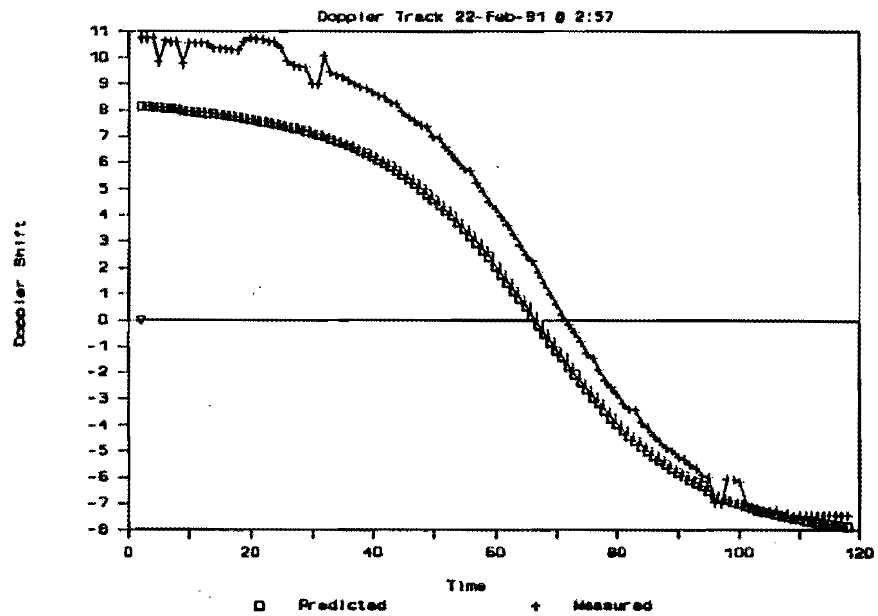
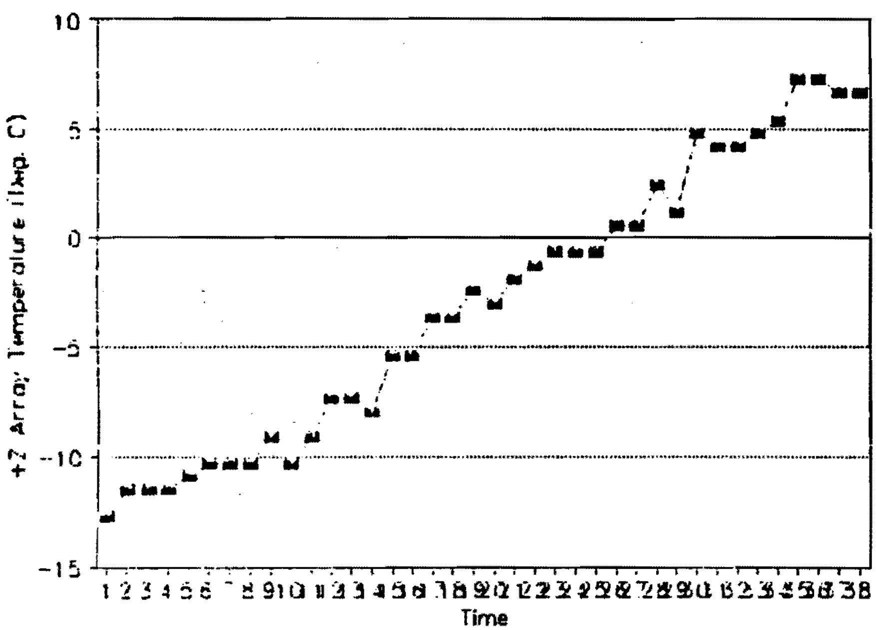


Figure 5 Change in DO-17 +Z Array Temperature During Pass



COSTS

Summarizing the costs of the items mentioned above, the list prices fall between a low and high cost depending on the amount you wish to pay. The summary is shown in Table 4. It should be noted that the high price items may not be better than the cheaper ones, particularly in the educational environment. This table is of course only a guide, since you will probably end up with something in between.

Table IV Range of Equipment List Prices

ITEM	Low Price ($)	High Price ($)
Antenna	2.00	100.00
Receiver	100.00	1200.00
Radio Modem (TU/TNC)	150.00	700.00
Tracking Software	25.00	350.00
Telemetry Decoding Software	35.00	35.00
TOTAL	312.00	2385.00

THE FUTURE

Apart from UO-2, SO-23 and WO-18 none of these spacecraft are designed for "Science" purposes. Their telemetry consists of spacecraft housekeeping parameters, monitoring on-board temperatures, voltages and currents. While much use can be made of these data, there isn't much real science data available. Apart from SEDSAT, although some of the ones currently under development are planned to contain science payloads, their primary in orbit missions are to provide amateur radio communications. The current crop of scientific spacecraft are in the main unusable by the average listener because information about the scientific payload is not readily available.

Let's make a start with these spacecraft, then look to a follow on activity. An OSCAR does not have to be a separate spacecraft. The Soviet Union has provided their amateurs with payload space aboard their weather satellites[12]. NASA could do the same for an amateur scientific spacecraft which would monitor radiation, the earth's magnetic field and solar activity; such data being of use to radio amateurs for predicting propagation and providing schools with data about the earth's environment. NASA has a 'Mission to Planet Earth' project to provide an Earth Observation Platform in 1997. An attached secondary payload to that platform, transmitting packetized scientific telemetry data (with well publicized formats) in the 145 MHz amateur band or in the 136 MHz scientific band could really bring not only the space program, but the educational and scientific use of space, into every educational institution in the country.

On the other hand, there is no need to wait for NASA. Amateurs have at least two projects well in hand.

STANDARDS AND SIMULATORS

A standard format for telemetry downlink data is about to be adopted. A simulator program generating this data is being developed for the PC by this author. This software should be ready for distribution with the preliminary SEDSAT parameters at the AMSAT-UK Space Colloqiuim in July 1992. In spite of not being finished, this piece of software has shown that telemetry data simulation can provide a powerful teaching tool, and has the capability to lead on to other simulation and modelling exercises.

VERY LOW FREQUENCY RADIO ASTRONOMY PROJECT

The Goddard Amateur Radio Club attached to NASA's Goddard Space Flight Center (GSFC) is in the requirements definition phase of a very low frequency radio amateur astronomy experiment follow on to SO-23. Their plan is to build experiment packages which can be flown on other OSCAR spacecraft and the MARS mission. If one package is flown, it will be a simple amateur radio astronomy experiment. If more than one are flown simultaneously on different spacecraft, then the scope of the experiment widens considerably.

SEDSAT AND TETHER EXPERIMENTS

The NASA Marshal Space Flight Center (MSFC) is conducting a series of space flight demonstrations of a tether satellite deployer mechanism called SEDS designed to provide a low cost means for testing tethered satellite deployment techniques. SEDSAT is to be flown as a secondary payload on the second SEDS flight currently scheduled for early 1993. SEDSAT is an international cooperative effort between the Students for the Exploration and Development of Space (SEDS) at the University of Alabama, the National Cheng Kung University of Taiwan, AMSAT, and the MSFC[13].

SEDSAT is designed to replace a 23 kg dead weight on the end of a 40 km long tether. In this flight it will be deployed upward and remain attached to the tether and the Delta II second stage. SEDSAT will gather high rate imaging data and acceleration data during the tether deployment and then continue to record data relevant to the long term deployment of a tether in space, as well as perform several other on-board experiments.

In its planning and production phase, SEDSAT is an opportunity to fly a student payload and expose students to the interdisciplinary activities encountered in designing and building a spacecraft, much as they would encounter in the real world following graduation from college. During its in-flight phase, SEDSAT will make available to the public, measurement data from its on-board experiments which will allow amateurs to do real research.

The SEDSAT project plan to use the Amateur Satellite Downlink Telemetry Format Standard and publish details of the seacraft, experiments and telemetry decoding information well before launch. The project also plans to use telemetry simulation software to provide a data source for building and testing ground station data analysis tools.

THE MARS MISSIONS

Signals from spacecraft on their way to MARS will be receivable during the near earth phase of the mission. However before the spacecraft gets too far out for reception by simple equipment, arrangements will be made to capture and distribute the telemetry data to those interested. **In fact for all these spacecraft, there is no requirement that the people analyzing the data are the same as the people who capture it.**

SUMMARY

This paper has been a top level overview of a fascinating field. There are satellites up there that can be received using equipment that is simple and low cost. More exciting ones are scheduled for launch in the next few years. If real time satellite tracking can be added to the educational curriculum, it has the promise to bring space science right into the classroom.

In this century, building crystal sets introduced thousands of people to amateur radio and electronics even though the signals they received were not from amateur radio stations. Capturing, decoding, displaying and analyzing telemetry from space has the potential to do the same in both the last decade of this century and in the 21st Century.

FURTHER INFORMATION

For further information about any of the spacecraft and the Radio Amateur Satellite program, as well as the equipment needed to receive their signals, look through amateur radio books and magazines in your local public library, contact your local radio amateur or mail a request for information together with a self addressed stamped envelope to the organizations listed below.

AMSAT-UK, 94 Herongate Road, Wanstead Pk, London E125EQ, England.
World Classroom Foundation, 85 Parkledge Drive, Amherst, NY., 14226.
ARRL, 225 Main Street, Newington, CT., 06111.
Project OSCAR Inc. POB 1136, Los Altos, CA. 94023-1136.
AMSAT-NA, 850 Sligo Avenue, Silver Spring, MD, 20910-4703.

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ELMER: An Expert System Based on a Finite State Machine

Joe Kasser

Abstract

This paper describes an expert system based on a finite state machine. In use, at any time the expert system is waiting for a question. The contents of the question will depend on the answers to previous questions. This is similar in concept to a state machine. The expert system is implemented in Turbo Pascal using a "Table Driven" approach for the knowledge, in the form of a state table and a large number of text files or programs. By providing the capability to shell to DOS and run external programs as well as outputting text files, a powerful yet simple tool has been created.

Introduction

An expert system contains knowledge about a particular field to assist human experts or provide information to people who do not have access to an expert in the particular field. It is an information system that can pose and answer questions relating to information borrowed from human experts and stored in the system's knowledge base [1]. Although they vary in design, most expert systems have a user interface, a knowledge base, and an inference engine.

The User Interface

The User Interface to the expert system is the way that the user interacts with the system to extract information from the system.

The Knowledge Base

The Knowledge Base of an expert system contains both declarative and procedural knowledge. The facts describing the situations, events and objects are called declarative knowledge. Procedural knowledge is the information about courses of action and the rules governing the actions. There are various kinds of rules that may be employed.

The Inference Engine

The Inference Engine controls how and when the information in the knowledge base is applied. It determines how the rules in the knowledge base are to be applied to the problem.

Features of an Expert System

The following list of features are desirable in any expert system [2].

Useful: The system should meet a specific need.

Usable: The system should function so that even a novice computer user finds it simple to use. It should be able to respond to simple questions.

Educational: The system should allow non experts to increase their expertise. In a similar vein, the system should be able to explain the reasoning behind its advice to allow the user to determine the validity of the advice.

Adaptable: The system should be able to learn new knowledge.

Using an Expert System

Expert systems take the form of software packages residing on a hardware platform (computer). The most common use of an expert system is via a man-machine dialogue. The user types something at the keyboard and the system replies. The user interface accepts the input. The input is parsed in some manner, the inference and knowledge engines process the user input in a predetermined manner and an output appears. The parsing function may be a simple pattern matching method commonly called keyword analysis, or a more complicated function using syntactic analysis. Keyword analysis is a logical function in which the presence of various keywords are detected. When a keyword is found, the system responds in the manner in which it has been programmed.

For example, if the system detects the words "what is systems engineering" in a question, it may respond with "*an iterative process of top down synthesis, development, and operation of a real-world system that satisfies, in a near-optimal manner, the full range of requirements of the system*".[3]

In syntactic analysis, a sentence is analyzed according rules which allow the system to respond differently to keywords which appear in different sequences. For example, the system may respond differently to the question "what is systems engineering" and "systems engineering" if it recognizes those words in a sentence.

The Semantic Network

The most general and oldest artificial intelligence scheme for representing knowledge is the semantic network. A semantic network is a collection of objects called nodes. The nodes are connected together by links. Ordinarily, both the links and the nodes are labelled [4]. A drawing of a semantic network contains bubbles to represent the nodes, and lines connecting the nodes to represent the links. Both nodes and links are labelled. The drawing looks just like a PERT or CP/M chart. It is also the drawing used to represent a state machine.

A State Machine

A state machine is a system that exists in several states. The system makes a transition from one state to another as a result of a stimulus. All states and transitions are defined at the time the system is designed. The links in the semantic network are the transitions in the state diagram.

The User Perception

The user perception of an expert system is shown in Figure 5. The system appears to be in a rest state. It receives an input from the user and enters a transition to a state in which it processes the data it has just received. After processing the input it generates an output and returns to what seems to be a rest state. In reality, as shown in Figure 6, the two rest states (initial and final) are different.

Figure 7 decomposes the transition state showing the intermediate states in the parsing sequence. The logic for the detection of words in sequence is set up in the state numbers. Upon detection of the word "what", the system advances from state 0 to state 1. In state 1 it looks for either "systems" (moves to state 2) or "englishman" (moves to state 4). All other words are ignored. The figure uses symbology reminiscent of a PERT Chart and a decision tree.

ELMER

ELMER is an expert system for the PC family of computers written in a few lines of Turbo Pascal. ELMER is based on a finite state machine using table driven software. The declarative knowledge is stored in the form of separate ASCII text and command files. The procedural knowledge is stored in the state table. The Data files (text and commands) in ELMER correspond to the Knowledge Engine (and the Inference Engine), the State Tables correspond to the Inference Engine. ELMER also contains an ASCII text editor for editing the state and text tables, and a tool to view the state table. These tools allow the user to "teach" ELMER new knowledge.

ELMER was build by re-using code from other projects. In fact the user interface and the editor modules were incorporated within ELMER without any modifications to those blocks of code. ELMER does not employ Object Oriented Programming (OOP) since code reusability is not unique to OOP. Approximately 90% of the code in ELMER is reused code. This programming approach allowed ELMER to be coded, debugged and tested in a few days.

ELMER currently does not have the capability to "learn" from user inputs. That feature can be added in the next revision by implementing a feature to expand the state table interactively and store it (and the text files) to disk. ELMER could be made to invoke this feature as a result of receiving a particular keyword. In fact this feature could be added to the current code in an external command. This and other features can be added to ELMER in subsequent releases of the software, but then its simplicity will become a forgotten feature.

Responses to an Input

ELMER has three kinds of reaction to a word match. It can do nothing, output a test file, run a command or overlay a new state table. ELMER's state table contains four entries:-

Current State: This is the state that the string match is performed in.

Next State: This is the state that the ELMER will advance to if a string match is found.

Repeat Flag: This is a flag to allow or disallow repeats. If it is a 0 repeats are allowed, if it is a 1, they are not.

Command Flag: This is a flag to tell the ELMER how to treat the file. If it is a 0, load a text file; 1, execute a command file; 2, overlay the current state table with the defined one.

Keyword: This is the text string to match in the syntactic analysis of the input text. The text string can be up to 15 characters long and can include spaces. The match is case insensitive, i.e. there is no difference between upper and lower case.

Data File: This is either a text file to be loaded or a command file to be executed, depending on the state of the Command File Flag.

ELMER's Advantage

The ability to run programs (BAT, COM and EXE files) provides extremely powerful capabilities. ELMER can even be used as an *expert engine* to drive a multi-media presentation.

The ability to overlay a new state table allows expert systems to be developed in a cellular manner. Current expert systems suffer from the disadvantage that they only provide information (in-depth) about a very narrow field. ELMER overcomes that by overlaying state tables. If a posed question lies outside ELMER's field, ELMER can overlay a whole new field of knowledge and continue. This capability allows Expert Systems to be developed and operated in a cellular manner. One example would be a medical system. ELMER begins in a general practicioner role. If the questions asked of it require in-depth answers, it can overlay the relevant specialist knowledge base. If the questions asked require answers about medicines, it can overlay a pharmacist knowledgebase and pick up from there. Systems Engineers require a broad knowledge about many engineering and program management disciplines. ELMER has the potential to provide the in-depth knowledge of each discipline to assist the Systems Engineer.

Syntactic Analysis

ELMER performs syntactic analysis on the input text in the manner shown in Figure 13. ELMER does a string match on the line of input text against each keyword entry in the state table. ELMER starts with the first entry. If a match is made, ELMER changes state and performs the transient function defined by the Command Flag. All words in the input text including the keyword are then deleted. ELMER then continues the string match until either the input line of text has been reduced to zero length, or, the line of input text has been tested against all keywords in the state table.

Programming ELMER

Programming ELMER is simple. The knowledge base is broken out in terms of states and transitions. States can be passive or active. A passive state is one in which ELMER does nothing other than accept/parse further input. An active state is one in which ELMER loads and displays a text file containing information or shells to DOS and runs an external program.

ELMER contains a set of tools for programming and debugging purposes. A state table for the procedural knowledge is drawn up using pencil and paper and a large sheet of graph paper. The built in text editor is then used to enter information into the table. The individual text files containing the knowledge are also created using the editor. The state table viewing tool is used to check the entries. The state table loading capability is used to exercise ELMER and verify the logic. Because the procedural knowledge is contained in the state table, all types of rules and linkages may be used.

Applications

ELMER's major applications are in situations where the computer reacts interactively with the user, such as in programmed learning situations and software support centers.

ELMER is an excellent educational tool for demonstrating expert systems and teaching logic. The simplicity of its programming allows anyone who can draw flow charts to build an expert system.

ELMER can provide interactive learning capability in a question and answer context. The content of different text files are displayed, or graphics pictures loaded as a result of user inputs.

ELMER can provide interactive documentation capability. The documentation for software can be split up into lots of data files. These data files may be text or even commands that demonstrate capabilities. ELMER can also be used by (or even replace?) service technicians who respond to descriptions of trouble symptoms to locate problems.

ELMER was initially developed for use

in the amateur radio environment for providing smart remote servers via digital packet radio links [5].

Most initial amateur radio contacts (QSO) are somewhat repetitive, in that they send the same information each time. In digital mode communications amateur radio operators (hams) don't type exactly the same information in every QSO, but in general the information exchanged is a subset of a standard set. Hams have noticed this phenomenon and have each created and used files containing standard information. This fact was noticed years ago, and the first so called "bragtapes" were invented to serve that need back when they were using teletypewriters and generated paper tapes for the standard information.

ELMER takes that concept a little further and provides expert system capabilities. By parsing the incoming text, ELMER will recognize certain words and transmit text files containing replies or further questions, just as if the operator was at the keyboard.

Hams can use this feature to build a smart sever they can put on-line on the Local Area Network. The server will prompt people and will serve an educational purpose. ELMER can be set up to teach people about packet radio, license upgrades, or anything else. ELMER can also be programmed to recognize different languages and hold a conversation in those languages. In fact, apart from the dedicated educational and informational server applications, ELMER may be configured with such a variety of vocabulary files so as to pass the Turing test in most typical amateur radio digital mode conversations.

Summary

Implementing an Expert System using a Finite State Table approach results in a simple, effective and powerful tool. It does however (at the moment) lack computation and interactive learning capabilities. The approach however is promising. The ablility to overload additional state tables provides an extremely powerful extension capability. There is however, scope for a lot more work which may overcome some of these lacking features at the cost of added complexity.

References

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3. H. Eisner, Computer Aided Systems Engineering (CASE), Prentice Hall, 1978.
4. Paul Harmon, David King, Expert Systems, John Wiley & Sons, Inc., 1985.
5. Joe Kasser, Applied Digital Communications, IEE 5th HF Radio Conference, Edinburgh, July 1991.

ELMER	ELMER	6/17/92 1

An Expert System

implementation based on a

Finite State Machine

by

Joe Kasser

ELMER	EXPERT SYSTEM	6/17/92 2

AN EXPERT SYSTEM CONTAINS

- knowledge about a particular field
  - to assist human experts or,
  - provide information to people who do not have access to an expert in the particular field.

AN EXPERT SYSTEM CONTAINS

- user interface
- knowledge base
- inference engine.

ELMER	PARTS OF THE SYSTEM	6/17/92 3

The User Interface

- Is the way that the user interacts with the system to extract information from the system.

The Knowledge Base

- contains both declarative and procedural knowledge.

  The facts describing the situations, events and objects are called declarative knowledge. Procedural knowledge is the information about courses of action and the rules governing the actions. There are various kinds of rules that may be employed.

The Inference Engine

- controls how and when the information in the knowledge base is applied. It determines how the rules in the knowledge base are to be applied to the problem.

ELMER	FEATURES	6/17/92 4

- ***Useful:***

  The system should be developed to meet a specific need.
- ***Usable:***

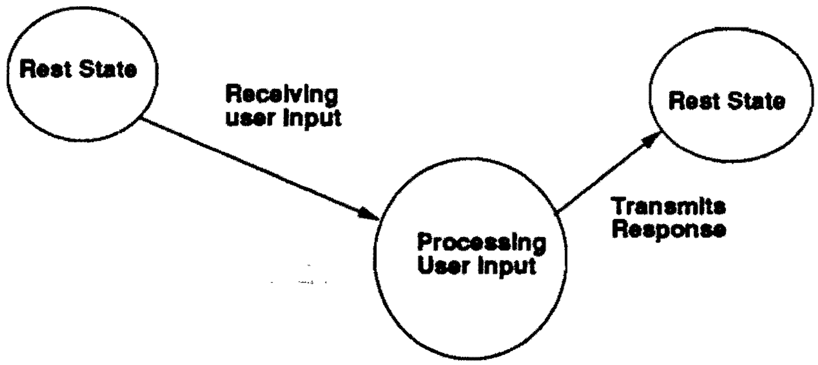
  The system should be desinged so that even a novice computer user finds it simple to use. It should be designed to respond to simple questions.
- ***Educational:***

  The system should allow non experts to increase their expertese.

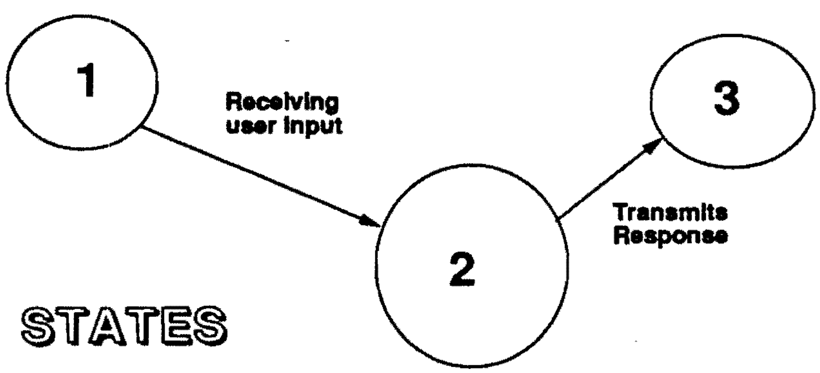
  In a similar vein, the system should be able to explain the reasoning behind its advice to allow the user to determine the validity of the advice.
- ***Adaptable:***

  The system should be able to learn new knowledge.

ELMER	**USER PERCEPTION**	6/17/92 5



ELMER	**USER PERCEPTION-2**	6/17/92 6

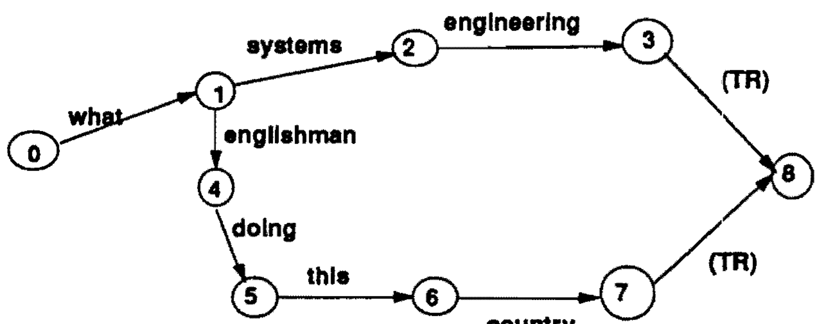


STATES

1 INITIAL REST
2 PROCESSING USER INPUT
3 FINAL REST

ELMER	PROCESSING USER INPUT	6/17/92 7

- Parse words
- Match words
- States Change depending on word matches



(TR) = transmit response

ELMER	FINITE STATE MACHINE	6/17/92 8

- all states and transition between states are known.

It is also possible to build 'hooks' into the machine to add additional states/transitions later.

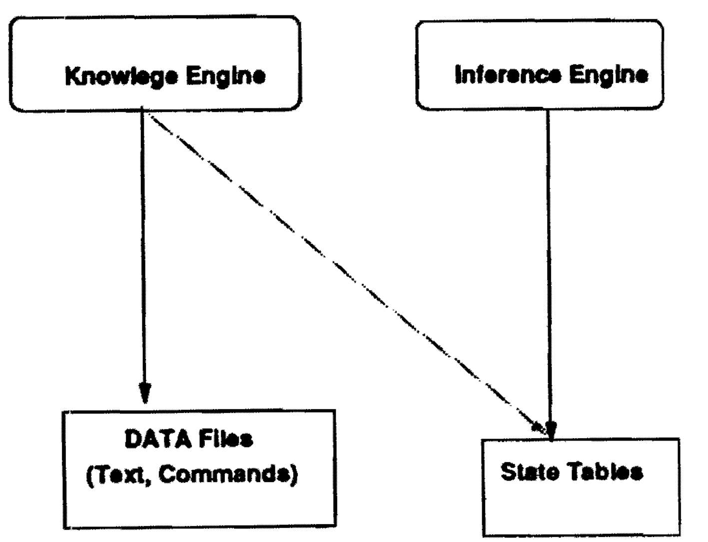
ELMER | GENERATING RESPONSES | 6/17/92 9

GENERATING RESPONSES

- Do Nothing
- Output text file
- run/execute a program
- overlay a new State Machine

ELMER | MAPPING | 6/17/92 10

MAPPING



ELMER	IMPLEMENTATION	6/17/92 11

- TURBO PASCAL
- REUSABLE CODE
- ASCII TEXT FILES & COMMAND FILES
- STATE TABLE FILE

ELMER	STATE TABLE	6/17/92 12

contains

- Current_State
- Character_String
- Next_state
- Load/Run/Overlay_Flag (Command State)
- Datafile

ELMER	SYNTACTIC ANALYSIS	6/17/92 13

START: {Received line of text}
Position pointer at first entry in State Table
DO WHILE (not end of table) and (length of line of text > 0)

- *(Is keyword in line of text) AND*
  (Is match permitted in Current State)?
- *YES BEGIN {Enter Transient State with Command State of 0,1,2}*
  - *Command State = 0 : Output data (text) file*
  - *Command State = 1: Excecute data (command) file*
  - *Command State = 2: Overlay data file (state Table)*
  - *Delete all words in line of text including keyword*
  - *Replace Current State by next state entry in State Table*
- END {of Transient State}

END DO

ELMER	APPLICATIONS	6/17/92 14

- **Programmed Learning**
- **Software support centers**
- **Amateur Radio**

AN AMATEUR SPACE EXPLORATION GROUND STATION PROJECT UPDATE

By Brent Helleckson for the Deep Space Exploration Society

Introduction

As was reported at last year's AMSAT-NA International Space Symposium, (Proceedings 1991 AMSAT-NA International Space Symposium "An Amateur Space Exploration Ground Station") the Deep Space Exploration Society (DSES), following the example of the successful ARRL, AMSAT, and amateur astronomy organizations, has been formed by a group of individuals who are interested in doing amateur space exploration. The purpose of the organization is to bring together those individuals who are interested in learning by doing, specifically by doing hands-on projects in space exploration.

Project Status

The initial project accepted by the DSES is the refurbishment of two, 18.3 meter, steerable, parabolic antennas located on Table Mountain, approximately 5 miles north of Boulder, Colorado. These dish antennas are estimated to be useful in the 100MHz to 10GHz range. For a more detailed discussion of the leasing arrangements, existing condition, capabilities, etc., see the previously referenced paper. Work during the past year has focused on the upper dish, therefore the following paragraphs serve to outline the progress made on that dish and provide some indication as to expected capabilities.

Organization

The organization of the DSES has solidified over the past year. Federal non-profit educational status has been applied for and is expected to be approved shortly. State non-profit status has been obtained, pending federal approval. Organizational bylaws have been drafted and approved by the first Board of Directors. A formal accounting system is in place and functional. The monthly "work parties" are anchored by 10-15 core volunteers and supported by an additional 10-15 volunteer workers.

Antenna Mechanical Hardware

A "critical path item" in the refurbishment schedule, progress on repairing the antenna mechanical hardware has proceeded steadily. Both of the 200 lb. azimuth drive motors have been removed, have had the primary bearings replaced, and have been re-installed in the towers. Similarly, the eddy current clutches for each motor have been removed, refurbished and replaced. A wiring diagram tracing paths from the control console to their respective terminating points has been roughed out and is being entered into a CAD system. The tower itself has been thoroughly cleaned and is being used for temporary storage.

Radio Frequency Hardware

In astronomical parlance. "first light" has been obtained through the instrument. A simple 437 MHz element has been installed at the antenna feed, and a length of high quality Heliax coax cable has been routed down to the control center. A rough (mostly aural, partially digital meter) measurement of solar noise was obtained and indicated that the antenna is performing as expected in this frequency range. Rough measurements also indicated that the beamwidth of the antenna at this frequency is between 2 and 5 degrees, which is again within the error bars around the theoretical estimate for the dish. A C-band transmit/receive satellite control station has been obtained from the owner of the antenna. The system includes a 15 ft parabolic antenna, transmitter, receiver, and associated gear - all still packed in their shipping crates! Also, a large number of frequency generators, signal analyzers, power supplies, PC's, etc., have been obtained.

Controller

Work on establishing PC-based control of the antenna has lagged other portions of the project. However, individuals within the organization are gaining an understanding of the operation of the

Selsyn synchro indication system. As of the last work party, the Selsyn indicators have become operational and A/D optical encoders have been rigged into the system to provide digital position output. Conversion from tube-based power amplification and control to analog card power amplification and A/D converted control is beginning. Similarly, a rudimentary interrupt program in BASIC is nearly ready to test. Systems engineering work has begun on a more permanent "Phase I" computer control system. In support of the effort to bring the facility into the digital age, several microcomputers have been obtained. These include an original-original XT, a 286 clone, an H-P Vectra, and a Microvax. These are being tested and configured, and are expected to be sufficient for the near term.

Facilities

A great deal of progress has been made repairing and remodeling the control building and the surrounding grounds. The parking lot has been cleared of debris, washouts, etc. The unusable equipment inside the control center has been disposed of. The interior of the entire building has been repaired, scrubbed, painted, and cleaned. A wall separating the control center from the remainder of the building has been erected, finished and painted. Hot and cold running water (out as well as in) has been established and toilet facilities are now working. The heating and ventilation system is functional and the air conditioning system has been deemed repairable. An exterior stairway has been repaired and the feed point scaffolding has been repaired and extended.

Calibration and Science Projects

The solar noise calibration experiment previously mentioned, and several hours of physical measurement have yielded the following rough engineering data:

2/3 deg per sec rotation rate
F/D = 0.41
Dish mesh size = 1/4 in.

Pointing accuracy = 0.5 - 1.0 deg (0.05 may be possible)

Frequency	Gain	Beamwidth
.145 GHz	26.3	8
.437	35.9	2.7
1.2	44.7	.9
2.4	50.7	.5
10	63	.1

Several calibration, science, and education projects have been discussed to date, however additional ideas and input are welcome and encouraged.

CONTACTS AND MEMBERSHIP

Membership dues for the DSES are currently set at $50 per year. An as-yet-to-be designed newsletter will be published and volunteers for specific hardware, software, science, and educational projects will be sought from the membership. Dues and correspondence should be addressed to:

Deep Space Exploration Society
c/o Rex Craig
5921 Niwot Road
Longmont, CO 80503

An electronic mail service and bulletin board has been provided by the Boulder Center for Science and Policy. The particulars are as follows:

(303) 494-8446
1200, 2400, or 9600 baud
8 bits
No parity
1 stop bit

The DSES is gaining momentum and membership. As we develop a clearer understanding of the capabilities of the antennas, interesting projects begin to suggest themselves. As an example, preliminary plans are in the works to support an "Edge of Space Sciences" high altitude balloon and amateur TV flight. We invite you to join and share your ideas for projects that make use of the Amateur Space Exploration Ground Station.

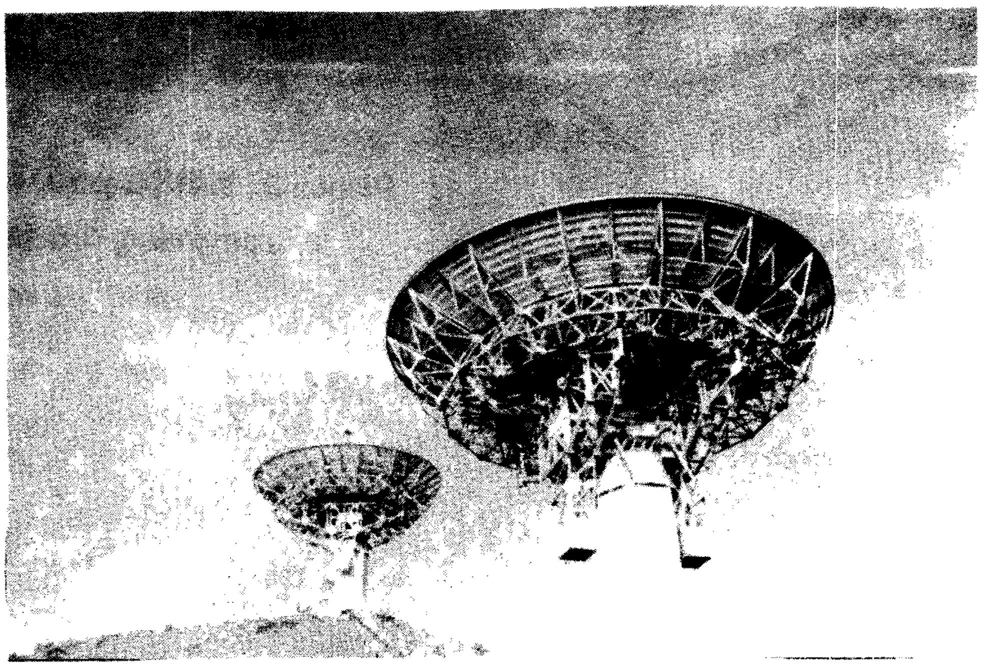


Photo 1: The Table Mountain antenna pair

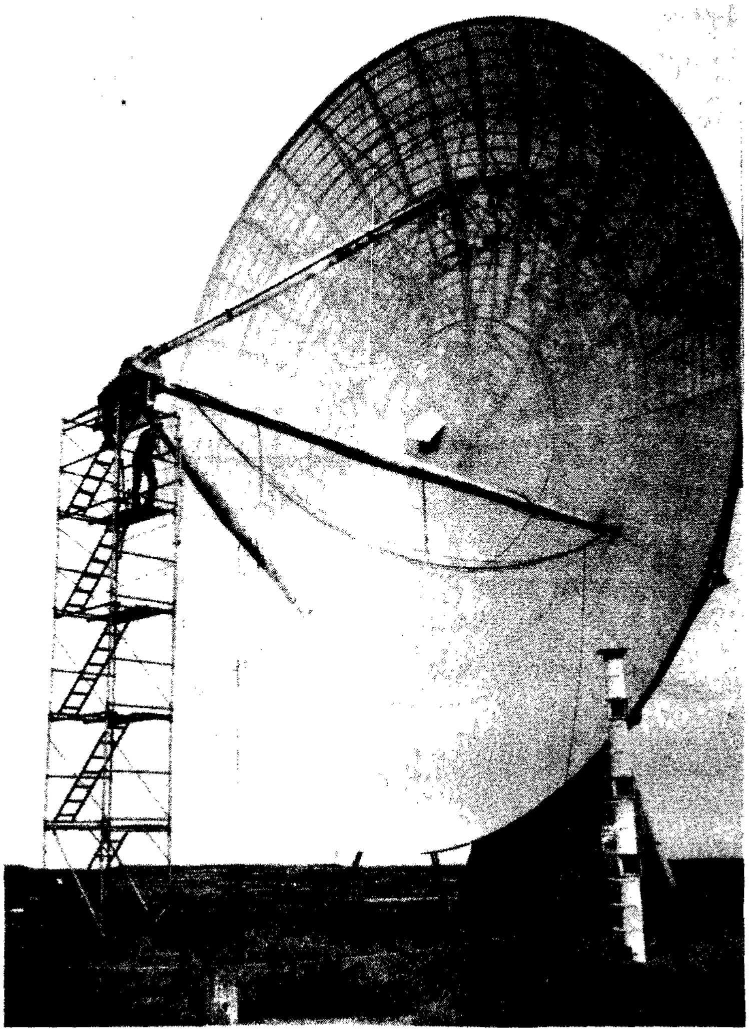


Photo 2: NØTQM and WDØE work on the feed for the upper dish

Photo 3: NØISE pauses while removing old feed line and wave guide

The AMSAT Awards Program

Andrew C. MacAllister, WA5ZIB
AMSAT Vice President User Services

ABSTRACT

In addition to awards for single event activities, AMSAT maintains a program promoting several ongoing awards ranging from the introductory Satellite Communicators' Club (SCC) certificate to the advanced OSCAR Century Award (OCA). Requirements for theses achievements go from proof of a single contact for the SCC to 100 qualified contacts for the OCA. Awards at intermediate levels are also included along with one from South Africa AMSAT. Another award based on scheduled transmission and reception tests is the K2ZRO Memorial Station Engineering Award. It has become the most popular of AMSAT's on-the-air satellite competitions.

INTRODUCTION

As thousands of amateurs have discovered, chasing satellites can be addicting. There is something very alluring about sending signals through space and making contact with others via amateur- radio satellites or "hamsats". Many a jaded ham, with walls full of rare QSL's and the familiar DXCC, WAS, WAC awards, has renewed his enthusiasm for amateur radio by earning those awards all over again--along with new ones--through the satellites.

Over the years AMSAT has promoted certificates to commemorate special events like the launch of AMSAT-OSCAR-10, the commencement of AMSAT-OSCAR-13 operations, donations for satellite solar cells, the twentieth anniversary of the launch of OSCAR-1, the Stoner Challenge Cup Competition and additional events. Further programs recognizing long-term activities were begun two decades ago and continue today.

The AMSAT Awards Program provides several awards designed specifically for the satellite enthusiast. The first was the Satellite Communicators' Club (SCC) certificate, started in 1973 after AMSAT-OSCAR-6 was safely in orbit. The intention of this program was to document the use of A-O-6 and to promote activity. Two years later, AMSAT announced a new award, the OSCAR Satellite Communications Achievement Recognition (AOA) certificate, in the June 1975 AMSAT Newsletter. Earl Skelton WA3THD coordinated the program for four years. During that time two other awards were added, the OSCAR Sexagesimal Award and the OSCAR Century Award. Jim Devilbiss WA3FUJ accepted the responsibilities of the Award Manager position from July 1979 until late 1986 when Andy MacAllister WA5ZIB took over the post.

SATELLITE COMMUNICATORS' CLUB

Just as with the low-band awards, some of the satellite certificates are more difficult to earn than others. Only a single satellite contact is sufficient to qualify for the Satellite

Communicators' Club certificate. The original certificate had a drawing of A-O-6 in the lower left. It was announced in "Satellite Operating Awards" by Ray Soifer W2RS in the June 1973 AMSAT Newsletter. Today's version shows a Phase-3 style satellite in the lower right corner (Fig. 1). Printing is with dark blue on light-gray textured paper. To receive the award, a report of a two-way contact through any amateur satellite is sent to the AMSAT S. C. C. Manager, P.O. Box 27, Washington, DC 20044. No form is necessary and submission of a QSL is not required. Pertinent information about the QSO along with a SASE and $1 ($2 for non-members) should be submitted. Walt Rader WA3DMF handles this program.

OSCAR SATELLITE COMMUNICATIONS ACHIEVEMENT AWARD

Originally known as the OSCAR Satellite Communications Achievement Recognition, the OSCAR Satellite Communications Achievement Award (renamed in 1992) is also known as the AMSAT OSCAR Award or AOA. This accomplishment requires proof of 20 qualified satellite contacts. A qualified QSO is one with a different state, Canadian call area or DXCC country, in any combination. Endorsements for each 10 QSO's above 20 are available only for those with certificates dated prior to 1992 when the certificate was updated (Fig.2). Printing is black on beige textured paper. The cost of the award is $3.50 for AMSAT members and $5.00 for non-members. Applicants should include QSL cards or other acceptable proof of contacts (ARRL W.A.S., DXCC, etc.) and return postage.

OSCAR SEXAGESIMAL AWARD

The program for the OSCAR Sexagesimal Award or OSA began in 1976 in response to the many endorsement sticker requests for the basic AOA. To receive the OSA, communication with 60 qualified stations is required. Costs and contact constraints are identical to the easier award. Less than 100 applications are on file for the OSA. The certificate (Fig.3) is printed with black on off-white parchment.

OSCAR CENTURY AWARD

The OSCAR Century Award represents another grade of difficulty beyond the OSA. One hundred qualified contacts via satellite are required for the award. In 1978 the cost was $5.00 for members. Today it is the same as the AOA and OSA, i.e. $3.50 for members and $5.00 for non-members. Less than 20 stations have applied for and received the OCA. The certificate (Fig. 4) is printed with black on off-white parchment with the AMSAT logo in red.

SA AMSAT SATELLITE COMMUNICATION ACHIEVEMENT AWARD

Countries besides the United States promote awards. South Africa AMSAT sponsors their Satellite Communication Achievement Award for making twenty-five two-way contacts through Phase-II satellites. Presently, that would include all RS and Fuji-OSCAR-20 activity.

A-O-10 and 13 (Phase-3) contacts are not allowed. The SA AMSAT award is available through AMSAT NA for the usual $3.50 for members and $5.00 for non-members. The certificate (Fig. 5) is signed by SA Awards Manager, Andre Botes, ZS2ACP (ex ZR2FK).

THE K2ZRO MEMORIAL STATION ENGINEERING AWARD

The K2ZRO Memorial Station Engineering Award Program, or just "ZRO Test", was begun seven years ago by Vern Riportella WA2LQQ via AMSAT-OSCAR-10. This technical achievement activity via satellite honors the memory of Kaz Deskur, K2ZRO. Kaz was known in satellite circles for his invention of the Satellabe OSCAR tracking calculator and his active participation in hamsat pursuits since the early days of A-O-6. The purpose of the competition is to promote operating skill and receiver performance by testing the listening capabilities of individuals monitoring the transmissions of a control station through the satellite transponder. The program continues today through the mode "B" and "JL" transponders of AMSAT-OSCAR-13. Test coordinators during the last seven years have included WA2LQQ, WA5ZIB, W6HDO and N5EM.

Test sessions are scheduled for periods when the satellite is positioned for optimum spacecraft antenna pointing angles with respect to all earthbound listeners. To provide consistency between tests, the best periods are usually near apogee with the satellite pointed directly at the center of the earth's disc.

During a test, which runs approximately 25 minutes, the control station will begin the event by matching his downlink signal to the level of the general beacon. After a short 10-word-per-minute message announcing the test, the numeric code groups begin. A random five-digit number is sent three times at the beacon level, level Z0. The control station will then pause and cut the uplink power in half (-3 dB) for a new random number at level Z1. The process continues to Z9 at 27 dB below the beacon.

The 27 dB decrease in uplink power is the result of cutting output power in half nine times. At the control station for Mode "B" tests, it is typically the difference between 25 Watts out at Z0 and 50 mW out at Z9 to a 13 dB gain antenna. The stations that have heard Z9 code groups correctly have copied an earth station the equivalent of a handie-talkie running a Watt to a seven-inch whip.

During the days of A-O-10 ZRO tests, a few stations copied level Z8. Soon after tests began via A-O-13 it was apparent that level 8 was not as difficult on the new satellite. Reports showed that many participants were interested in a new challenge, Z9. Calibration checks were made and the new level was sent with every test after January 1989.

The ZRO Test certificate is off-white parchment with dark blue printing and the AMSAT logo in red. It has positions for sixteen endorsement stickers, eight for mode "B" silver stickers and eight for mode "L" gold stickers. The addition of a Z9 endorsement was not envisioned when the program was created four years earlier. Since there was little room on the certificate for much else without marring one of AMSAT's finest awards, a new enhancement to the ZRO program was created, the Z9 Club. For those who qualify, there is a special individualized certificate (Fig. 7).

Results of the ZRO tests are shown in tables one and two for reception reports via Mode B (two-meter downlink) and Mode L (70-cm downlink) respectively. The listings include only callsigns for successful reception reports from Z4 (12 dB below the beacon to Z9 (27 dB below the beacon). Sorting is by callsign suffix, call area and prefix. Over 400 stations have participated in the tests. Reception reports are free to anyone submitting copied code groups to WA5ZIB. The results are recorded should a certificate be requested at a later date. Test schedules are announced via the AMSAT nets. ZRO brochures describing the award and participation requirements are available from WA5ZIB at 14714 Knightsway Dr., Houston, TX 77083 for an S.A.S.E. with two units of postage. The cost of the basic award is $3.50 for members and $5.00 for non-members. All reception reports and certificate requests should be sent directly to WA5ZIB. Foreign participants are encouraged to include additional funds to cover airmail postage.

SUMMARY

The AMSAT Awards Program has been active since the launch of A-O-6. Emphasis in recent years has been on the ZRO Tests, but all of the earlier awards, the SCC, AOA, OSA, OCA and the South African version of the AOA are still available and make excellent additions to any station.

Table 1. RESULTS OF ZRO TESTS FROM 05MAY85 THROUGH 30MAY92 LEVELS 4 THROUGH 9 MODE "B"

MODE B - Z4

DG7AAH, FC1BCU, WQ5C, WY0C, N1CHM, ON9CHZ, WI6D, KA2DWV, VE7EFF, DH0GMA, W3GYK, PA0HOP, DL1IU, DJ2JJ, DG9MAQ, KB3ML, KI6QE, WA0QJE, AJ9U, WA3YGQ, DG5ZP, M. Bennett

MODE B - Z5

KB6A, VE7AHX, WD4AHZ, WA1AYT, N5BKW, PA3BLY, W9BOZ, N6EEG, DG4FBC, W4FCJ, VE6GK, WB5HLZ, NG1I, DL3IAS, KY7J, K0JAN, K7JRA, WA9KCU, W9KFB, KF7KN, W4KSV, KA9LNV, 4X1MK, IK4MSV, WA3NAN, WA0NZI/HI8, DB7OB, DJ2OQ, KH6OS, WA3PGQ, DD1PI, KO9Q, WB0SMX, NW2T, WA7TSD, AB1U, W5VGF, WB0WAO, WA3WHE, JR8XPV, W5XR, KS8Z, KC3ZG, WA4ZZU, J. Gricci, F. Hahnel

MODE B - Z6

WA9AFM, VK5AGR, PB0AIO, ZL1AOX, OK2AQK, KJ4BF, N2BKT, KE4BM, W0BPP, WB1BRE, DK2BS, K7BZ, KA9CLP, N4CU, N1DBB, DG3DBI, WD0E, DL1EJK, N2EK, KM4EM, N8ENX, W0EOZ, WD6EPV, N3ET, DC6EV, WJ9F, DG6FAL, W7FF, W4FJ, KC5FP, N5FVM, K0GCJ, AB4GK, K2GLS, WA3GPP, DH5HAN, VE3HD, G2HIO, N9HR, PA0HTR, WA1HUM, WC5I, DC7IB, VE3IDJ, WD9IIC, W6ISO, KC7IT, W5IU, WA5IWB, N5JXO, DL5KBG, DK1KC, N6KDY, DD9KE, DK1KQ, WA6LXB, WT0M, WA1MBA, DJ9ME, N4MEY, W6MFO, DG5MHG, K2MPE, DG8NAB, KA9NAH, DG4NAX, DL1NDN, AA6NP, DJ3NY, WZ7O, K9OPO, WB3OSS, IK6PBX, W8PGP, K6PGT, VE3PQ, K1PXE, KA1QY, WA5RCL, SM3RF, HB9RHV, K8RSP, W0RUE, KB5SA, W6SHP, 9H1SW, AE3T, K4TWJ, W7UAB, DB4UF, KE2UK, DJ0UN, KA3VGD, W3VVP, W2WD, K6WE, KD6WG, VE5XU, W9YCV, K4YYL, ND9Z, WA5ZIB, K4ZQX, B. Lindholm

MODE B - Z7

VE7AAL, W6ABN, W1AIM, N8AM, VE4AMU, WB9ANQ, W2APU, WA6ARG, KF4AU, G3AUB, DK3AX, KR6B, NI0B, DG7BBX, K0BEJ, PY2BJO, IW1BMJ, K4BQH, SM1BUO, AE1C, I8CVS, NY0D, DL6DBN, WA7DEO, DB8DK, N4DZP, KF6E, WD0EQP, K5EVI, WD4FAB, WB2FCP, WA2FHL, N3FKV, W4FX, DL3GAX, W8GQW, W8GUS, N3GXC, W6HDO, LU1HGN, WA4HHG, KF8HI, W4HJZ, N3HQX, LU1HUC, SM3JSW, KK3K, PE1KDO, W4KDP, K1KSY, SM0KV, DL6LAU, N4LC, KG6LC, N5LCO, DK2LM, W5LTR, VE7LY, W9MBL, WB6MJN, PY2MSG, W6MSG, KB5MU, K9MWM, WA5MWW, WT0N, WD4NAE, WB0NCR, AB4NJ, VP8NO, DL8NP, N4NR, KE7NR, KG5OA, DL3OAG, W3OEJ, AJ9P, WA5PCN, WA7PIB, DG1PJ, AA6PJ, W3PM, SM5PPS, KA8PTQ, KJ4PU, WD8QCN, WA5QGD, DJ5QX, WA1QXR, WA0RGV, W5RRR, WA8RYD, DL9SAD, WA4SBC, DL3SBP, WA4SIR, KA5SMA, KC4SNP, DK5ST, WA4SXM, W6SZ, AF1T, G5TU, DL1TV, DK0UB, WB4ULT, KB7UZ, NB2V, K2VPR, W6VQT, W0WGZ, KE7WR, VE7YC, DL1YDD, DL6YDH, DJ1YQ, WB8YSE/5, W6YVO, DG5ZF, DF4ZK, KA8ZLA, K6ZXE, W0ZZQ

MODE B - Z8

NM3A, W3ADO, N8AI, W5AL, DL5BBL, N5BF, W5BKK, SM5BVF, AA5BY, ON5CD, DL1CF, DL9CI, W0CL, W0DEN, KA5DNP, DF5DP, DG3EAS, LU8EBH, N4EL, N5EM, WB2EMS, N9EP, N0ERC, KJ9F, N5FD, HB9FD, AA7FV, W5GEL, W2GFF, WB6GFJ, DL3GS, WA4GSS, NJ1H, NU9H, W2HG, W9JI, W8JLE, W4JNN, DJ5JQ, LA1K, DL6KG, W3KH, W7KRC, W8LBC, WB6LLO, DF6LO, VE6LQ, KA1M, W4MFZ, W4MAL, K1MON, K1MYL, DL6NDI, WA5NOM, W1NU, WD4O, WB9OEP, AA6OJ, WA4OSR, W8QX, W4RDI, K2RDX, W0ROD, G3RUH, NF6S, KB8S, DG3SCJ, W0SL, DK2SM, W6SYA, KG4TM/WB0RXX, ZL1TRE, N5UB, DD1US/A, VE6VM, WA3WBU, K8XF, OE6XHF, G4XXW, W8ZD, B. Hall

MODE B - Z9

PA2CHR, DL5DAA, N8DUY, PA3EON, KO4HD, W7ID, W7KIV, OH5LK, SM1MUU, K9NO, DG1PJ/C6A, N4SU, KC0TO, WB5UUK, DF7IT/DL0WH

Table 2. RESULTS OF ZRO TESTS FROM 05MAY85 THROUGH 30MAY92 LEVELS 4 THROUGH 9 MODE "L"

MODE L - Z4

F9FT, WS0H, DJ2JJ, W3KH, DK2LM, W2LRJ, WA6LXB, DG5MHG, KB5MU, W0RUE, DL9SAD, K1SC, 9H1SW, AE3T, WA5TWT, DB4UF, W1XT

MODE L - Z5

W6ABN, AE1C, DL1CF, DL9CI, KA5DNP, N5EM, KC5FP, WH6I, I5IT, K0JAN, W4KSV, SM0KV, W1NU, DJ3NY, WB9OEP, SM5PPS, W5RRR, K8RSP, DK0UB, WB0WAO, DL1YDD, R. Hoad, B. Lindholm

MODE L - Z6

NM3A, VE7AAL, DL5BBL, DG7BBX, K4BQH, DK2BS, NA5C, WY0C, N8DUY, KF6E, WD0E, DG3EAS, N4EL, WB2EMS, DC6EV, DG5FAL, N3FKV, W6HDO, W4HJZ, PA0HTR, W6ISO, DK1KC, DL6KG, DK1KQ, K9MWM, DL6NDI, N4NR, DH0OAH, AA6OJ, K6OYY, DJ9PC, DG1PJ, DG1PJ/C6A, VE3PQ, KA8PTQ, KI6QE, WA5QGD, DJ5QX, WA0RGV, HB9RHV, KB5SA, DL3SBP, NB2V, K3VDB, KA3VGD, VE6VM, KD6WG, KE7WR, VE7YC, DL6YDH, K4YYL, ND9Z, KC3ZG, WA5ZIB, M. Bennett

MODE L - Z7

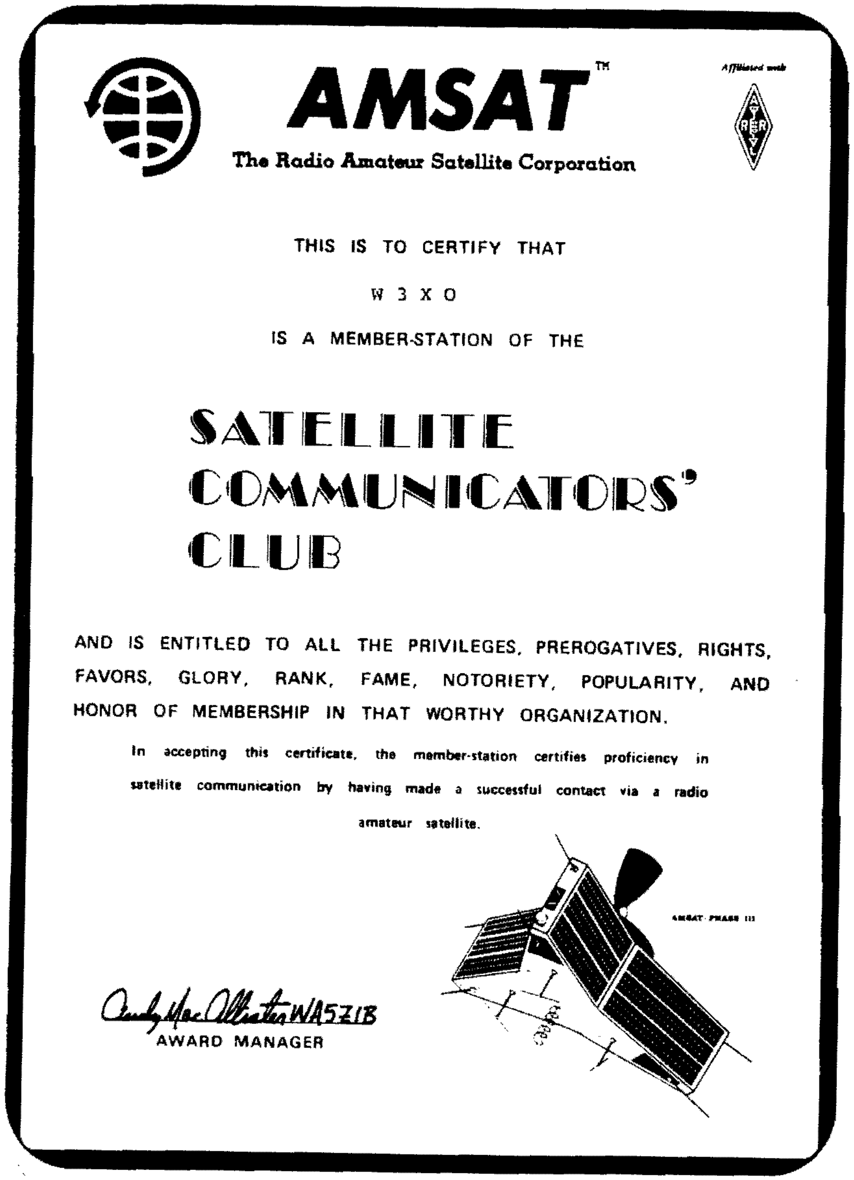
VE4AMU, N5BF, DL5DAA, DL6DBN, N9EP, HB9FD, AA7FV, K1MYL, WD4O, AJ9P, K2RDX, DK2SM, W6SYA, K2VPR, W0WGZ

MODE L - Z8

W3ADO, N8AI, N8AM, DK3AX, N5BKW, SM1BUO, SM5BVF, I8CVS, N8DNX, LU8EBH, K5EVI, W5GEL, W2GFF, WB6GFJ, W8GUS, W2HG, G3IOR, W8JNN, DJ5JQ, N5LCO, WT0M, K9NO, WA5NOM, AA6NP, KE7NR, KG5OA, WA4OSR, AA6PJ, WA7TSD, G5TU, DD1US/A

MODE L - Z9

VE7CLD, DF5DP, W7ID, KG4TM/WB0RXX, DF7IT/DL0WH


AMSAT™

The Radio Amateur Satellite Corporation

Affiliated with ARRL

THIS IS TO CERTIFY THAT

W 3 X O

IS A MEMBER-STATION OF THE

SATELLITE COMMUNICATORS' CLUB

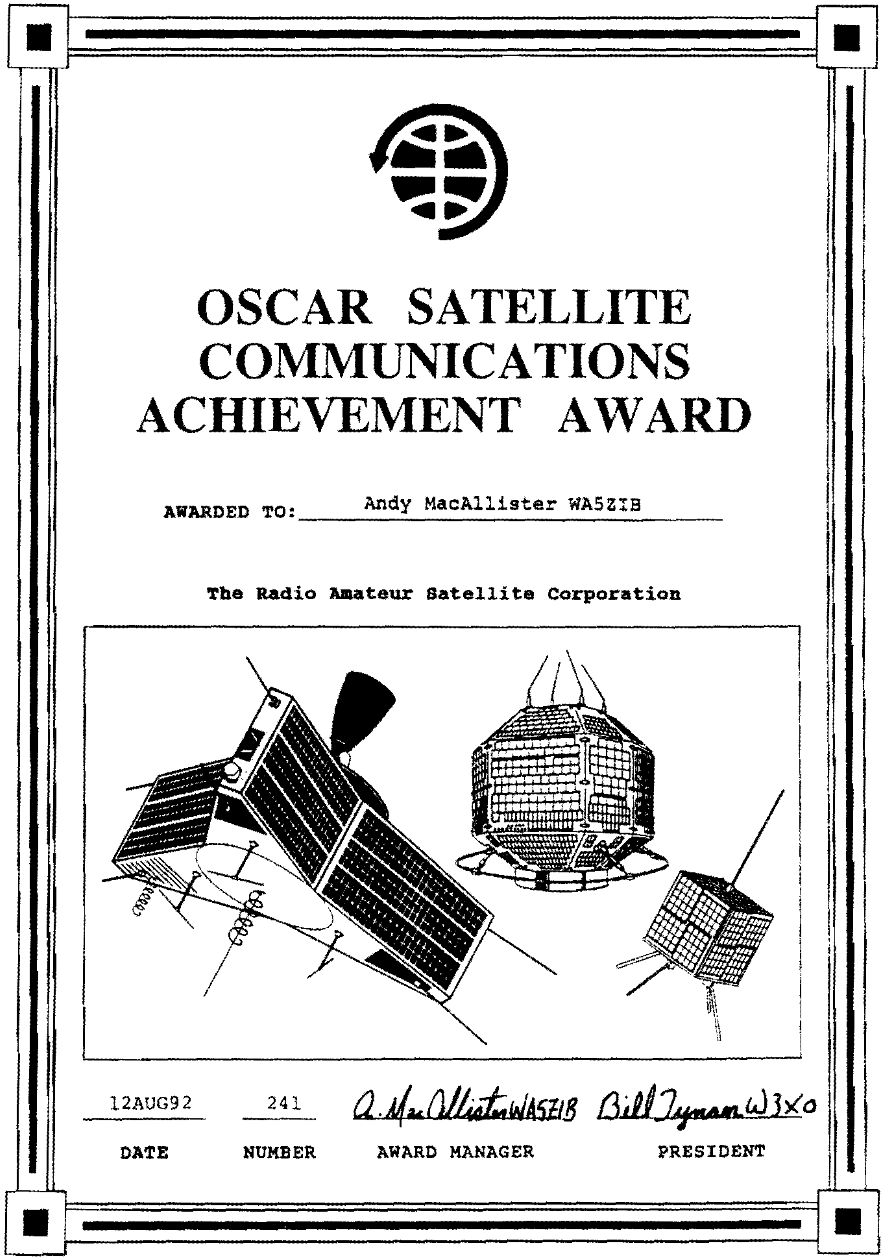
AND IS ENTITLED TO ALL THE PRIVILEGES, PREROGATIVES, RIGHTS, FAVORS, GLORY, RANK, FAME, NOTORIETY, POPULARITY, AND HONOR OF MEMBERSHIP IN THAT WORTHY ORGANIZATION.

In accepting this certificate, the member-station certifies proficiency in satellite communication by having made a successful contact via a radio amateur satellite.

AMSAT PHASE III

Andy MacAllister WA5ZIB
AWARD MANAGER

Figure 1.


OSCAR SATELLITE COMMUNICATIONS ACHIEVEMENT AWARD

AWARDED TO: Andy MacAllister WA5ZIB

The Radio Amateur Satellite Corporation

12AUG92	241	A. MacAllister WA5ZIB	Bill Tynan W3XO
DATE	NUMBER	AWARD MANAGER	PRESIDENT

Figure 2.

OSCAR SEXAGESIMAL AWARD

This certifies that Andy MacAllister operating Amateur Radio Station WA5ZIB has submitted evidence to AMSAT Headquarters of having conducted two-way Satellite Communication with other Amateur Stations in at least sixty different Canadian call-areas, United States, other countries, or any combination thereof. This certificate is awarded by AMSAT in recognition of this outstanding achievement in Amateur Satellite Communication.

12AUG92	90	A. MacAllister WA5ZIB	Bill Tynan W3XO
Date	Number	Award Manager	President

Figure 3.

Figure 4.

OSCAR CENTURY AWARD

This certifies that Andy MacAllister operating Amateur Radio Station WA5ZIB has submitted evidence to AMSAT Headquarters of having conducted two--way Satellite Communication with other Amateur Stations in at least one hundred different Canadian call-areas, United States, other countries or any combination thereof. This certificate is awarded by AMSAT in recognition of this superlative achievement in Amateur Satellite Communication.

12AUG92	15	A. MacAllister WA5ZIB	Bill Tynan W3XO
Date	Number	Award Manager	President

SA AMSAT
SATELLITE COMMUNICATION
ACHIEVEMENT AWARD

Andy Mac Allister WA5ZIB

This award is made in recognition of having made twenty-five two-way contacts through Phase II Satellites.

André Botes ZR2FK
AWARDS MANAGER

AWARD NUMBER S.A.1

Sir Speedy

Figure 5.


The AMSAT Technical Achievement Award

AMSAT

presents the

K2ZRO Memorial Station Engineering Award

to:

DJ8TJ

for

Demonstrating Outstanding OSCAR Station Performance in an AMSAT-Sanctioned Test

Bill Tynan W3XO — President

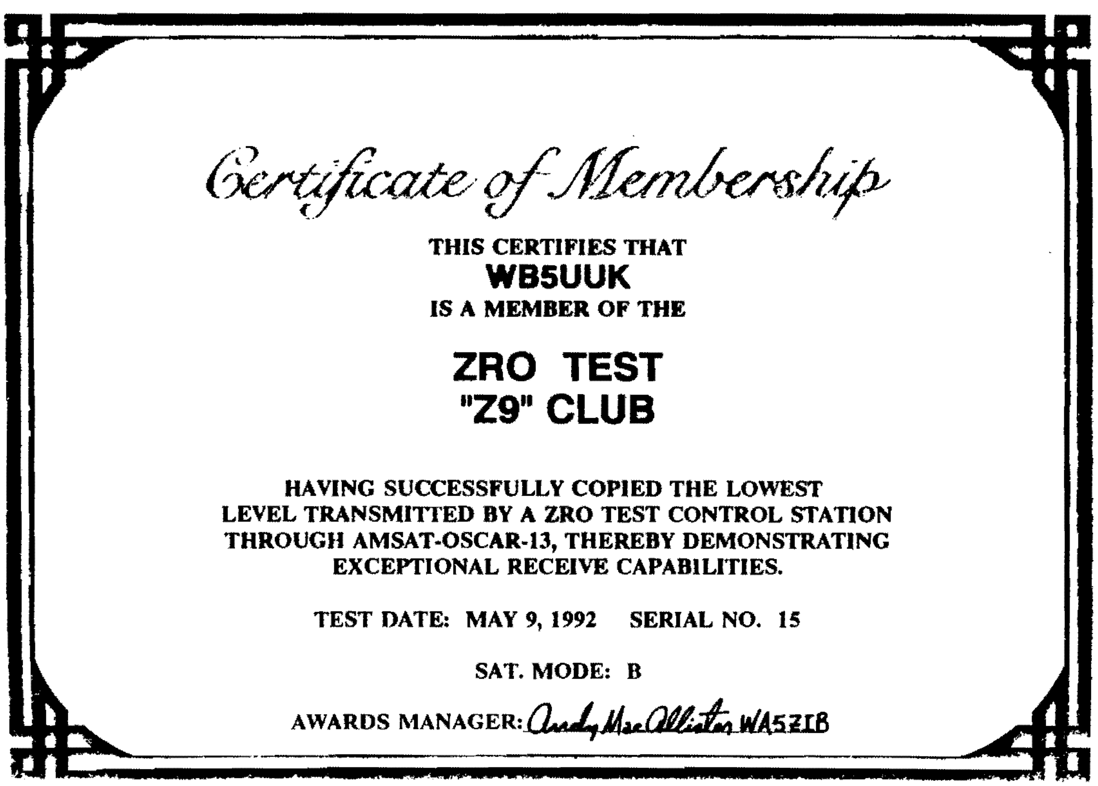
NOVEMBER 23, 1991 — Date

Mode B Endorsements

Mode L Endorsements

Figure 6.

Figure 7.


Certificate of Membership

THIS CERTIFIES THAT

WB5UUK

IS A MEMBER OF THE

ZRO TEST
"Z9" CLUB

HAVING SUCCESSFULLY COPIED THE LOWEST LEVEL TRANSMITTED BY A ZRO TEST CONTROL STATION THROUGH AMSAT-OSCAR-13, THEREBY DEMONSTRATING EXCEPTIONAL RECEIVE CAPABILITIES.

TEST DATE: MAY 9, 1992 SERIAL NO. 15

SAT. MODE: B

AWARDS MANAGER: Andy MacAllister WA5ZIB

AMSAT's COMMUNICATIONS BACKBONE: WHAT IS AMSAT.ORG ?

Tom Clark, W3IWI
Paul Williamson, KB5MU
Brian Kantor, WB6CYT

Let's start with a bit of history -- Since its inception in the late 1960's, AMSAT has continually faced communications problems:

- How do we get information to satellite users around the world?
- How do we get information back from the users?
- How do we coordinate world-wide operational activities?
- How do we coordinate the people developing hardware and software?
- And, since the HF nets have always been important to AMSAT's activities, how do we get material to the Net Control stations?

In the early 1980's, AMSAT began using a commercial electronic mail (E-mail) network called TeleMail (then owned by GTE, now by US Sprint) as a communications backbone and AMSAT arranged accounts for a number of individuals. TeleMail worked well because most users could access a local X.25 port with a local telephone call. E-mail services were good and reliable. AMSAT's TeleMail services provided bulletin board facilities for discussions of AMSAT issues, mailing lists for working groups, and reliable person-to-person communications.

But TeleMail is a commercial venture, and AMSAT had to pay for the services. The portion of each users account that would be subsidized was always a contentious issue, and Martha found it a painful duty to send out statements asking for payment. The cost to the AMSAT treasury reached levels of as much as $25,000 per year. Because of the cost issues, it impossible to offer TeleMail "membership" to all -- and hence many viewed the TeleMail network as an internal AMSAT clique.

While the AMSAT management was wrestling with this problem, an alternative was developing. In the early 1980's the Dept. of Defense subsidized a group of universities and research groups to build the ARPANET. This community developed a set of networking protocols, known as TCP/IP (Transmission Control Protocol/Internet Protocol) which allowed a relatively easy way to interconnect diverse computer resources. The "big" network was really a way to allow connectivity between smaller networks, which in turn connected even smaller networks.

The mid-1980's saw several developments in computer networking. The research communities of the USA (and some foreign countries) saw that computer networking was the wave of the future. The original ARPANET became the Internet with major sponsorship from the National Science Foundation (NSFNet), NASA (NASA Science Internet), Dept. of Energy, etc. More and more facilities became connected, and the quality of links continued to improve. Each sponsor and institution saw it was to his advantage to fund the network infrastructure and to connect the institution.

This explosive growth was aided by the parallel development of low-cost high-performance computers. From the introduction of DEC's VAX (and later MicroVAX) and UNIX-based workstations (Sun, Apollo, Hewlett Packard, Iris, etc.) support of the Internet protocols became commonplace. Phil Karn, KA9Q led the effort to develop these capabilities for amateur applications running on PC-clones, MACs, AMIGAs and other machines we have in our hams shacks.

Amateur radio was developing its packet radio networks at the same time, as packet bulletin board systems (PBBS) started handling messages on a regional and trans- and inter-continental basis. AMSAT worked with the packet community to use these amateur channels to distribute news information and Keplerian elements to the users. The @AMSAT bulletins were "fed" to selected gateways for redistribution on the air. This "feed" made use of AMSAT's TeleMail network.

In 1989, AMSAT-NA embarked on its Microsat development program. Immediately we saw that these satellites would make heavy use of personal computers for mechanical and electrical CAD activities. Also, the Microsat project had significant activities spread out over a dozen states plus Canada, Argentina and Brazil. The technical groups saw the need for enhanced communications to develop the hardware and software. We saw that we needed more communications capabilities than TeleMail could provide.

The growth of the Internet, the rising costs of TeleMail and the need for better communications led to an experiment to see if the Internet could take over from TeleMail. The first phase of this experiment was to use Internet (augmented by the new capability to interchange E-mail between Internet and CompuServe) as an alternative to TeleMail for the distribution of @AMSAT bulletins. W3IWI set up his Internet host named "tomcat" (originally standing for Tom C's AT -- its "full" Internet name is tomcat.gsfc.nasa.gov) to distribute the @AMSAT material to a list which rapidly grew to 200 subscribers on all six continents. KA9Q and W3IWI confirmed with the powers that be that AMSAT's nature as a non-profit, scientific/educational group qualified it to make use of the Internet, making a migration perfectly legal.

Tomcat ran (and still runs) on a 386 PC clone with a version of KA9Q's "NOS" TCP/IP software. Unfortunately NOS was never built to "explode" a message to a list with hundreds of entries, resulting in 100+ outgoing messages being queued, and the system reliability left something to be desired. A get-together with the "providers" and the "users" at the 1991 AMSAT Annual Meeting in Los Angeles decided that, despite the reliability problems, the experiment was a smashing success. It was shown that Internet (plus CompuServe for those lacking direct Internet connectivity) could do the job at a much lower cost to AMSAT than TeleMail. Brian, WB6CYT (in charge of managing the U.C. San Diego E-mail resources) agreed to take on the task of hosting a dedicated (and hopefully more reliable) AMSAT Internet gateway at UCSD. W3IWI reported on these developments and the AMSAT Board concurred. The AMSAT Board authorized money to purchase a suitable host.

THUS AMSAT.ORG IS BORN

Brian managed to "build" an antique Sun 2/220 UNIX computer out of spare parts. He registered the domain name "amsat.org" with the Internet hierarchy, and proceeded to bring the system online in San Diego. W3IWI transferred all of tomcat's list to the new "amsat.org" host, and in March, 1992 the AMSAT mailer functions were moved from the east coast to the west coast. Paul, KB5MU stepped in at the same time to handle the primary list maintenance chores.

Even though the present Sun 2/220 hardware is an antique, it has been quite reliable. It had one day down due to a failed disk controller card, but other than that it has been in 24 hour/day service. AMSAT will soon replace the antique Sun 2 with a newer Sun 3/60. W3IWI's "tomcat" host still provides file server support for AMSAT. As more disk space is available on AMSAT's amsat.org host, the file server functions will migrate from tomcat to AMSAT-owned hardware.

As amsat.org has become better known. The master "aliases" list which equates an individual's call to his real E-mail address now has about 400 entries on every continent. The "exploder" lists that send the @AMSAT bulletins or the Keplerian elements have about 250 "subscribers".

E-mail addresses are always confusing. As we have set up amsat.org, each person served by the mailer has an alias entry something like these:

```
g7kvi:kichoi@satrec.kaist.ac.kr
hb9xj:100015.33@compuserve.com
hl9pit:det15wx%osan-emh.af.mil@trout.nosc.mil
i2kfx:i2kfx@vnet.ibm.com
jf7wed:913284%JPNTSUK2.BITNET@pucc.Princeton.EDU
jk1vxj:ohara@leland.stanford.edu
jm1mcf:katoh@tansei.cc.u-tokyo.ac.jp
k2iyq:73060.1636@compuserve.com
k3wgf:cdiekman@ftsmhstn-hsc.army.mil.ddn
ka1m:drew@shiva.com
ka1rho:keith.erskine@east.sun.com
ka1uev:ka1uev@torrey.umm.maine.edu
ka2pbt:ROSCHEWSK+pR+la+rNYIS+la+rNYCCORP%Continental_Grain@mcimail.com
```

Each entry shows an amateur's call (the alias) and the real E-mail address for that person. In some cases, the hieroglyphics associated with a "real" address are mindboggling. The call-letter based alias is intended to remove a lot of the mysteries associated with E-mail. By example, if you were a masochist, you could address an E-mail message to the last of these sample entries, KA2PBT as

```
ROSCHEWSK+pR+la+rNYIS+la+rNYCCORP%Continental_Grain@mcimail.com
```

or you could send it to

```
ka2pbt@amsat.org
```

Which would you choose?

AMSAT.ORG Mailing List and Remailing Services

[Note --the following material is taken from the standard files sent to a "subscriber" who asks for help]

AMSAT-NA operates the Internet host AMSAT.ORG to provide for efficient communications between people interested in the amateur satellite program. At this time two services are provided: a message remailing service and a mailing list service.

In the future, an archive of files will be accessible by anonymous ftp or possibly by email. In the meantime, check the hosts tomcat.gsfc.nasa.gov and ucsd.edu by anonymous ftp for AMSAT-related files. Consult your local Internet guru for help on using anonymous ftp.

The message remailing service permits users to send each other mail on the Internet without keeping track of each other's Internet address. The remailing service allows each user to receive mail sent to the address callsign@amsat.org, where callsign is that user's amateur radio callsign, or other unique identifier. Mail sent to that address will be routed first to the AMSAT.ORG host at UCSD in San Diego, then remailed from AMSAT.ORG to the network address specified by the user. In most cases, this process delays the message by only a very few minutes.

The mailing list service groups subscribers into mailing lists to receive certain types of messages. There are public mailing lists available to anyone, and private mailing lists available only to certain people (for example, AMSAT Board of Directors members or PACSAT command stations). Currently the following public mailing lists exist:

ANS AMSAT News Service

This mailing list carries official news releases from the AMSAT News Service. These messages are posted in a form suitable for direct posting to a packet radio BBS system. Each message contains a Bulletin Identifier (BID), which permits the message to be introduced into the packet network at many places without resulting in duplicate bulletins at any BBS. The primary purpose of this mailing list is to distribute ANS bulletins for redistribution (via the packet net or on AMSAT voice nets), but individuals may also subscribe for their own use. If your local packet BBS doesn't seem to get the ANS bulletins reliably, you are encouraged to post the ANS bulletins yourself.

Only authorized AMSAT News Service personnel should send messages to the ANS mailing list.

AMSAT-BB AMSAT bulletin board

This mailing list carries general AMSAT information. This information may NOT be suitable in content for transmission via amateur radio, so automatic reposting of AMSAT-BB messages to packet radio BBS's is discouraged. The purpose of this mailing list is to provide a forum for general discussion of any satellite-related topic.

Anyone may send messages to the AMSAT-BB mailing list. Simply address your message to

amsat-bb@amsat.org

and it will be automatically forwarded to all subscribers to the AMSAT-BB mailing list.

Editors of publications should ask permission of the sender before publishing anything seen in AMSAT-BB elsewhere, unless the posting was obviously a public press release. However, posters should realize that anything posted to AMSAT-BB is essentially public.

KEPS Keplerian Elements mailing list

This mailing list carries official postings of Keplerian element sets for satellites of interest to radio amateurs. Like the ANS bulletins, these messages are posted in a form suitable for direct posting to a packet radio BBS. Only authorized AMSAT personnel should send messages to the KEPS mailing list.

NASAINFO NASA related information mailing list

This mailing list contains information about current and planned NASA space missions. Be forewarned: at times this mailing list delivers many large messages.

SAREX Shuttle Amateur Radio Experiment mailing list

This mailing list contains information and press releases pertaining to SAREX missions.

To subscribe to any of these services (lists), just send a message to the address

listserv@amsat.org

This address may be reached from CompuServe MAIL as:

>INTERNET:listserv@amsat.org

For the moment, the maintenance of the AMSAT.ORG mailing lists and remailing aliases is done manually. Later, this service will probably be automated and you will have to follow a strict message format. For now, you may send requests in free format. They will usually be processed within a few days. In general, you will not receive an explicit reply to your request.

You should not send messages about your subscriptions to any of the mailing lists. Send them to listserv@amsat.org instead. This includes questions, requests for changes, requests for information about mailing services, and complaints.

The list of amateurs who may be reached via the message remailing service may be obtained by requesting the "address book". Note that the address book as distributed contains only the callsigns of the available addressees, not their actual Internet addresses. The address book is updated occasionally, and does not necessarily contain the very latest information.

You may request to be added to the list, to be deleted from the list, or to have your Internet address changed on the list. Please include your callsign if you have one. If you don't have a callsign, that's OK, but please say so. If you have more than one Internet address you want to have available on the AMSAT.ORG remailer, you may so specify. For instance, if you have a regular Internet address and a CompuServe account, you may appear in the address book as both w1xyz and w1xyz-cis. Mail sent to w1xyz would go to your Internet address, and mail sent to w1xyz-cis would go to CompuServe. MCImail accounts have the form w1xyz-mci, and so on.

You may also subscribe or unsubscribe to any of the public mailing lists described above. Send a message to listserv@amsat.org, specifying clearly which mailing list(s) you want to add or drop, and giving your callsign if you have one. When you subscribe to a mailing list, you will automatically be added to the remailing service as well, because the mailing lists are maintained by callsign. If you have more than one address listed in the remailing service, please indicate which one(s) you want the mailing list messages sent to.

Additional mailing lists, public or private, can be set up as needed. Send mail to listserv@amsat.org for details.

Questions about any service offered by AMSAT.ORG may be directed to listserv@amsat.org as well. Just so you know, mail to listserv really goes to KB5MU with a copy to W3IWI. KB5MU does the work, and W3IWI is there to provide backup assistance.

At some time in the near future, the maintenance functions provided by the listserv@amsat.org function will be done by a mindless automaton. When that happens, we will notify the users of the new listserv subscribe/unsubscribe format and we will establish a different address for you to send messages when you want them to be addressed by a human being.

FAQ (Frequently-asked Questions) and Complaints (and Answers):

1. Why do I get "MCI Mail Rejected a Message" responses each time I send a message?

MCI won't accept mail from CompuServe via the Internet. This is just corporate policy. There isn't anything we can do about it, short of banning MCImail addresses from the mailing lists.

2. Why did the mailing list messages suddenly stop coming to me a few weeks ago?

Something may have been temporarily wrong with mail delivery to your site. If a message to you bounces back to the poster, you may be removed from the mailing list without notice. If you think this has happened to you, send a message to listserv@amsat.org and ask.

3. I never get an answer from w1xyz when I send him mail via AMSAT.ORG.

If his mail isn't getting delivered, you *should* receive some kind of automatic message indicating there has been a delivery problem. If you don't get such a message within a few days of sending your message, chances are that your message made it to the addressee's mailbox. However, the addressee may be behind on reading email, or may simply not bother to reply, and there isn't much we can do about that.

Another possibility is that the message you sent contains a bad "From:" address. This will prevent the recipient from replying to your message. If you suspect this may be happening, include your real Internet address in the text of the message. If you find that this is happening, please complain to your system administrator.

4. My computer says "unknown host" whenever I try to reach AMSAT.ORG.

This indicates a problem with domain name service. AMSAT.ORG *is* a fully official domain name, and your host should be able to find it. Check with your local network administrator (tell him to check the nameserver at ucsd.edu). As a workaround, you may be able to use an address of the form

callsign@amsat.ucsd.edu (or listname@amsat.ucsd.edu)

or use the form

callsign%amsat.org@ucsd.edu

or, if you are coming in from UUCP,

ucsd!amsat!callsign

to force the message to pass through the UCSD.EDU mail host on its way to AMSAT.ORG. If your local system can't find ucsd.edu, you're in real trouble!

5. I have an important announcement I'd like to make. Can I send it to the ANS mailing list?

Not unless you're an official ANS station. You may send it to AMSAT-BB, and/or submit it to the ANS editor (wd0hhu@amsat.org) for possible inclusion in the next issue of ANS.

And no, the computer doesn't enforce this rule. You're on your honor.

6. I can't get Internet access!

Yes, you can. It may not be very easy or cheap, but you can. You have a number of alternatives:

* Find a local connection. Most hams have inside connections they don't even know about. If you know somebody at the local university or at a high-tech company, ask them if there's any way for you to have access to the Internet through their system. Sometimes the answer will be yes. If you are in a position to grant access, *please* make this service available to local AMSAT folks.

* Check with your local BBS. Some telephone BBS systems have access to a mail gateway that will allow you to send and receive Internet mail; ask the questions "Do you support UUCP mail?" and "Are you in Fidonet?". Also in some areas the local packet TCP/IP guru may have arranged for an "ENCAP Gateway" or some other wormhole into Internet. These may not be the fastest way to receive the mailing lists, but it is probably the cheapest if you don't have free access.

* Subscribe to a pay service that offers Internet or UUCP mail services. There are several systems that offer Internet access for a fee. CompuServe subscribers can find a list in the Internet library of the TELECOM Forum. AMSAT does not maintain a current list of public Internet providers.

* Subscribe to CompuServe. Many subscribers to the mailing lists receive their mail via CompuServe. This is an expensive choice, but it is very easy and available in most developed parts of the world. CompuServe is often a local telephone call, and they have an 800 number for people in the less-populated areas of the US. CompuServe starter kits are available at computer stores, and there's often one included free when you buy a modem.

  CompuServe users can send mail to Internet addresses by adding

  >INTERNET:

  before an Internet E-mail address. The ">" and the ":" are required, and "INTERNET" must be in uppercase. For example, to send mail to w1xyz (assuming w1xyz is on amsat.org's lists, you can use the address

  >INTERNET:w1xyz@amsat.org

  from CompuServe MAIL. Note that there is no way to communicate between Internet and a CompuServe forum like HamNet. The Internet gateway only works for CompuServe MAIL.

  There may be an additional surcharge for receiving messages from the Internet on CompuServe. As a CompuServe subscriber, your mail may also be subject to additional delays. Worse, CompuServe limits the amount of mail you can have pending in your mailbox, so you must read your mail frequently. Check with CompuServe for details.

7. There's too much XYZ being posted to mailing list ABC!

It's not possible for the mailing lists to contain exactly what you find interesting. If we are to share information freely, all subscribers must be prepared to cope with a certain amount of traffic they find boring or useless.

Sometimes it becomes a clear problem, with one subject generating so much traffic that it becomes a burden on a more general mailing list. In those cases, a new mailing list can be created to make it possible for only those who are interested to receive the information. However, there is a practical limit.

8. I posted a message to mailing list ABC, and I got a bunch of bounce messages back.

Most automatically-generated problem report ("bounce") messages should be automatically routed to the list administrator. These messages usually signal a transient problem somewhere in the network. Often, the problem is at the receiving end. If a particular subscriber generates repeated bounce messages, that subscriber will be removed from the mailing lists.

If by some mischance a bounce messages comes back to you, the poster of a message to one of the mailing lists, please forward the bounce message (or a sample if many arrive) to listserv@amsat.org. Please forward the entire message including headers as received. If the echoed text is large, you may edit it down, but preserve all headers and bounce message text.

Do NOT forward bounces resulting from sending messages from CompuServe to MCImail. There's nothing to be done about that.

AMATEUR TELEVISION VIA THE PHASE 3D SATELLITE?

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Preface: The following paper is a technology update of a paper and demonstration videos which were presented at the 1991 AMSAT Space Symposium in Los Angeles, CA, November, 1991.

The fact that most of the world of communications, both amateur and commercial, is "going digital" comes as no surprise to informed radio amateurs. The advantages to be gained by digitalization open up new, previously undreamed of capabilities, the most obvious of these being packet radio. This is merely the beginning of a long and increasingly rapid process of change in electronic communications. Currently digital signal processing (DSP) has an impact on equipment design; several products incorporating this technology have already appeared in the amateur market. This article, explores much deeper into the digital world, not just the digitalization of data or text as in packet radio, but the transmission and reception of digitized motion images. This is a new form of Amateur Television (ATV) which is far more efficient, both in terms of spectrum use and power density, than its conventional analog relative. Just as SSB seemed much different than AM voice when you first experienced it, this new mode seems strange at first. In the same manner, it won't take long to realize the tremendous practical advantages of the new approach. Seeing the person with whom you're talking on the air won't be difficult. It's called digital video, and because the simplified approach suggested here is aimed at radio amateur experimenters, it is referred to as Amateur Digital Video, ADV for short.

BACKGROUND

The planning to construct the AMSAT Phase 3D Satellite, an advanced communications OSCAR in high-earth orbit, includes providing a wide bandwidth digital transponder with the capability of handling traffic in the range of 64 Kbps or possibly higher speeds.

The use of Amateur Digital Video (ADV) communications is based on a device known as a coder/decoder, or simply a "codec." Progress in the areas DSP and digital communications technology would eventually make compressed motion digital video communications possible. The availability of efficient and economical codecs has significantly accelerated developments. Such a codec, with the appropriate modem, could be used to digitize the motion video output from any standard baseband video such as NTSC, PAL, or SECAM source (the codec can be equipped to accept varied video inputs yet still permit communications compatibility), such as a home video camera or video cassette recorder (VCR) for a terrestrial digital video transmission on a suitable UHF band, or uplinked to the future AMSAT Phase 3D Satellite to span the continent. This codec could also take an incoming digital video motion signal from your receiver or downlink system and convert it to an analog video motion signal for display on any appropriate monitor.

Using digital video compression techniques such as vector quantization (VQ) or the newer discrete cosine transform (DCT) technology, or some combinations of both VQ and CDT, excellent communications quality motion video can be achieved from digital speeds of 1.5 Mbps down to as little as 64 Kbps. This need not be a monochrome or black and white image. By employing color sub-sampling compression algorithms, a color image suitable for interpersonal communications can be achieved while as little as 20% of the available bandwidth.

Digitized motion video can be taken from its uncompressed digital form of approximately 90 Mbps down to 64 Kbps for far more efficient transmission between ground stations, or between ground stations and a spacecraft, than conventional analog television. Current techniques, even at these tremendous compression ratios, provide acceptable color contrast and image resolution, with moderate motion compensation capability. Anticipated production of higher performance custom microchips for digital video such as the Vision Processor from Integrated Information Technology (IIT) promise even better image quality in the months and years ahead. The current line of IIT microchips perform well above the 50 Mips level, resulting in more than 2 Gops!. More importantly for radio amateurs, the continued use of very large scale integration (VLSI) technology in chip production means rapid declines in equipment cost. This will make experimentation, and later ADV development, less expensive.

This rapidly declining cost cycle has been the trend in digital video compression over the past few years. The net result has been a steady reduction in digital bandwidth requirements and equipment cost, while the motion image quality level has improved considerably. We are now quickly approaching the development stage where a simple codec system is starting to come within financial range for Hams. Certainly long before the launch of the AMSAT Phase 3D Satellite, now scheduled for the 1995-1996 time frame, we should literally begin to see many developments in digital video transmission. For example, ADV would provide an acceptable signal to noise ratio and link margins for Amateur ground stations without the need for excessive power levels as indicated for even low earth orbit (LEO) activities during the SAREX Space Shuttle video reception tests. This is an important consideration when planning such future amateur activities from the space station. ADV could also provide a type of terrestrial video communication which is considerably more spectrum efficient than analog ATV. Schools, and other interested parties, could use an even simpler and less-expensive decoder (i.e., receive only) unit.

FACE-TO-FACE CONTACTS

Meeting face-to-face provides the most effective means of interpersonal communications. The apparent reason for this, as amateurs working in the visual modes are well aware, is that a great deal of the communications between two individuals is non-verbal. This important observation is one of the driving forces behind the explosive growth in the use of digital video teleconferencing by business. Developments in the area of very large scale integration (VLSI) and digital video compression technology are approaching the stage where radical changes in the economics of the situation are about to take place.

The day of the video telephone for interpersonal communications, envisioned long ago, has now arrived. Recently AT&T released a product called the Videophone 2500. However, this is an analog device using a codec which is compressing the video to an extreme degree (9.6 Kbps) so that a modem can send it over analog telephone lines in the home. The effective frame rate is only about one frame per second. Amateurs can readily use a similar codec operating with different software at 64 Kbps or higher speeds to obtain a higher frame rate and fewer digital video artifacts (i.e., a better motion image). Even at digital bandwidths of 64 Kbps, frame rates of 8-10 per second are feasible. A common frame rate at a digital video speed of 384 Kbps is 30 per second, a rate similar to conventional television, in which even fewer artifacts are observed.

WHAT ARE ARTIFACTS?

Because we are examining motion digital video and not analog television, it is necessary to discuss new terminology regarding image quality. The currently accepted P0 through P5 numerical measurement to describe the subjective quality of analog television is not very adequate for this purpose. Although no similar numerical measurements are widely accepted for digital video, terms are developing to describe perceived distortions. The most common of these are: loss of sharpness, granular noise ("the dirty window effect"), motion judder, busyness around edges ("mosquito noise"), appearance of block boundaries, and chroma bleeding. A codec can be informally evaluated by the extent to which these artifacts are observed.

WHAT IS DIGITAL VIDEO?

You have been watching a wide bandwidth form of digital video for years and may not have realized it! As mentioned earlier, to digitize an analog video signal takes about 90 Mbps. The national TV broadcast networks take this digitized video signal, compress it 2:1, and broadcast it to their affiliated stations. The digitalization and compression of television broadcasts allows networks to send their programming over special terrestrial circuits that handle the resulting 45 Mbps digital video signal. Digital video compression at this level, when converted back to analog, retains all of the characteristics of the original NTSC video.

And you're about to see a lot more digital video! The high definition television (HDTV) currently under industry development and FCC review for the consumer entertainment television broadcasting field is essentially a form of high bandwidth digital video. Commercial direct digital video satellite broadcasting of movies and other forms of video entertainment to the home is under development by companies such as Compression Lab,Inc. (CLI). The system, called SKYPIX, uses digital video bandwidths of 2.9 to 6.6 Mbps and dish antennas as small as 0.75 meters (about 30 inches across). Serious consideration is being given to replacing conventional private analog business television (BTV) broadcasts, generally via commercial Ku-Band satellites, for university educational seminars, product announcements, training programs, etc. with digital video broadcasts, either via terrestrial commercial fiber optic lines or via commercial satellite.

This approach allows companies to put as many as 12 channels of video on one commercial satellite transponder.

If digital video signals are further compressed, say by a factor of 60:1 to 1.5 Mbps, there is still more than sufficient quality remaining to use them for relatively economical business two-way communications via a special digital circuit called a T1. This current method allows commercial organizations to hold group meetings without having to travel to distant locations. True, you would probably not want to use this highly compressed digital video 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 video bandwidths down to 384 Kbps, and recently, even to 128 Kbps while still maintaining excellent image, color and voice quality.

THE ADVANTAGES TO AMATEURS

Although these developments are impressive from a commercial perspective, they do not presently provide many alternatives for amateurs. However, amateurs are very resourceful and deal effectively with reduced quality of communications to put a new technology to use in an affordable manner.
Recent developments to reduce the digital video bandwidth to as little as 64 Kbps for commercial Integrated Services Digital Network (ISDN) video telephony start to look promising for amateur hardware applications. ISDN is a new class of digital telephone line that is becoming widely available in Japan and will soon be available in the US.

At the bandwidth of 64 Kbps, the video image quality is significantly reduced as compared to standard television (NTSC, PAL, or SECAM), but it is far superior to the consumer video phone and is more than adequate for most amateur two-way motion video 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 any currently envisioned amateur satellites to transpond these signals. Even ATV communication with the Space Shuttle requires very big gun ATV stations. Digital video techniques must be used for the average amateur to become involved with video space communications using moderate power levels and reasonably sized antennas. According to Dr. Karl Meinzer DJ4ZC, President of AMSAT-DL, based on a guideline of 350 bps per watt effective isotropic radiated power (EIRP), approximately 64 Kbps are achievable on the planned semi-geostationary, high-altitude AMSAT Phase 3D satellite. By using quadrature phase shift keyed (QPSK) modulation, such a transponder would probably be suitable for ADV purposes. The Tele-Tech Corporation 9211 Series of QPSK Modulator/Demodulator devices is the hardware currently being investigated by the author for this application. This is the type of device that will be incorporated into the next generation of digital audio cellular telephones, replacing the current FM systems.

It is possible that by the time the AMSAT Phase 3D satellite is launched, acceptable compressed digital video down to a bandwidth of 19.2 Kbps may be possible. 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 AMSAT Phase 3D Satellite. This means that three digital video transmissions with frame rates of approximately 2 to 4 per second could be handled at the same time. Alternatively, the codec speed could be increased to 64 Kbps for an ADV bulletin broadcast at 8 to 10 frames per second. When not being used for ADV, the transponder could handle packet radio trunks, or other high-speed digital traffic.

There are tremendous possibilities in the amateur satellite community for technology that allows handling of motion video signals digitally. Not only would two-way digital video contacts via amateur satellite be possible in the future, but long duration connectivity via digital video with the space shuttle/space station relayed through the AMSAT Phase 3D Satellite for educational activities could also become a reality. An ADV team at an emergency site, with not much more gear than presently used by PACSAT and other packet radio operators, could transmit color motion digital video of the disaster to all suitably equipped sites on the satellite downlink across the country, greatly facilitating the shipment of the most appropriate relief supplies and assistance. The possibilities are numerous when you can SEE what it is you're talking about!

THE ECONOMICS

Codec manufacturers are introducing models of PC-based codecs that operate satisfactorily at 384 Kbps and currently sell for about $2,000 US (excluding the PC). These prices are still beyond the amateur market, but they are far less than half what they were last year. As all of you who may have purchased a 2400 baud modem long ago for nearly a grand well know, that's not the end of the story. Prices drop quickly once a product is accepted and it is in wider use in the market place.

When the codec chips and chip sets become more available in 1992 they are expected to initially sell for approximately $400 US. These prices will fall as supplies become plentiful, other manufacturers enter the market, and the initial supplier has recouped its research investment. Digital video codecs that are PC-based are already on the market, and video telephones began to make an appearance on the consumer scene in June 1992. Further along, it is likely that a codec-on-a-chip, which will make PC-based systems and video telephones even more economical, will be introduced. The amateur radio video experimenter will have plenty of options from which to choose.

These factors, coupled with the new international standards developments relating to digital video telecommunications (e.g., CCITT H.261) are quickly combining to continue to drive prices rapidly downward. By the time the AMSAT Phase 3D Satellite is launched, a card that can be inserted into an expansion port on your PC, probably will be available. This card, connected to a suitable modem and with appropriate modification of an FM transceiver for wider IF filtering, will enable the sending and receiving of motion color digital video transmissions from a suitably equipped future Amateur satellite such as the AMSAT Phase 3D or for terrestrial communications. The codec output would be converted for display on your computer monitor (RGB). By connecting a home video camera or other NTSC, PAL, or SECAM video source such as a VCR, the video could be digitize and uplinked to the AMSAT Phase 3D satellite, or beamed across the country side to meet with friends many miles away for a two-way motion and color ADV contact. Remember, the much narrower bandwidth of ADV (possibly less than 0.5 MHz at 384 Kbps) as compared to analog ATV (approximately 6 MHz) will allow for a much higher power density and significantly greater range, all other factors being equal. It also reduces the demands on other station equipment, e.g. antenna forward gain need not be sacrificed for the purpose of getting wide bandwidth, etc. Furthermore, the digital video speed or bandwidth could be varied to accommodate the signal-to-noise ratio available over the particular link being used for the communications. As long as the stations at both ends of the path are operating at the same digital speed (and using the same compression algorithm), they will continue to see each other.

For example, if you have an ADV colleague who lives only across town and there is plenty of signal margin, you may wish to use an ADV speed of 384 Kbps so that the images you each see appear more similar to TV. Correspondingly, if another friend lives several counties over or if you're operating through a future OSCAR digital transponder, you may need to reduce the speed to 64 Kbps for improved signal to noise ratio. The image quality will be less depending on the lower bandwidth selected, but you can maintain a contact that otherwise might not have been possible. The operating technique would be something similar to switching in a tighter receiver filter to pick the weak signal out of the noise that you could barely hear, or not hear at all, with a wider IF passband filter.

WHERE DO WE GO FROM HERE?

Obviously much more research is needed, but the basic preliminary design of an Amateur Digital Video system has been completed. Two configurations are currently being evaluated. One of these is a PC-based codec design while the other is a stand-alone unit having its own combined CPU, codec, and modem unit. Hardware work has started and discussions are underway with a commercial manufacturer of amateur radio equipment regarding the possibilities of producing an economical product. That doesn't necessarily mean that you can expect to see the first ADV product released at the next Dayton HamVention, but you can rest assured ADV is not in the too distant future for amateurs.

SUMMARY

Amateur Digital Video (ADV) contacts could be made possible by a suitably equipped AMSAT Phase 3D satellite, while the terrestrial use of ADV instead of analog ATV would vastly improve spectrum efficiency. This would allow far more users to be accommodated in the increasingly popular 440 MHz, 900 MHz and 1.2 GHz video band segments. Some amateurs have argued that 64 Kbps ADV could even be legally operated on the 222 MHz band or other Amateur bands where high data rates are permitted. Once the feasibility, efficiency, economy and DX capability of Amateur Digital Video is demonstrated, existing analog ATV operations will go the way AM voice communication went when SSB was introduced. More importantly, it would be possible to have a wide area digital ADV telecast via the AMSAT Phase 3D satellite for Amateur Radio video bulletins and educational purposes. Amateur Digital Video from the space shuttle or the space station could be uplinked to an OSCAR for viewing directly by Hams, ADV satellite gateway stations, and schools. You could even store images of your favorite QSO or your best ADV contact on your computer's CD style hard disk storage device for viewing later. Such a 3 to 5 inch disk should be able to hold almost 3 hours of video. This could give a whole new meaning to "See you on the Bird!"

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About The Author...

John Champa, K8OCL, an Advance Class Radio Amateur, has been licensed for over 30 years. He is employed by the Unisys Corporation, a major international producer of commercial and governmental information systems, as the Manager and Chief Engineer of the Unisys worldwide video teleconferencing network. He is a certified Master Engineer by the National Association of Radio and Telecommunications Engineers (NARTE). John is also the editor of OSCAR Satellite Report and Satellite Operator, two leading publications in the Amateur Radio space communications field. In addition to being a life member of both the ARRL and AMSAT-NA, John is a Technical Advisor (TA) for the League. When not pursuing his telecommunication interests, he enjoys hunting and camping with his family in the Michigan wilderness. He also finds time to write about his adventures in the outdoors.

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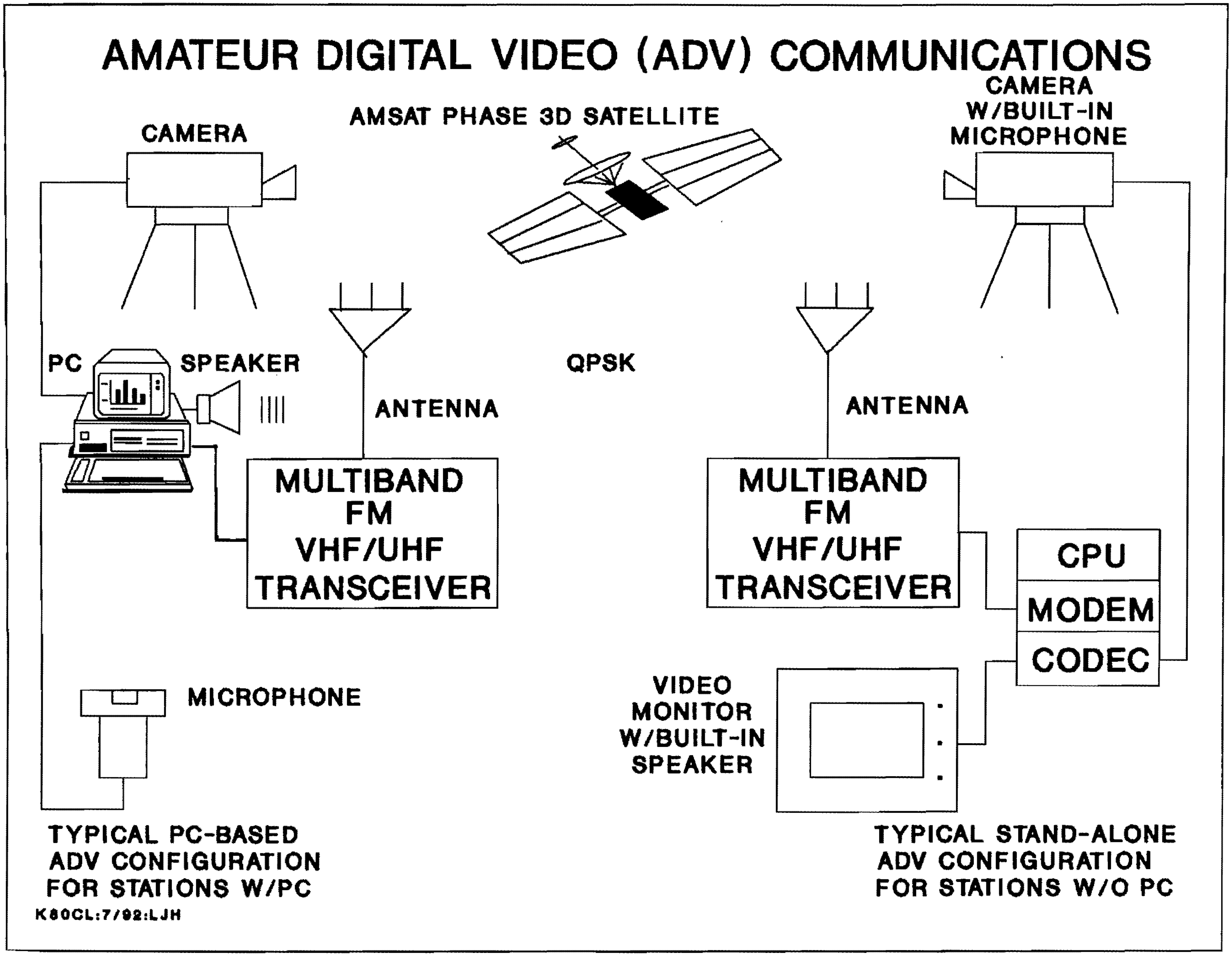
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MODEM
CODEC
MICROPHONE
VIDEO MONITOR W/BUILT-IN SPEAKER
TYPICAL PC-BASED ADV CONFIGURATION FOR STATIONS W/PC
TYPICAL STAND-ALONE ADV CONFIGURATION FOR STATIONS W/O PC
K80CL:7/92:LJH

A Moveable Antenna System For AO-13 Modes B and J

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1. Introduction

Antennas are a critical part of a satellite station. While a good antenna system for AO-13 is small compared to high performance antennas used in terrestrial communications, it is large enough to be a problem in cases of limited space, restrictions on outside antennas, or for portable installations. The challenge to the satellite operator is to install an antenna system that meets the requirements of his individual situation and provides the performance needed for reliable communications.

This paper describes a high-performance antenna system for AO-13 Modes B and J that addresses the requirements of limited space, restricted use, and portable operations. The design described here is meant as an example to stimulate thought -- individual circumstances will dictate the detailed design. This design works quite well - the author made thirty three contacts on AO-13 and AO-10 during the 1992 Field Day contest using this system, and as of this writing, it has not been challenged by the homeowners association at the author's home.

2. Requirements

The antenna system had to meet requirements affecting the performance, design details, and selection of specific components. These requirements were:

1. Provide reliable communications on AO-13 Modes B and J with modest transmitting and receive equipment, with performance as close to a permanent installation as possible.

2. Have sufficient portability and performance for use at Field Day and similar special events.

3. Meet requirements and recommended practices for mechanical, electrical, and RF safety.

4. Meet the limitations established by the architectural regulations at the author's subdivision, and minimize the possibility of a direct challenge to the antenna installation.

The first requirement established target values for antenna frequency, gain, and directivity. The second requirement provides the ability to demonstrate satellite communications at Field Day and at special events. The third requirement ensures the antenna system is safe to erect and use.

The fourth requirement resulted from the author's home being located in a subdivision that restricts outdoor antennas. While a satellite array could fit within the limits of the architectural restrictions, there was a real possibility of a protracted legal dispute to establish that right (approval for the author's existing wire and vertical antennas took 2 1/2 years!).

During his research into antenna restrictions, the author learned of several instances where portable antennas not permanently affixed to a structure placed the antennas outside the jurisdiction of the local regulating body. The antennas could not be attached to a permanent structure and had to be storable out of sight when not in use.

The resulting design goal became to develop a moveable antenna system that retained as much of the performance and ease of use of a permanent installation as possible. An added benefit was that such an antenna system would be readily usable for Field Day and other temporary operating situations.

3. Antenna System Design

3.1 Antenna Selection

Several antenna designs available commercially or as plans provide the transmit and receive capability on 2M and 70cm required for a modest Modes B and J station. Antenna selection is a tradeoff between antenna gain, size, complexity, ease of assembly and disassembly, and cost.

Smaller antennas lend themselves to portable installations. Examples of portable Oscar antennas have appeared in amateur radio magazines.[1] Smaller antennas place compromises on station performance. More power is required for an adequate uplink signal, and poorer receive performance constrains the ability of the station to make contacts reliably.

Extreme portability was not required for this installation, and the author wished to avoid compromising receive performance. The author's plans to use the antenna system in an a QRP-class Field Day station dictated using antennas with as much gain as possible. Thus, only larger antenna designs usually used in permanent installations were considered.

Calculations of theoretical signal levels indicated that antennas from Telex/Hy-Gain, M^2, and KLM could all provide reliable communications.[2] Homeowner association guidelines limited antenna dimensions to under fifteen feet, eliminating the larger M^2 and KLM designs.[3] The Telex/Hy-Gain antennas

[1] MacAllister, Andy, WA5ZIB, "Hamsats," 73 Amateur Radio Today, August 1992, pp. 66, 68.

[2] Davidoff, Martin, PhD, K2UBC, The Satellite Experimenter's Handbook, American Radio Relay League, Newington, CT, 1990, Chapters 9 and 13.

[3] Hastings Hunt Community Association, Architectural and Environmental Regulations, Herndon, VA, December 1991.

were selected as a good compromise between performance, size, and cost. Alternatively, the author could have selected a design suitable for home construction to reduce the cost of the antenna system.

3.2 Rotors

Azimuth and elevation rotors are a useful operating convenience for AO-13 Modes B and J. While manual antenna pointing is feasible for temporary installations, such as Field Day and special event stations, rotors are preferable for permanent stations.

The author had a CDE TR-44 rotor available for this project, and acquired an Alliance UD-110 rotor for elevation control. These rotors are not directly controllable by automatic antenna controllers. The additional operator workload to point antennas is minimal for Phase 3 satellites, but would be considerable for low orbit satellites. Other antenna rotor systems could be used, as long as they are capable of handling the weight and wind load of the antennas and cross boom.

3.3 Cabling

The cabling for the antenna system must minimize signal losses and permit easy connection and disconnection. Cabling is required for RF signals, antenna rotor controls, and power and control of mast mounted preamplifiers and antenna polarity switches. Because the antenna system is moveable, the connectors must allow easy connection and disconnection of cables while maintaining the physical and signal integrity of the cables.

RF feedlines use Belden 9914, a flexible low-loss cable with performance similar to Belden 9913.[4] Flexible feedline is essential for a

[4] This cable is also sold under the name "Flexi4XL."

moveable antenna system, and eliminates the need for a separate rotor loop of flexible cable. Type-N connectors are used for most connections (the 2M antenna feedpoint uses a PL-259 connector). Weather-proof caps are used to protect exposed connectors when cables are disconnected.

Multi-conductor cable is used for rotor control and to provide power and control for preamplifiers and antenna polarity switches. Automotive trailer connectors are used to enable easy disconnection/connection of rotor controllers and power sources when moving the antenna system. These connectors provide adequate weather protection without additional taping or sealing. There are two cable sets -- one for the TR-44 azimuth rotor, and one for the UD-110 elevation rotor. As the UD-110 elevation rotor requires only four conductors, the remaining four supply power and control of preamplifiers and antenna polarity switches.

3.4 Base

The antenna system's base consists of a tripod, mast, and the moveable base itself.

3.4.1 Tripod and Mast

A mast and supporting structure provides ground clearance for the antennas. A 5 1/2 foot mast, supported by a 5 foot tripod, carries the antennas and rotors. A second short piece of mast supports the elevation rotor. The mast was sized to allow full elevation of the antennas while allowing the fully or partially assembled antenna system to fit within the author's garage for storage.

3.4.2 Moveable Base

The moveable base is the key element of the antenna system. The base had to be sufficiently small and light to facilitate movement while providing a stable base for the antennas.

A molded fiberglass garden utility cart was obtained for use as the base. The cart is small enough to pass through a fence gate separating the author's garage from the rear yard of the property, and can carry the weight of the mast, tripod, rotors, and antennas. The mast and tripod are bolted to the cart body.

The author discovered upon assembly of the antenna system that the unmodified cart is too flexible to provide a stable support for the antennas. Clamping the cart's handles to the cart body and addition of metal angle stock added the needed stiffness to the cart.

The author also discovered that the cart's three-point base (two wheels and a front skid) lacks sufficient stability for the antenna system. The author used guy lines to stabilize the cart for initial home and Field Day operations, although the guy lines interfered with antenna movement at high elevation angles.

To stabilize the cart for long-term home use, the author added cross braces mounted to angle stock bolted to the tripod and cart body. The cross braces widen the effective base of the cart, reducing the likelihood of tip-over. They also provide attach points for anchoring the cart that are clear of the antennas at all elevation angles.

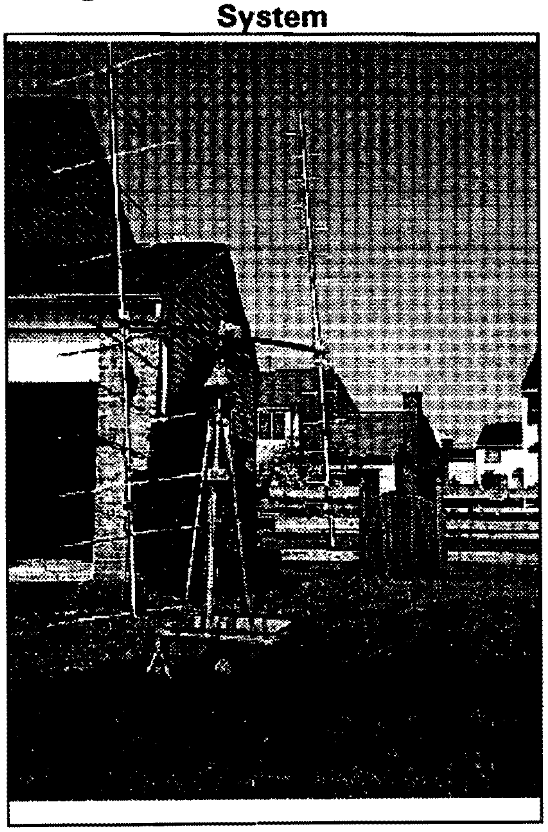
The cross braces are removed when moving the antenna system to or from storage. By mounting the cross braces directly to the tripod, the antenna system's stability no longer depends on the stiffness of the cart's own structure.

Table 1 lists the items used to assemble the antenna system. Figure 1 shows the assembled antenna system before the addition of the stabilizing cross braces.

Table 1. Moveable Antenna System Equipment List

Item	Description
2M Antenna	Telex/Hy-Gain 216S
70cm Antenna	Telex/Hy-Gain 217S
RF Feedline	Belden 9914, Type-N connectors
Control Cables	8-conductor rotor cables, trailer-type connectors
Mast	5 1/2 foot steel pipe
Tripod	5 foot aluminum tripod
Base	Fiberglass Utility Cart
Preamp	Landwher GAsFET Preamp
Azimuth Rotor	CDE TR-44
Elevation Rotor	Alliance UD-110
Misc. Items	Preamp/Polarity Switch Control Box Mounting Hardware Stabilizing and Stiffening Braces (angle stock)

Figure 1. Moveable Antenna System



4. Using The Antenna System

4.1 Home Operation

The primary goals for the moveable antenna system were to enable safe and reliable satellite communications from the author's home while avoiding problems with the homeowners association's limitations on antennas. The antenna system appears to have met these goals. The antennas provide good uplink and downlink performance, while there has been no complaint (so far!) from the homeowners association.

Safety was a major concern for this antenna system. The author places the antennas in a fenced back yard to reduce the chance of passersby accessing the antennas. The base provides enough support to keep the antennas upright in strong winds. The system is moved indoors when severe weather is expected and during extended off-the-air periods, protecting the equipment from wind and lightning damage. Power is removed from all cables when the antennas are stored. Most AO-13 operation requires high antenna elevation angles and occurs at night, reducing potential RF energy exposure to people on the ground.

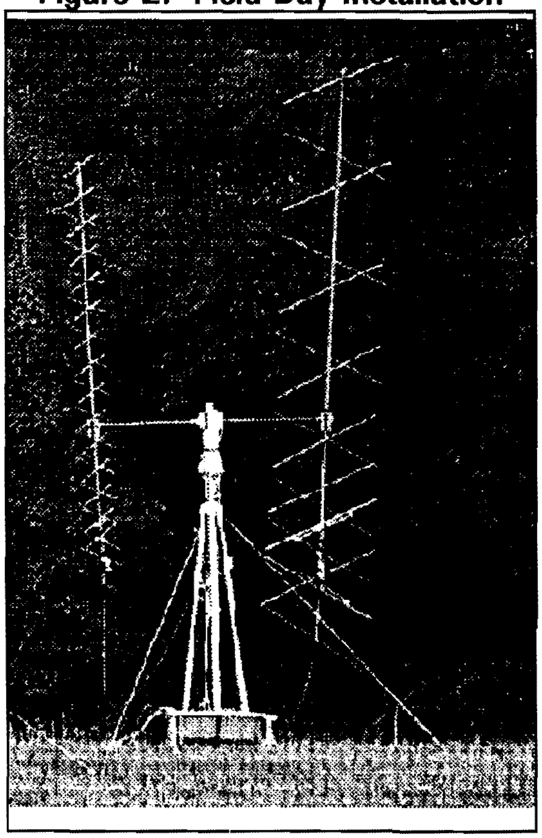
The antenna system is brought into the author's garage for inside storage. Storing the antenna takes only a few minutes. To store the system, the antennas are elevated to 90 degrees and rotated to place the cross boom along the width of the base. The forward section of the 70cm antenna is removed just above the pivot point of the antenna by loosening a wing nut and removing the retaining bolt. A new cut and splice joint was made in the 2M antenna's boom to provide a similar separation for the 2M antenna (the manufacturer's forward boom joint is too far ahead of the 2M antenna's pivot point). Cables and feedlines are disconnected at the preamp outputs, connectors are capped, and the stabilizing braces removed. The antenna system is then rolled into the garage, where it easily stores upright (it must be tilted to pass through the garage door, however).

Keeping the main portion of the antennas attached for storage reduces the wear and tear on mounting hardware, feedlines, cables, and connectors. The ability to bring the antenna system out of the weather should prolong the life of the antennas, rotors, preamplifiers, and mast/tripod. Although not as convenient as a permanent installation, the moveable antenna system provides effective and reliable communications on AO-13.

4.2 Portable Operation

The second objective for the moveable antenna system was use in portable installations, such as Field Day, special events, and demonstrations of amateur satellite communications. The antenna system has proven quite successful in this role, beginning with its first use in the 1992 Field Day contest. Figure 2 shows the antennas in use at the Field Day site. The author has received requests for the antenna system to support demonstrations of satellites at a licensing class and at local AMSAT chapter events.

Figure 2. Field Day Installation



The antenna system breaks down into two major components for transport: the base, mast/tripod, and rotors; and the two antennas. A small pickup truck can carry the antenna system this way. The rotors and cross boom can be removed from the mast/tripod assembly to allow transport of the antenna system by smaller vehicles.

The major concern when transporting is protecting the antennas from damage. When using a pickup truck, the stabilizing braces are formed into A-frames standing in the truck's bed. The antennas are then attached to the A-frames, protecting the antenna elements from damage during transport.

5. Modifying the Antenna System

The moveable antenna system provides good results on AO-13 Modes B and J. It can also be used as an antenna support for other Modes or satellites.

The moveable antenna system can easily support addition of Mode L or Mode S capability to the station. There is enough space on the cross boom to mount a Mode L or Mode S antenna between the 2M and 70cm yagis. A transmit converter and amplifier for Mode L or a receive preamplifier and converter for Mode S can be mounted in a weather proof enclosure resting inside the utility cart body. By manually reconnecting one feedline or with the addition of a remote-control antenna relay, the 2M feedline and transceiver can be used as a Mode L exciter or tunable IF for a Mode S receiver. The major difficulty anticipated adding Mode L or S is the effect of the additional antenna on the stability of the base. Antennas with low wind loading, such as loop yagis, are therefore preferable to dishes.

Omnidirectional antennas for accessing low-altitude satellites using Modes A, B, or J can be mounted above the elevation rotor. The 2M and 70cm antenna feedlines can be manually reconnected for the satellite passes, or remote control antenna relays can be used for the operator's convenience. Alternatively, the AO-13 antennas can be set at a moderate elevation angle suitable for the specific pass, then tracked in azimuth. This technique reduces the operator's workload and improves the station's link margin for all but very high elevation passes.

6. Conclusions

The moveable antenna system provides reliable access to AO-13 Modes B and J and other amateur satellites. The antenna system's mobility places it outside the scope of restrictive covenants and architectural regulations that would otherwise prevent effective satellite operations. The antennas can be moved out of sight between passes to provide greater protection against homeowner association complaints, and to reduce the effects of weather on the equipment

The antenna system is very useful for setting up temporary stations for Field Day, special events, and demonstrations of amateur satellite communications. By replacing the cart with a road-capable flatbed utility trailer or pickup truck bed, the antennas become easily road-transportable, and may eliminate the need to completely remove the antennas from the rest of the assembly for transport.

The uses for a transportable antenna system to help publicize amateur radio satellites are endless. With battery powered transceivers, computers, and rotors, a complete Oscar station can be established anywhere that is accessible to a small pickup truck or trailer.

The major problems with the moveable antenna system are the poor stability and structural integrity of the fiberglass base. Using a wider cart or a higher mast to allow guying without hindering antenna movement would improve the base's stability. Carts made of stronger materials, such as wood or steel, could have greater stability without additional bracing. Using a flatbed trailer or pickup truck as a base should eliminate most concerns of tip over or structural failure.

NAVAL ACADEMY SATCOM PACKET RADIO EXPERIMENTS

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During the last two years the US Naval Academy has performed a number of satellite communications experiments including tests with a packet radio network for communications with its boats during summer cruises along the East Coast. The Academy is fortunate to have obtained the 12 meter dish antenna from NASA in 1989 which is shown in figure 1. The antenna is used to demonstrate a number of communication and orbital dynamics concepts to students in a variety of labs and special projects. The AMSAT OSCAR satellites are favorite test objects and provide excellent classroom demonstrations of tech-nical and engineering concepts. The AMSATs, weather satellites and Transit navigational satellites sum to about 30 objects that can be received using a simple VHF scanner. These satellites are used to demonstrate tracking using the Instant-track program, and received signal strength is used to make link calculations.

Several special student projects, however, have been able to obtain experimental time on some of the DOD satellites. Primarily the geo-synchronous Fleet Satellites and the Defense Advanced Research Projects Agency (DARPA) Microsats launched in July 1991. The MICROSATS, carried on the second Pegasus launch barely made it to orbit and were only expect-ed to last about 6 months before reentry. Due to the short life of these satellites, several students were able to obtain several hours of access time for a variety of experiments, including AX.25 packet links.

Figure 1. Twelve meter satellite tracking antenna at the US Naval Academy.

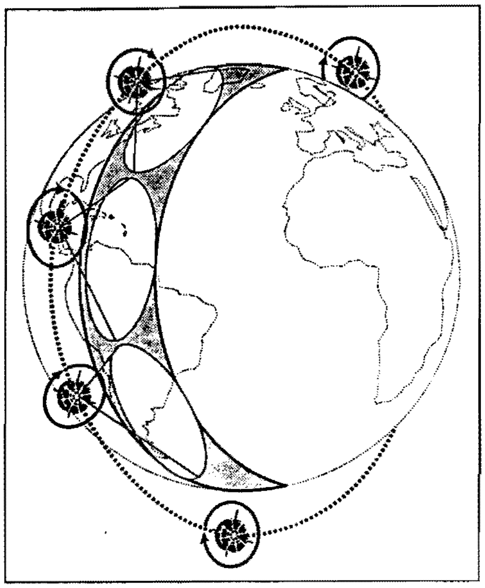


Figure 2. The seven DARPA Microsats were evenly spaced in a near polar orbit which provided nearly 45 minutes of continuous coverage in the mornings and evenings

DARPA MICROSATS

The seven microsats were evenly spaced in a near polar orbit shown in figure 2 which provided morning and evening passes of a combined duration of over 45 minutes with about 7 minutes on each satellite. The 22 kg satellites shown in figure 3, carried single 10 watt UHF transponders operating through a simple dipole antenna. Their small size resulted in a negative power budget, so all operating periods required advanced scheduling. Ten minutes operation per satellite per orbit was typical. One student used doppler plots to calculate orbital period and observe the decaying orbit due to atmospheric drag. Another used tactical SATCOM radios and a prototype constructed from HAMTRONICS modules for Marine Corps field operations. The most extensive test, however, was a demonstration test for the Military Afilliate Radio System (MARS).

MARS SYSTEM TESTS

In the last two weeks of the Microsats, permission was obtained for a nationwide test between MARS operators. Unfortunately, permission came over the Christmas holidays when it was difficult to get the word out. Secondly, of the seven satellites, only one was finally made available for the tests scheduled over the weekends of 4 and 11 January 1992. With the very low orbit at this point, however, passes lasted on the order of only four minutes or so and the communications were brief. Thirty five stations across the country were able to join in the test including four stations on Navy ships.

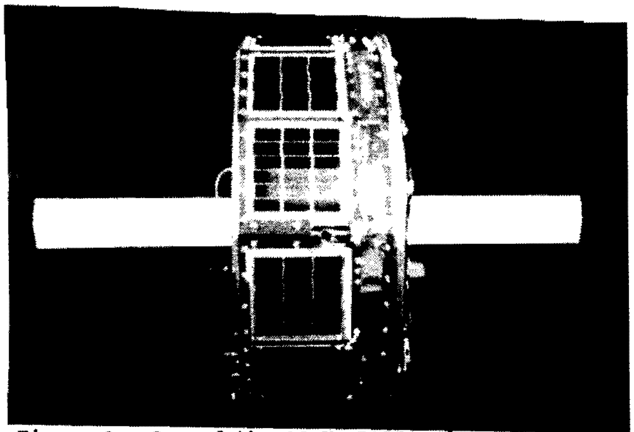


Figure 3. One of the 18 Kg DARPA microsats shown with its single UHF Dipole deployed.

ACADEMY SATELLITE PACKET RADIO EXPERIMENTS

The primary Naval Academy objective, however, was to experiment with AX.25 packet radio links for low cost communications with its boats during ocean cruises. The AX.25 packet radio system used a combination of HF and SATCOM links for exchanging record traffic and automatic position reports. During the life of the MICROSATS, periodic beacons on the satellite uplink frequency were relayed to Annapolis via any satellite which came within view. These satellite-relayed packets augmented the HF beacons which were used for status and position reporting. During the 6 months leading up to re-entry of the constellation on the 25th of January, 1992, over 89 orbits were used for active exper-iments. Our one second beacons, once a minute were not disruptive to other users of the channel and demonstrated the value of a CSMA satellite channel for low duty cycle remote status reporting. We were fortunate to be able to participate in the microsat experiments but have been unable to find any other sharred access on a DOD UHF satellite channel that can accommodate our type of asysynchronous low duty cycle reporting. After the demise of the DARPA microsats, the Academy occassionally obtained one hour late at night on one of the geosynchronous Fleet satellites. With the near-real-time success of HF to carry the minimum position and status reports during most of the day, however, a one hour time slot on the UHF satellite was underutilized. The ideal satellite access for our application was 20 seconds out of every 4 hours, instead of one hour dedicated once a day.

The constellation of seven DOD microsats in low earth orbit had been ideal for our application, since we were permitted to radiate beacons freely on a low duty cycle and take advantage of overhead passes when they occurred. The irregularity of our satellite access showed the advantage of having a fully integrated HF system as part of the UHF satellite AX.25 network.

PACKET RADIO TACTICAL COMMUNICATION NETWORK

The objective of the AX.25 network at the Naval Academy was to provide position and status reporting and to permit the exchange of record traffic between the Academy and its fleet of almost forty Yard Patrol craft (YP's) and sail-boats during extended summer cruises. The exchange of message traffic was straight forward using a centralized PBBS linked by Kantronics KA nodes to three HF channels, one VHF frequency for local operations, and one UHF SATCOM channel (when available). The innovation in the network, was the use of periodic beacons for position and status reporting. Central to the success of this periodic reporting was a special program running on a PC which monitors the packet channels and accumulates the position and status beacons and then provides a tactical color map display of the location of all units on a scaleable map of the East Coast. Since the network uses inexpensive amateur radio packet modems interfaced to existing radio systems, it demonstrates an excellent application of packet networking which can be extended into other areas such as emergency and disaster preparedness and network topology monitoring. The purpose of this article is to share the unique application of the Academy packet radio system and to suggest a similar position and status reporting system for the general amateur community. The details of that network will be submitted at the 199? ARRL Computer Networking Conference.

The Naval Academy AX.25 packet radio system provides a significant improvement in tactical communications for the boats which often travel as far as Mexico and Nova Scotia and which were previosusly restricted to unreliable HF voice communications or to telephone communications once in port. Since experimental time on DOD satellites is limited, the network was fully integrated with HF and VHF links to provide connectivity without total reliance on satellite access. The resulting master station at the Academy satellite facility for the first summer grew to consist of modems on three HF frequencies, a local VHF frequency and one UHF satellite frequency as shown in figure 4. Eight

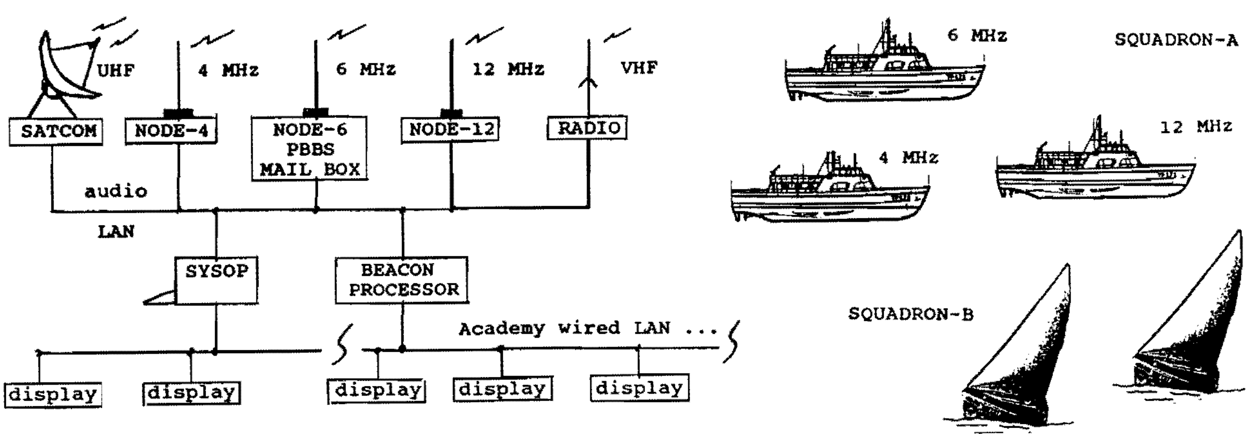


Figure 4. The Academy Network consists of three HF nodes integrated with a local VHF frequency and UHF SATCOM system via dual-port KA nodes. By August 92, 10 boats were configured with packet radio.

of the Academy's twenty boats were outfitted with packet radio modems by the end of the second summer. This number of units was sufficient for the network since boats always sailed in small squadrons with no more than four major deployments in progress at any one time.

HARDWARE IMPLEMENTATION

For reliability, there are no computers required in the system. The master station simply consists of three dual port TNC's, one on each HF frequency. The audio from the VHF ports of these three TNC's are all summed together and fed to the SATCOM transceiver and local VHF transceiver as shown in figure 4. This simple audio node serves as a local area network to link everything together without additional hardware and node complexities. The KA node function built into the dual port TNC's manages traffic between the TNC's. The message store and forward capability is simply the 16K PBBS internal to the one TNC on the 6 MHz frequency. This PBBS can be accessed directly from HF on 6 MHz, from VHF, and from the SATCOM system via the audio node. On the two other HF frequencies, the boats must first connect to the KA node internal to the TNC on that frequency, and then ask for a connection to the PBBS (via the audio node).

The master station is further available to dozens of officers and staff via the Academy local area network (LAN) which provides a serial port in every office at the Academy. Again without complexity, this was accomplished simply by connecting the TNC RS-232 serial port to the network and telling the network that the address was a Host. This LAN interface allows duty officers to log into the TNC PBBS from anywhere in the Academy as well as dial-up from home to list and read message traffic. A one-transistor interface between the "CONNECTED" LED on the TNC and the LAN handles all handshaking. (Three similar TNC interfaces permit HAMS on the Naval Academy LAN to access MIR, DOVE and the local packet network)

POSITION REPORTING BEACONS

To take advantage of propagation openings on HF, all units in the network are programmed to transmit a periodic beacon signal once every ten minutes. For the boats, the beacon was loaded with position and status. For the master station at the Academy, the beacons included short announcements or lists of traffic pending. On the boats, a casual glance at the time of receipt of the last beacons on the CRT terminal would indicate propagation conditions. If the last beacons were received in the last half hour, then conditions were probably good for message traffic.

At the master station during the first summer, all position report beacons from the boats were logged on the printer. The position reports were foramtted so that position, course, speed, fuel, water, casualties, next port, estimated time of arrival, and intentions were all included in the single line beacon. By the second summer a computer program was written to

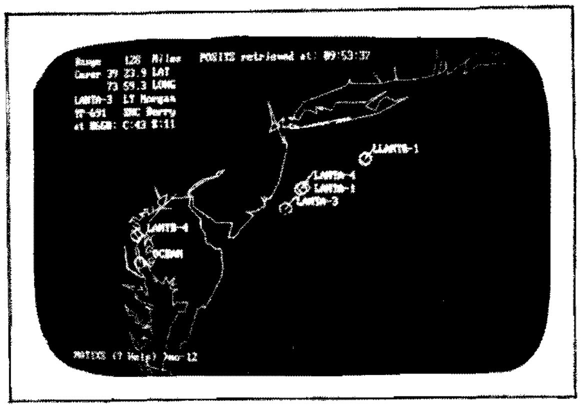


Figure 6. The tracking and display software can display the location of all packet units to any scale from 1024 down to 4 miles. Here, several units are enroute to New York.

parse and sort all beacons and display the position and movement of the boats in full color graphics which included charts of the entire East coast with user selected scales of 4 to 1024 miles. See figure 6.

To be sure that all beacons on all frequencies were visible to all users, particular attention was made to the default paramters in each TNC. First of all, all TNC's on the boats were set to beacon to the address BEACON via the address of ECHO. Then the gateway callsign of the three dual port TNC's at the Academy were programed with the identical callsign of ECHO. With this arrangement, a beacon originating on any one HF frequency is digipeated (ECHOed) onto the master station audio node which in turn goes out on VHF and SATCOM. Any beacon originated on VHF or SATCOM is similarly digipeated (ECHOed) out on all three HF frequencies. A Beacon can be further distributed from one HF frequency onto the local VHF node and then back out on the other two HF frequencies by simply telling the originating TNC to beacon via two addresses: ECHO, ECHO.

OPERATIONS

Beacons from the deployed boats were automatic as long as power to the packet terminal was applied and the radios were properly configured. The crew was encouraged to update their beacons once a watch every four hours or whenever significant changes occurred. Similarly, the crews were encouraged to watch for beacons from the master station and to check in at least twice a day when conditions were favorable. Each squadron had three boats equipped with packet, one one each of the three HF frequencies at 4, 6 and 12 MHz to take advantage of frequency diversity. The system software accumulated statistics on the number of beacons received from each unit per hour and made that information available to users as shown in figure 7.

BT @1800/3927.4/07639.5/030/10/heading for philia. Will call on arrival.

Time Lat Long Cse Spd Free text comments . . . up to 80 characters

HISTOGRAM OF BEACONS PER HOUR for 07-26-92. (Usually transmitting 6 per hour)
SSID shows assigned frequency of operation for that unit.

Time(EDT)	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	23	22	21	20	19	18	17
LANTA-6	.	.	1	2	3	2	4	4	.	.	.	.	.	.	1	.	.	1	1	2	.	.	.
LANTA-12	.	1	1	2	3	2	5	3	2	3	2	.	.	.	.	1	.	.	2	4	1	3	.
LANTA-4	3	1	.	.	2	1	2	1	3	.	.	.	.	.	.	.	.	.	.	.	.	3	3
OCEAN-6	1	2	1	2	2	1	2	1	2	2	2	2	1	2	1	2	2	2	2	2	2	2	2
LANTB-6	4	1	4	2	3	3	5	4	2	2	.	.	1	2	.	1	1	1	1	2	3	2	2
LANTB-12	2	4	5	6	4	6	6	6	6	3	.	.	2	2	.	3	9	6	3	5	5	2	3
LANTB-4	.	.	.	.	1	3	4	.	.	.	.	.	.	.	.	.	1	.	.	3	.	.	.
BRMUDA-6	4	6	2	2	6	3	1	2	.	.	.	.	.	.	.	.	.	1	.	.	1	1	2
NEWENG-6	3	4	3	6	6	5	3	2	.	.	.	.	.	.	.	.	.	.	.	1	.	3	.

NOTES: LANTA arrived NY this morning. LANTB arrived Newport RI last night.
Sailboats enroute up Deleware coast and into Deleware Bay.

Figure 7. Statistics on the number of beacons received per hour from each unit over the last 24 hours are available to system users with a single keystroke.

A highlight of the summer was the three week cruise of the one boat that is configured as an oceanographic research vessel. With GPS and several computers on board, a serial port was dedicated to send a new position report beacon text to the TNC every ten minutes. At a cruise speed of 10 knots, this resulted in a fresh position report accurate to better than 100 feet every two miles during a 400 mile cruise. A replay of the positions of this boat are shown in figure 8.

RESULTS

Although the system was only experimental the first summer with three boats, more than 400 messages were exchanged over the system and 200 position reports were logged. Communication success with packet approached 83% compared to about 19% for the HF voice system used before.

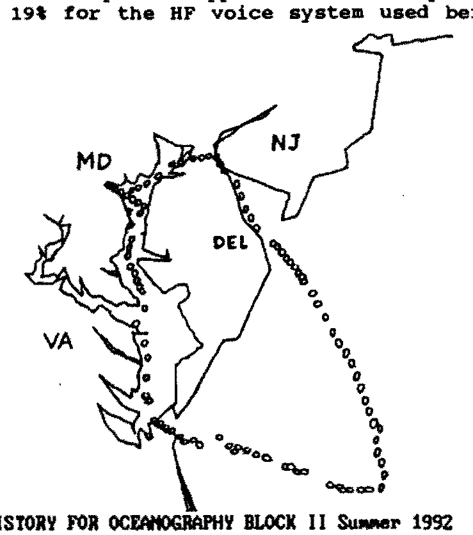


Figure 8. A plot of the 3 week track history of the one unit equipped with an interface to a GPS receiver to provide an automatic fresh position into the TNC beacon text every 10 minutes.

During the first summer, the system evolved through a number of significant changes. The first month only one HF frequency was operational, by the second month all three were operational but one frequency was lost due to reassignment. Our UHF satellite access was lost due to higher priority users before the UHF transceivers were completed, and all summer deployments of the boats were complete by the time we gained access to the low-earth-orbiting DARPA MICROSAT's in late August 1991 noted above.

By the second year, a total of nine boats were configured for packet. For every deployment, there were always three boats able to monitor all three HF frequencies simultaneously to improve HF connectivity through frequency diversity. The significant improvement in the system which transformed it from an interesting experiment to a useful and productive tool was the completion of the tactical display software in time for most of the summer of 1992. This software which runs on any computer with connectivity to the Acadmey LAN provided everyone with fresh graphic display information on the position and status of all units. The use of computer displays in real time was far superior to the colored pins on a wall chart which had always been used in the past. The tactical display using EGA graphics, showed a map of the East Coast at any scale between 4 to 1024 mile range and centered anywhere from Nova Scotia to the Florida Keys. A picture of the display showing several units enroute to New York is shown in figure 6. Using the cursor, any unit may be selected for a detailed dump of data on that unit. Further, a single key stroke will dead reckon all unit positions to their estimated current positions based on course and speed from their last reported position as shown in figure 9. It is this tactical display software which I think would be useful in the amateur packet radio network for displaying the location and status of all packet stations. See the final section of this paper on the Packet Position Display System.

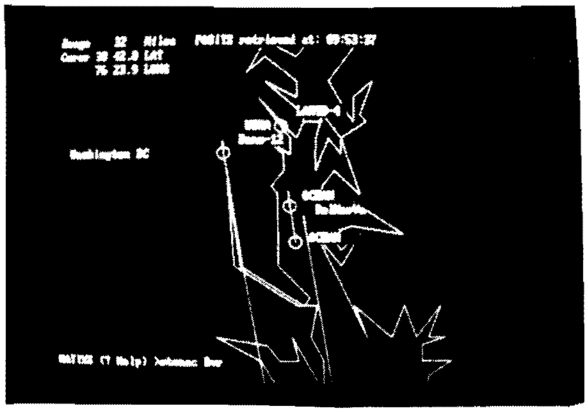


Figure 9. Another picture of the tracking display showing the dead-reckoned position of one unit. Two other units, off screen, also DR'ed into the present view.

REMOTE TELEMETRY VIA PACKET

An interesting sidelight to the packet network was the use of a Kantronics Telemetry Unit on one boat to monitor seven channels of engine conditions remotely and dump these readings over the packet radio link. Unfortunately the only way to locate engine readings of interest was to transmit every single data sample (16K per day) over packet and then search for the few high and low readings of interest. The result was a thousand-to-one ineffeciency in the use of the packet channel. We were disappointed in the absence of any filter, search, or threshold comparison commands in the KTU to help identify high or low readings of interest. Secondly, there was no way to remotely select the KTU. The KTU must have a dedicated TNC or a human operator to manually switch it into the circuit. For these reasons, we found the KTU to be of no value as a remote telemetry unit in this application.

PACKET POSITION DISPLAY SYSTEM (PPDS)

We feel that the tactical display software used in the Naval Academy application could be very useful in other packet radio networks, especially in support of emergency and disaster communications, or for tracking recreational vehicles, mobile HF'ers, or offshore boaters. There is even a HAM air traffic control net on 14,278 KHz which could enter air contacts into the system. In the current amateur packet radio network, the Monitor Heard log in each TNC is the only function which provides realtime information on the status of the network. This information only identifies the last 16 callsigns and when they were last heard. The PPDS software is a dramatic improvement on this concept, as it would display all call signs geographically when heard. The colors would fade from bright white through the rainbow to dark gray as time elapsed. This way, a glance at the screen would show which stations were currently active. Lines could be drawn between pairs of connected stations including all intermediate links. In this way, geographically correct network charts would just appear on the screen after monitoring the channel for only a few minutes of heavy use.

The key to this system, of course, is knowledge of every station's geographical position. Using beacons, as we have done at the Naval Academy, is the mechanism. Periodic beacons are not required for fixed stations. In fact, as more and more stations run this software and collect position reports from cooperative stations, a community file could be built up and distributed using the normal BBS file distribution capability! If the idea cought on, BBS's could actually monitor beacons and collect and maintain the position files. Local stations need only update their position data when they move or go portable! Then, only one properly formatted beacon need be transmitted successfully for the community to grab your change in status.

Going back to the monitor heard logs, there is no reason why the TNC manufacturers could not modify their firmware to save the text of the latest beacon heard from each station in the MH log. A new TNC command would give the owner the option of collecting beacon text in his MH log, or not.

SUMMARY

The purpose of this article was to use the example of the Naval Academy AX.25 packet radio network to show the value and capabilities of a system which includes position location information in packet beacons. The extension of this capability into the amateur radio network could have many benefits. A previous article on the subject of position and status reporting in the amateur packet network appeared in the Feb 91 issue of Gateway. I intended to evolve the PPDS software from the Naval Academy software, but by the end of this summer's intensive use, there were enough lessons learned to require a total re-write before the system could be extended to world wide use. The Latitude and Longitude fields need to be extended for whole Earth coverage, and the time fields need to be extended beyond 24 hours to include the day as well. Also, provision needs to be included for other position reporting formats as suggested in the earlier Gateway article. I repeat, that the PPDS software is NOT yet written. As I re-organize the formats of the Academy System for next summer, however, the necessary changes will be included for a more general application such as for the amateur packet network.

OSCAR at 30+		1 G3ZCZ 5/25/92

Amateur Radio

in Space

Joe Kasser,W3/G3ZCZ

AUGUST 1992

OSCAR at 30+	Agenda	2 G3ZCZ 5/25/92

- HISTORY & ORGANIZATION
- PRINCIPAL ACTIVITIES
- FACTORS FOR SUCCESS
- HIGHLIGHTS & ACHIEVEMENTS
- OSCAR SERIES
- TYPICAL RECEIVING EQUIPMENT
- TELEMETRY
- COSTS
- MANNED SPACE ACTIVITIES
- THE FUTURE
- FURTHER INFORMATION

OSCAR at 30+	History & Organization	3 G3ZCZ 5/25/92

- Project OSCAR in early 1960's intiated program on West Coast.
  - responsible for first 4 OSCARs
- AMSAT founded in 1969 to continue the program.
  - Incorporated in DC. as an Educational Not-for-Profit Organization
  - Rapidly grew to world-wide organization with 6000+ members.
- Growing hardware capabilities in Affiliate AMSAT Groups in other Countries

Great Britain	Brazil	France
Germany	Belgium	Chile
Japan	Israel	Sweden
Canada	Argentina	Finland
S Africa	The Netherlands	Spain
Italy	Mexico	Russia

OSCAR at 30+	Principal Activities	4 G3ZCZ 5/25/92

- Design, Construction, testing, launch, an on-orbit operation of satellites in the Amateur Service
- Negotiate with launch authorities for transport to orbit
- Support of educational programs using Amateur Satellites as Educational tools.
- Dissemination of information on use of operating satellites to the world wide amateur radio community
- Provide infrastructure for (volunteer) innovation and high-tech experimentation.
- Fund Raising
- Membership Services

OSCAR at 30+	Factors for Success	5 G3ZCZ 5/25/92

- A core group of highly motivated individuals
  - technically qualified
  - amateur radio backgrouds
  - aerospace experience
- Access to High Technology, Aerospace-oriented Facilities
- Financial Support
- Industry Support
- Government Support
  - access to technical facilities
  - frequency coordination/licensing
  - launch arrangements
- Interaction with other Amateur Radio Satellite Technical Groups
- Hard work, Perseverance, Good Fortune

OSCAR at 30+	On-orbit Highlights	6 G3ZCZ 5/25/92

- <u>OSCAR 1 12/12/61</u> first non government satellite
- <u>OSCAR 3 6/2/62</u> first free access communications satellite (LEO)
- <u>OSCAR 4 12/21/65</u> first satellite communications between US and USSR
- <u>OSCAR 5 1/23/70</u> first OSCAR with ground command capability
- <u>OSCAR 6 10/15/72</u> first demonstration of ELT techniques, first paractical long life LEO communications satellite.
- <u>OSCAR 9</u> 10/6/81 first University Satellite. Monitored radiation from Chernobyl
- <u>OSCAR 12</u> 8/12/86 first low earth orbit store-and-forward satellite
- <u>OSCAR 23 7/92</u> first amateur radio astronomy satellite monitoring signals from Jupiter

OSCAR at 30+	On-orbit Results	7 G3ZCZ 5/25/92

AMATEURS HAVE:

- TOTAL EXPERIENCE 40+ SPACECRAFT
- PRACTICAL COMMAND & CONTROL OF SPACECRAFT IN BOTH LOW EARTH AND ELIPTICAL (MOLNIYA) ORBITS
- USERS WORK WITH LOW COST COMMUNICATIONS TECHNOLOGY
- EXTENSIVE EXPERIENCE WORKING WITH SMALL SATELLITE TECHNOLOGY
- 6 MANNED SPACECRAFT EXPERIMENTS SINCE 1983
- ESTABLISHED AMATEUR RADIO AS A FIXTURE ON MIR
- 50+ SPACECRAFT-YEARS OF EXPERIENCE ON-ORBIT SINCE 1961

OSCAR at 30+	OSCAR Series	8 G3ZCZ 5/25/92

- Communicator Class of satellites

  - not much science, mainly housekeeping telemetry
- Scientific class

  - not much data published on what instruments are aboard the spacecraft and how to decode and display the data.

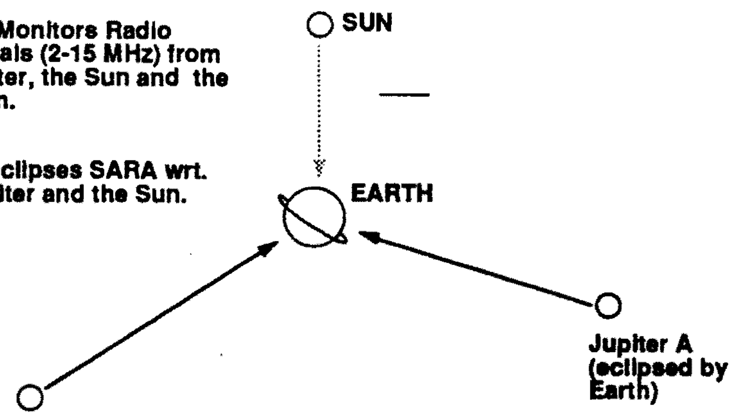
OSCAR
at 30+

SARA-OSCAR 23

9
G3ZCZ
5/25/92

SARA:-Monitors Radio Signals (2-15 MHz) from Jupiter, the Sun and the Earth.

Earth eclipses SARA wrt. Jupiter and the Sun.



GSFC-ARC Very Low Frequency Radio Astronomy Experiment Follow Up.

OSCAR
at 30+

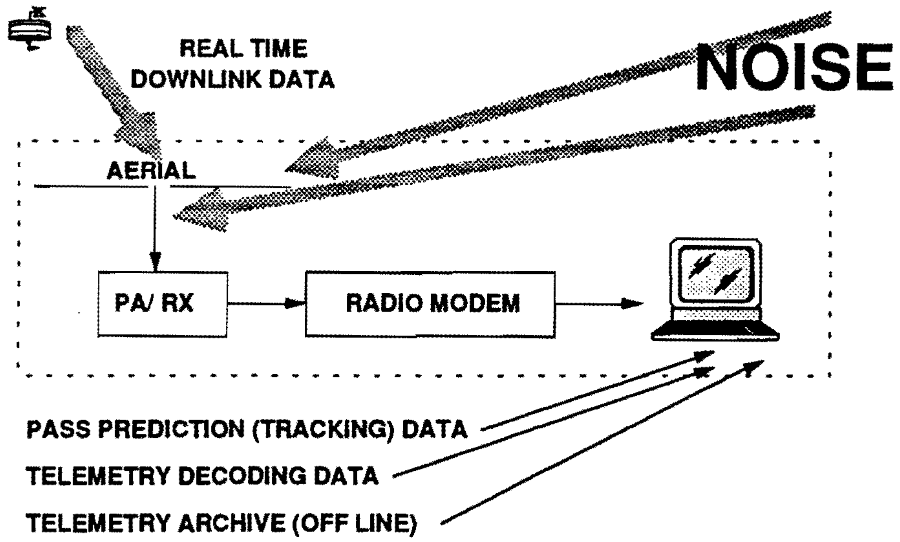
Command History

10
G3ZCZ
5/25/92

- OSCARs are Autonomous on-orbit
- AO-13 Command History 1988 - 1991 (Source G3RUH)

Initial Load Jun 1988	1173
1st reload Oct 1989	389
2nd reload Oct 1989	222
3rd reload Dec 1989	759
4th reload May 1991	336
	2879

OSCAR at 30+	Typical Receiving System	11 G3ZCZ 5/25/92



OSCAR at 30+	Telemetry Data Types	12 G3ZCZ 5/25/92

- PUBLIC TELEMETRY
- USED BY ANYONE WHO HAS ACCESS TO THE DATA

  - ENGINEERING DATA
  - VOLTAGES, CURRENTS, TEMPERATURES
  - SCIENCE DATA
  - ON BOARD SENSOR DATA

- PRIVATE TELEMETRY
- USED BY COMMAND STATIONS AND OTHER SPACECRAFT SUPPORT PERSONNEL

  - COMMAND ACKNOWLEDGEMENT DATA
  - DIAGNOSTIC DATA
  - TEMPORARY STATUS DATA, OBC STATES

OSCAR at 30+	Spacecraft Data Products	13 G3ZCZ 5/25/92

REAL TIME

- RECEIVED DURING A PASS
- CHECK EVERYTHING IS IN TOLERANCE
- VIEW TRENDS (IE. TEMPERATURE CHANGES)
- (DOPPLER DATA)

QUICK LOOK

- POST PASS ANALYSIS
- PARAMETER PLOTS

PRODUCTION

- LONG TERM CORRELATIONS
- ARCHIVE STORAGE AND RETRIEVAL

OSCAR at 30+	Software	14 G3ZCZ 5/25/92

- Orbit prediction (Tracking)
- Telemetry Decode and display
- Post pass data analysis

OSCAR at 30+	Tracking Software	15 G3ZCZ 5/25/92

S/C	WNDOW	AOS	LOS	PASS	MA	ALT	AZ	EL	RANGE	DPLR
AO-10	08:15		02:05	08:11	64	27896	257.23	48.99	29212	
UO-11	05:47	23:37	23:47	00:09	77	672				
RS10/11	04:55	22:45	22:58	00:12	202	990				
AO-13	01:26		19:16	01:22	215	21796	285.79	67.16	22195	
UO-14	00:07		17:57	00:03	3	786	321.25	14.46	2055	
AO-16	00:35	18:25	18:34	00:08	161	799				
DO-17	00:05		17:55	00:01	9	786	295.17	18.40	1836	145.8249
WO-18	00:47	18:37	18:45	00:07	130	801				
LO-19	00:11		18:01	00:07	251	785	349.53	3.52	2909	
FO-20	00:31	18:21	18:35	00:13	206	1203				

OSCAR at 30+	Telemetry Decode and Display	16 G3ZCZ 5/25/92

Solar Panel Temp #1:	15.20 Deg.C	Total Array Current:	1105.89 mA
Solar Panel Temp #2:	31.92 Deg.C	Battery Charge :	102.87 mA
Solar Panel Temp #3:	32.68 Deg.C	Battery Voltage :	14.806 V
Solar Panel Temp #4:	29.64 Deg.C	Battery Center :	6.744 V
Baseplate Temp. #1 :	40.73 Deg.C	Bus Voltage :	17.259 V
Baseplate Temp. #2 :	41.42 Deg.C	+5 V Regulator :	5.214 V
Baseplate Temp. #3 :	40.87 Deg.C	-5 V Regulator :	0.000 V
Baseplate Temp. #4 :	41.14 Deg.C	+10 V Regulator :	10.471 V
Temperature Cal. #1:	1.30 V	Offset Voltage #1 :	0.000 V
Temperature Cal. #2:	1.29 V	Offset Voltage #2 :	0.000 V
Temperature Cal. #3:	1.75 V	Calibration Volt #2:	1.230 V
Battery Temp. :	45.04 Deg.C	JTA TX Output Power:	0.46 W
JTD Temperature :	42.12 Deg.C	JTD TX Output Power:	3.52 W

OSCAR at 30+	Costs (Summary)	17 G3ZCZ 5/25/92

ITEM	LOW	HIGH
ANTENNA	2.00	100.00
RECEIVER	100.00	1200.00
RADIO MODEM (TNC)	150.00	700.00
TRACKING SOFTWARE	25.00	350.00
TELEMETRY DECODING S/W	35.00	35.00
TOTALS	312.00	2385.00

OSCAR at 30+	Manned Space Activities	18 G3ZCZ 5/25/92

- Space Shuttle
  - educational
  - public affairs
- MIR
  - educational
  - combats boredom of long duration flights

OSCAR at 30+	THE FUTURE	19 G3ZCZ 5/25/92

- More OSCARs
- More HAMS in Space
  - MIR, SAREX
  - Space Station Freedom
  - Moonbase, Mars missions

OSCAR at 30+	LAUNCH OPPORTUNITIES	20 G3ZCZ 5/25/92

SPACECRAFT	COUNTRY	MISSION	LAUNCH DATE
ARSENE	France	Long Life Intercontinental AX.25 Communications	1992
KITSAT	Korea	Educational Construction Project	1992
SEDSAT	USA	Educational Construction Project	1993
TECHSAT	Israel	Educational Construction Project	1993
IT-AMSAT	Italy	Similar to AO-16 with science experiment.	1994
SUNSAT	S. Africa	Educational Construction Project	1994
MARS	Germany and an International Team	Interplanetary probe and long range communications relay	1995
AMSAT-PHASE 3D	Germany and an International Team	Long Life Intercontinental Communications	1995

OSCAR at 30+	SUSIE's Mission	21 G3ZCZ 5/25/92

- Educational aspects of space sciences and orbital dynamics.
- Real opportunity for new discoveries.
- Building on existing missions.

OSCAR at 30+	PRIMARY PAYLOAD	22 G3ZCZ 5/25/92

- Radio Receiver monitoring frequencies below 30 MHz
- Cosmic Radiation Detectors
- Similar instruments on several Spacecraft

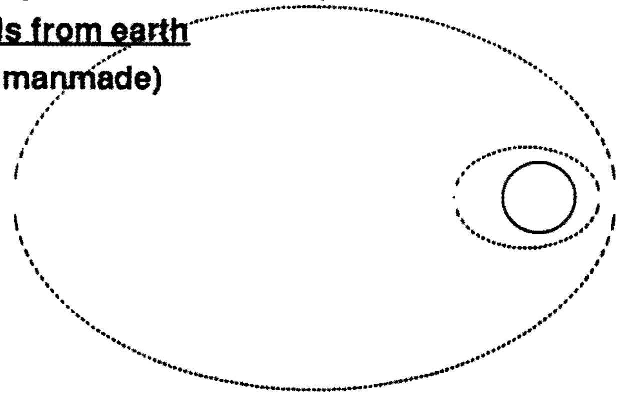
OSCAR at 30+	Missions (Cont.)	23 G3ZCZ 5/25/92

- Signals from space

(Sun & Jupiter, cosmic noise)

- Signals from earth

(AKR, & manmade)



OSCAR at 30+	SUSIE's PROGRAM	24 G3ZCZ 5/25/92

- Publish educational curriculum materials
- Publish details of telemetry
- Publish information well before launch
- Build experiments for inclusion in existing spacecraft under development, AND/OR, separate small spacecraft (depends on available resources)

OSCAR at 30+	SEDSAT	25 G3ZCZ 5/25/92

- BUILT BY Students for the Exploration and Development of Space for STUDENTS on earth
- Use of pre-launch Telemetry Simulator
- Summer 1993 launch with NASA's SEDS 2.
- 5 year planned lifetime
- Investigate tether technology
- Investigate Boeing/Kopen (20% efficiency) Solar Cell characteristics
- Investigate OVONIC Battery technology
- On board camera
- Amateur Radio Transponder

OSCAR at 30+	Mission(s) to MARS	26 G3ZCZ 5/25/92

- Phase 3D Launch
- WSF Solar Sail Project

- Near earth real time telemetry acquisition by schools
- Opportunities for competition for reception from furtherest distance, or specific distances.
- Spaced out telemetry acquisition by specific stations (well equipped) and distribution of data to interested parties.

OSCAR at 30+	Further Information	27 G3ZCZ 5/25/92

- Magazines and Books
  - QST
  - 73
- Local Library
- Local Radio Amateurs
- National Organizations
  - ARRL
  - Project OSCAR
  - AMSAT
- World Classroom Foundation

OSCAR at 30+	Summary	28 G3ZCZ 5/25/92

- AMATEURS HAVE (AND CONTINUE TO) PIONEER SATELLITE TECHNIQUES
- AMATEUR RADIO IS IN SPACE TO STAY
- AMATEUR RADIO PROVIDES A PERSONAL WAY OF GETTING INVOLVED WITH SPACE

An Update on the ARSENE Project

Bernard Pidoux, F6BVP

ABSTRACT

This presentation is an update on the ARSENE project.

ARSENE began in the early 1980's about the same time as Phase 3. The spacecraft is built from parts left over from other projects by students and apprentices and is scheduled for lift off on the Arsene V58 flight in the spring of 1993. ARSENE is 3 axis stabilized and carries two transponders, Mode B (digital) and ModeS (analog). The Mode S downlink is linear on 2446.540 MHz (0.8W). The link budget is such that you will probably need a 2.5 meter dish. The uplink is centered on 435.110 MHz with a 16 kHz Bandwidth. The mode B uplinks are digital at 435.050, 435.100 and 435.150 MHz, the downlink is on 149.975 MHz (15/2W) using standard AX.25 FM equipment. The orbit is 36000 km apogee with a 20000 km perigee at an inclination of 0 degrees. This will result in an orbit with an approximate 16 hour period.

ARSENE Operations Planning

Joe Kasser, W3/G3ZCZ

The ARSENE satellite due for launch in the spring of 1993 carries a conventional AX.25 digipeater using FM uplinks and downlinks. There are only two differences between the ARSENE digipeater and a conventional terrestrial digipeater. These differences are as follows.

1. The device is cross band. You uplink to it on 70 cm and receive it on 2 m.
2. The device is moving, and will only be available for predictable but specific times of the day.

The digital transponder is a digipeater. There is no BBS aboard. All users will have to contact stations (in real-time) directly to send them messages. BBS stations will have to contact other BBS stations for message forwarding, individuals will contact each other, and they will all be digipeating through the same ARSENE spacecraft. Working through ARSENE will be similar to working through AMSAT-OSCAR (AO) 13. Received signal strengths however, are expected to be much stronger than those of AO-13.

ARSENE is going to be very easy to use especially for BBS SYSOPs who are equipped for the 145 and 440 MHz bands. The ARSENE uplink is on 435.050, 435.100, 435.150 MHz, the downlink is on 145.975 MHz. You may use any of the uplink frequencies, they are all active in parallel. BBS SYSOPS will be able to use conventional BBS forwarding techniques for automatically passing messages over intercontinental distances. No software modifications will be required to an existing BBS station although some software changes will make operations more efficient.

Hardware and software devices for pointing antennas at an OSCAR and following its motion are readily and inexpensively available. They can be operated in conjunction with, but separate from the BBS software.

This ease of access will probably encourage power VHF and UHF SYSOPs to add an ARSENE port to their stations. ARSENE will give them intercontinental forwarding capabilities without the licensing headaches of HF. Remember, unattended operation is legal on ARSENE's uplink and downlink frequencies.

The major problem from an operational aspect is that ARSENE is 10 years in the making and operates on 1200 bauds. If you look at the packet channels in your local area, you will notice that certain ones are congested. If you live in densely populated areas you will certainly notice it. Have you copied a MIR packet pass lately? Look at all those disconnect replies from that spacecraft. Think of ARSENE's potential problem. It will be in range of not just your urban area, but of hundreds at a time. The potential for congestion could be worse than trying to get a packet through MIR.

To get the maximum use of ARSENE we are going to have to use it in a planned or a controlled manner, not control access to the spacecraft itself. Access should be provided to the Roddy's of this world, namely, any suitable equipped individual who wants to send packets through it. BBS message forwarding should be limited to designated BBSs for intercontinental message forwarding. There is a precedent here in the closed HF nets which forward messages over long distances. If BBS access to ARSENE can be limited in such a manner, the probability of the channel choking is lower than letting a free for all take place. This approach to message forwarding is an interesting alternative to the UoSAT low Earth orbit Gateway Store and Forward approach.

While some individual stations will leave their systems active via ARSENE all the time, the majority will not. Individuals will use ARSENE in two ways, non real-time message transfers and real-time keyboard to keyboard QSOs. They will probably come on-line on the frequency at local evenings and weekends. One way to optimize individual message transfers is for stations to use the beacon to signal the presence of a message, and to use software such as LAN-LINK to scan the contents of packets appearing on the frequency. The LAN-LINK approach works in the same way either for terrestrial links, or for the ARSENE link.

The LAN-LINK approach works in the following manner. As an individual LAN-LINK user, leave a message on your system. To ensure that people know that you have left a message for them a 'MAIL for' list is loaded into your Packet Beacon and transmitted every 30 minutes (Refer to the BTEXT command in the TNC manual) as ':QTC:' followed by a list of calls.

Should a station that receives such a beacon message, recognize its callsign, it will issue a connect request to the callsign of the LAN-LINK station that originated the beacon transmission. If the connect is made, the other station will send the message automatically which LAN-LINK will "capture to disk". The connect will time out and terminate a few minutes later. The only change the individual LAN-LINK user will have to do is set the packet UNP parameter to via ARSENE-1 (or whatever call sign the ARSENE digipeater uses).

Keyboard to keyboard contacts will proceed exactly as they do on terrestrial links, notwithstanding the QRM levels.

For BBS message forwarding, a number of software changes comes to mind. These changes are modifications to the existing way of doing things, not a whole new approach. The changes are described below.

1. Modify the BBS forwarding files to inhibit forwarding attempts with stations who do not have access to the satellite at that time.
2. Instead of having all stations try to transfer messages at the same time, as is done on HF, use a master-slave approach. This approach uses a master station that controls the transfer and will allow individual users time on the satellite. The Master station signals to each BBS on the network when to start forwarding by sending it a token. The BBS that receives the token initiates a forwarding cycle to each BBS on the network in turn, then returns the token to the Master. The BBS software modification is to add the master/slave token scheme. If the slave BBS cannot return the token to the Master, it takes over as the Master. This situation will arise when the satellite has passed beyond the range of the previous Master station.

ARSENE can provide an alternative dimension to packet radio if we don't choke it at birth. Think about ARSENE, and plan for its optimal use. At the same time, you might care to speculate on how different packet radio would be today, if the RUDAK packet radio BBS on AO-13 had worked.

Foreword

For the second year, we're pleased to publish, as part of the Proceedings book from the AMSAT Annual Symposium, papers that focus on the educational use of Amateur Radio satellites and space operations. These papers result from presentations given at the second AMSAT/ARRL co-sponsored educational workshop held at the AMSAT Symposium. Topics that authors wrote about included using satellites in elementary school science classes through college engineering courses, plus papers about activities evolving from the Shuttle Amateur Radio EXperiment (SAREX). Amateur Radio and education go hand in hand, quite nicely, at all grade levels. These papers give readers examples of how teachers implement the two in their classrooms. We wish to encourage as many teachers as we can to make use of Amateur Radio satellite and SAREX activities in order to bring science to life for their students.

David Sumner, K1ZZ
Executive Vice President, ARRL

October 1992

OSCAR Satellites and an Amateur Radio Partnership with a High Tech High School

by Ben Acton, KC3QP
Professor, Montgomery College

Paul Skellchock
Technology Education Resource Teacher
Watkins Mill High School

Dan Jayjock
Technology Education Teacher
Watkins Mill High School

INTRODUCTION

Montgomery County is a suburb northwest of Washington, DC. This county has the highest high tech employment in the state, having more than 55,000 high tech jobs. To handle the future requirements for technical support personnel, Montgomery College, the county community college, established a partnership with the county public school system and the Montgomery County High Technology Council (MCHTC). The MCHTC is responsible for:

- increasing the presence of higher education in Montgomery County;
- establishing linkages among high tech firms, entrepreneurs, and support industries;
- educating the public on needs and trends in the high technology community.

Through this partnership, we established a program called "Imagine Your Tomorrow--The College Preparation Technical Program in Systems Engineering Technology." We refer to it as "Tech Prep." This program is designed to prepare students to enter the work force as well-qualified technical support professionals.

Tech Prep is a 4-year academic/technical program. It begins in the 11th grade and leads to the completion of an Associate in Arts degree at Montgomery College. We also call this program "2 + 2." Students can also continue into a bachelor's degree program in a technical field or technology management. The program involves an industry mentor program, college technology seminars, field trips, career counseling, and a speakers' program.

The general goals of the program are:

- to raise student achievement in the basic skills of communication, computation, and problem solving;
- to increase the percentage of high school graduates choosing to pursue technical careers to enter the technical work force;
- to provide opportunities for all high school students to obtain the quality post secondary education needed to qualify for rewarding employment in a technological society;
- to better inform students, parents, and educators about expectations of

employers and labor force needs of this decade and beyond;

- to continue to improve student attitudes toward school and learning.

The high school chosen for the initial effort was Watkins Mill High School, a $27 million high tech school, opened in 1989. This school was the subject of a feature article in the Science & Society section of *U.S. News & World Report*, October 28, 1991.

The high school portion of the college tech prep program includes a core of technical education and academic skills in science, mathematics, communications, and related technologies. Those students in the program who complete the academic requirements can earn up to 14 credit hours by Montgomery College toward an AA degree in computer assisted drafting and design (CADD), telecommunications technology, or electromechanical technology.

Beginning in the Fall of 1991, an extensive publicity campaign was begun to publicize the benefits of the College Preparation Technical Program. Federal and state grants helped fund this effort, which was lead by Ms. Lois Roberson, Career Programs Specialist at the college. A professional video tape was made which highlighted the program and its benefits.

PRINCIPLES OF TECHNOLOGY AND RELATED COURSES

The two year Principles of Technology curriculum course covers the following units with an emphasis on interrelated systems:

- force work
- rate resistance
- energy power
- force transformers momentum
- waves & vibrations energy converters
- transducers radiation
- light & optical systems time constants

The Introductory and Intermediate Electricity and Electronics courses include theory of simple to complex digital circuits. Topics include ac and dc fundamentals, magnetism and solid state devices. Hands-on experience is emphasized using test equipment and training boards.

In Intermediate Mechanical Drawing, students produce increasingly detailed technical drawings which involve the use of problem-solving and mathematical skills. Students receive instruction in applied geometry, principles of design, dimensioning, specification writing, and CADD/CAM drawings. The fields of mechanical, aeronautical and structural engineering are covered.

A HIGH TECH STUDY AND A REPORT

During the Summer of 1991, the Maryland Department of Economic and Employment Development, Division of Business Resources, through the High Technology Council, convened a planning group of telecommunications industry representatives and education, training, and employment resource representatives. The purpose of the group was to develop a strategy for education, training, and employment needs for the telecommunications industry. Ben Acton, KC3QP, Associate Professor of Telecommunications Technology and Computer Science at Montgomery

College, was a member of the planning group.

In September 1991, the High Technology Council published the results of the planning group work in a report titled "Developing a Strategy for Education, Training and Employment Needs for the Telecommunications Industry." The report gave an overview of the telecommunications industry and the drive to make Maryland a world class leader in telecommunications. It cited a recent study prepared by the Task Force on High Tech Occupations, which stated, "... the supply of engineers, engineering technicians, architects and computer professionals will be highly inadequate to meet labor market demands in Maryland during this decade."

In the report were several recommendations for public and private education and training. In the public school area, the following recommendations are significant for this purposes of this paper:

- Encourage student enrollment in tech-prep programs;
- Incorporate computers and communications concepts into the education process;
- Introduce information communications techniques in science and technology programs;

TEACHING ASSISTANCE REQUESTED...

Also during the Summer of 1991, WMHS and MC discussed the need for someone to teach the recently established Principles of Technology courses at the high school for the 91-92 school year. The two technology education teachers, Paul Skellchock and Dan Jayjock already had a full teaching load. They also wanted to enhance the courses by having more material on telecommunications. Based on the partnership agreements, plus the emphasis on telecommunications, Ben Acton, KC3QP, Associate Professor at MC, agreed to take the assignment.

IBM AND GPS

Another partnership was established between WMHS and the Federal Systems Company of IBM. IBM loaned the technology education department of the high school with a Global Positioning System (GPS) receiver and technical support. We used Tracksat software to monitor the locations of GPS satellites and we used the GPS receiver to obtain geographical coordinates and learn about data acquisition through a Geographic Information System. The students learned the value of GPS in navigation, surveying, and mapping. They applied trigonometry and triangulation plus data obtained from the GPS receiver to plot the exact positions of the school ground fence posts and compute the perimeter distances.

WMHS AMATEUR RADIO CLUB

Another of the first telecommunications related activities we undertook was to establish an Amateur Radio club. We met each Wednesday after school from 2 to 3 PM. The club grew to three members. One member already had a tech license, Jon Bary, N3LIM. In addition to helping the club students study for the licenses, we did such things as install and test upgrade options for a Yaesu FT736R transceiver loaned to the school by MC, and work on an HF dipole antenna.

SECOND SEMESTER EMPHASIS ON PROJECT ACTIVITIES

At the beginning of the Spring semester 1992, the two technology teachers, Paul and Dan, thought it would be a good idea to have a Principles of Technology project in telecommunications. We decided that the focus would be Amateur Radio satellite communications. This activity would be shared with the communications technology class and the electronics class as well as the Amateur Radio club. One thing that sparked our interest was the AMSAT Journal of November 1990. It contained a letter from Dr. Alex Zaitzev, RW3DZ/UZ3DXB of Moscow, Russia. Dr. Zaitzev was with a school club that was interested in using the PACSATS for international links between schools for educational purposes. We brought this letter to the attention of our Career Programs Specialist, Ms. Lois Robertson, who had hosted visiting teachers from Russia. She sent a letter to Dr. Zaitzev, explaining our project and our desire to cooperate with his club. We are still waiting for a reply.

MONTGOMERY COLLEGE RESOURCES

Fortunately, MC had some resources to support an Amateur Radio project. On the Germantown faculty of MC, we have four hams: Ben Acton, KC3QP, Andy Nelson, KV3S, Alex Benitez, WX3Q, and David Fox, KA3HAJ. We also have a complete program in telecommunications technology which is designed to train entry-level technicians. MC has the usual electronic test equipment such as meters, 'scopes, sig gens, & freq counters, as well as a good supply of electronics parts. We had a Cushcraft AOP-1 2m/70 cm crossed Yagi antenna system and a Yaesu alt-azimuth rotator system sitting on a shelf waiting to be assembled. The college had just acquired a new Yaesu FT-736R transceiver which could be made available. Satellite tracking software was also on the shelf not being used that semester so we could use that at the high school.

We were able to borrow copies of What's Up, TLMDCII, CAST Weberware, and PBG, as well as copies of publications such as the *Satellite Experimenter's Handbook*, the *ARRL Handbook for Radio Amateurs*, *AMSAT Journal*s, *QEX*, *OSCAR Satellite Report*, *Satellite Operator*, *A Beginner's Guide to OSCAR-13*, and the *ARRL Satellite Anthology*.

MONTGOMERY AMATEUR RADIO CLUB - ANOTHER PARTNERSHIP

We knew that we still did not have all the expertise or resources to undertake this project. We called upon the members of MARC for help. Steve Todd, K2IYQ, president of the club, and Ken Nichols, KD3VK, needs coordinator, quickly came through with an old Drake HF transmitter and receiver pair, as well as mike, antenna tuner, a watt/SWR meter and a Clegg 2-meter transceiver.

Members of MARC were always ready to assist. We needed coax cables. They provided cables and connectors. We needed troubleshooting assistance on the PSK modem and the TNC connections. They provided the assistance. We needed advice on decoding signals. They provided the advice.

Ken Nichols, KD3VK, also sponsored us so we could participate in the Kenwood K.I.D.S. program. Kenwood supplied us with ten copies of *Now You're Talking*, an Amateur Radio world map, and a copy of their new HamWindows software.

AMATEUR RADIO ACTIVITIES

One of the major activities of the students included assembling, adjusting and installing the crossed Yagi satellite antennas. Two girls in the second year P.O.T class did the majority of the work, yet they previously had no experience with tools, mechanics, or interpretation of diagrams. Others assembled and mounted a broad band VHF/UHF discone vertical antenna, and an HF trap dipole. They also soldered on the antenna cable connectors. An eight foot antenna tower was made of storage shelf angle iron and brackets. The antennas were mounted on the roof of the school. One P.O.T. student was also in the Intermediate Mechanical Drawing class and made CADD drawings showing the major components of the station. Another girl showed skill at making free-hand sketches, so she made drawings of the backs of the equipment in the shack and the cable connections.

We obtained a TAPR 1200 BPS PSK modem kit. Two students took on this project. They patiently assembled and tested the modem. We started using an AEA PK232MBX but later an MFJ 1270B TNC was loaned by MARC and modified by Alex Benitez, WX3Q, to mate with the TAPR PSK modem.

SATELLITE AND SHUTTLE TRACKING

The college provided its copies of Graftrak and Instant Track. We also got a copy of Tracksat from W3INK's land line BBS. Graftrak was the primary program we used as it is so easy to use. We like the antenna footprint display and the ground track patterns, as well as the ability to show the "bird's-eye view" orthographic projection. The delta time feature is very handy also. Tracksat is also an easy one for students. They liked the multiple satellite display feature. Instant Track has the benefit of colorful world maps coupled with the geographical positioning feature which highlights the sub-satellite point. Being able to print the satellite visibility schedule and satellite co-visibility schedule is most valuable.

Our primary sources of keplerian elements were the W3INK PBBS & land line BBS and BITNET via the college main frame computer. During SAREX flights, we tuned in to NASA Goddard's WA3NAN rebroadcasts and commentaries.

SATELLITE SIGNAL RECEPTION

Though we did not have preamps, we were able to track and receive signals from several OSCARs, including AO-13, RS-10/11, DOVE, and WeberSat. We copied packet and voice signals from MIR, but we were unsuccessful in making a QSO. We were able to receive signals from the space shuttle SAREX flights of March and June, but we could not communicate with them either.

SHORT WAVE LISTENING

Short-wave listening was an interesting activity also. We enjoyed the foreign language broadcasts and music. This was a great opportunity to explain HF radio wave propagation. For accurate time, we relied on listening to WWV on a Yaesu FT-980. It was fun watching the students comparing how accurate their watches were from one day to another.

RESULTS

Newspaper Articles...

Two local newspapers, the Frederick Post and the Montgomery County Journal, carried stories and pictures describing the technology program and the role of Amateur Radio in it. The May issue of the WMHS newspaper, *The Current*, had a two column article and photo describing the Amateur Radio activity.

Visitors...

For visitors, we conducted many demonstrations of our technology education facilities as well as our "ham" shack. We demonstrated satellite tracking and signal reception, and packet radio for parents as well as teachers, counselors, administrators and superintendents from other school systems across the country. We had over two hundred visitors during the school year and most were during the Spring semester. They were fascinated with the technology curriculum in general and were amazed at how Amateur Radio can be used as part of the program. They seemed particularly pleased with the idea of partnerships.

Hands-on experience with real results...

Students had the benefit of hand-on experience building something that obtained real results. Actually tracking a satellite and receiving and decoding signals was a thrill for everyone, teachers included.

Students were exposed to the telecommunications field...

Students were exposed to some the basics of the telecommunications field and have a better idea of some of the technical tasks. They also realize that telecommunications can be a hobby as well as an occupational area.

Students and faculty interested in getting licenses...

Not only are our two technology education teachers working on getting licenses, but two teachers in the science departments expressed an interest. We provided them with copies of *Now You're Talking*. Studying for the Technician class license is now part of the curriculum for the second year of the Electricity and Electronics course.

Governor's interest...

The local publicity, as well as the publicity campaign of the College Tech Prep Program, caught the eye of Maryland Governor Schaefer. He wanted to visit the school and see students in action in May but scheduling problems prevented him from doing it. We are trying to schedule his visit for this Fall.

Awards...

Taraneh Norouzi, one of our second year Principles of Technology students, received an award for "excellence in systems engineering technology" at the Seventh Annual Awards Program at the National Institute of Standards and Technology, sponsored by The Citizens Coalition for Vocational-Technical Education.

The first annual Technology Awards Banquet in May was sponsored by

Montgomery County Public Schools, the three of us teachers received awards for our program. MARC also received an award for their support of the program.

One student got a license...

One of our club members, Ben Eater, now N3MVO, got his ticket over the summer. This student is also enrolled in the Principles of Technology course this year.

Enrollments in the technology curriculums are UP...

The Electricity/Electronics classes have 24 students each this Fall, and most of these same students are also in the Principles of Technology I course.

PROBLEMS

Including nine weeks of Amateur Radio activity into an already crowded schedule for Principles of Technology and Electronics meant that something had to be left out, so we did not cover as much other material as we should have.

Since we started in February, by the time we had built up enough enthusiasm among the students, those who wanted to study for their licenses were already swamped with homework projects and preparing for final exams. Arranging a license exam schedule during the last days of the semester was not possible.

Via VHF and HF packet radio, we were able to have several QSOs, but QSOs via satellite will have to wait until we have preamps at the antennas. Our antennas are one hundred feet of coax cable away from the shack. We did not try mode A with the RS satellites.

FUTURE PLANS

We plan to install an FM voice repeater system, as well as a VHF packet radio BBS. The communications curriculum can use some hands-on television so we will be working on an amateur television capability.

A fundamental goal of our efforts is to use Amateur Radio as a link with other schools. HF may be part of this effort but more than likely amateur satellites will be the primary media used.

We still hope to link with Dr. Zaitzev's school in Russia. Receiving satellite photo images, such as those provided by Kitsat and Webersat is high on the priority list.

We plan to step up efforts to bring Amateur Radio into other county high schools. Members of the Montgomery Amateur Radio Club are enthusiastic about "elmering."

Currently, the crossed-Yagi OSCAR antennas are manually controlled. We will soon be cabling a PC to the rotator control box to automate the antenna tracking functions via Graftrak or Instant Track.

Since Montgomery College and WMHS are in line-of-sight communications, we want to experiment with packet radio telemetry and remote control links.

During the Spring semester, the PCs used for packet radio and satellite tracking had to be shared with students needs for CADD and desktop publishing. This summer, MC loaned us a PC-XT for packet radio, and we expect another one this Fall for the satellite tracking software.

Also, over the summer, MARC donated an HF rotary-beam antenna and tower.

That will be another installation project involving MARC and the students.

To properly communicate via satellites using mode B or mode J, we need preamps installed at the antennas. We hope to have students build and install them.

Based on last years experience, the goals of the telecommunications unit within the curriculum at the high school has been established as follows:

Students should be able to...

- understand the dynamics of technical systems used to devise, transmit, receive, and use information;
- understand the underlying principles of physics, science, and mathematics that drive telecommunications systems;
- understand the specific uses of electromagnetic spectrum and transmission media such as cables, fiber optics, microwaves, and laser beams to send and receive signals;
- use OSCAR satellites as examples to explain orbital mechanics, signal propagation, and functions of telemetry data;
- explain the uses of the GPS and be able to perform basic surveying functions based on GPS data;
- understand and use satellite tracking software, computers, ground station transmitters and receivers, and telemetry decoding software;
- establish communications with Amateur Radio stations in other schools and other countries via OSCAR satellites;
- appreciate the cultural and political functions of international broadcasting via short wave radio;
- understand the vocational and avocation possibilities in the telecommunications industry.

BENEFITS

Our experience highlights a few of the benefits for education in establishing partnerships among high schools, colleges, industry and Amateur Radio clubs. Such relationships can improve the quantity and quality of students participating in technology programs. High schools can have made available to them resources and expertise they may not be able to obtain otherwise.

Amateur Radio gains through such partnerships by obtaining more licensees and by providing an avenue for the expression of helpfulness and public service which characterizes Amateur Radio.

Our work force gains because we have directly enhanced the capabilities of students to better themselves and to make a contribution to society.

AMSAT involvement in such partnerships is excellent public relations which can highlight the participatory and cooperative nature of the OSCAR projects. In time, we hope AMSAT will have more new members and more active participation in AMSAT projects at all levels.

SUNSAT MICROSATELLITE PROGRAMME STATUS - JUNE 1992

Garth W Milne *
Department of Electrical and Electronic Engineering #
Stellenbosch University ++

20 JUNE 1992

ABSTRACT

Sunsat is a 50 kg 45cm side cubic micro-satellite, planned as an auxiliary payload for the Ariane 4 Helios mission in mid-1994. This staff and graduate student project, led by Stellenbosch University's Electrical Engineering Department, in association with SA AMSAT, will join the group of Oscar satellites. South African electronics organisations including Grinaker, Altech, and Plessey, are providing student support, certain modules, quality assurance, environmental test facilities, and technical advice.

The satellite is similar to the UoSats of the University of Surrey, and will provide Amateur communication and data relay facilities. Sunsat also features precise reaction wheel attitude control, and a 20 metre resolution, three colour, visible and near IR stereo imaging capability.

INTRODUCTION

Sunsat was introduced to the Amateur community at the AMSAT conference at the University of Surrey in August 1991 (1). Reports in the international space press (2, 3) and South African media (4) widely covered the announcement of the programme, and gave generally accurate descriptions of Sunsat's concept and intentions.

This paper describes the programme status in June 1992 and gives some results of design study work.

- more -

ORIGINS OF THE PROGRAMME

Many visitors have admired the Satellite Engineering Unit at the University of Surrey, where UoSat design, construction, and operation is the core activity. Advice by Prof Martin Sweeting, and experiences of Stellenbosch staff (5) while studying there encouraged us to start a similar program. Initial thoughts evolved finally into the announcement of Sunsat.

Sunsat focuses our department's (7 Profs, 20 lecturers) capabilities in EM field theory, microwaves, DSP, control and simulation on this technology application. National and international interest has been created, benefitting our electronics industry, which is currently marketing its capability for military and space quality development at attractive rates.

Electronics companies, Grinaker Electronics, Altech and Plessey, together with SA AMSAT have thus joined us to form the Sunsat Advisory Board, which meets occasionally to integrate interests, and help locate funding. These and other companies have sponsored our graduate students and are energetically seeking funds to permit a final go-ahead.

PROGRAMME GOALS AND PROGRESS

Programme goals include

- Establishing a continuing graduate student micro-satellite programme.
- Increasing international academic and industrial interaction with our department.
- Stimulating interest in technology and science among SA school children.
- Testing micro-satellite high precision attitude control and imaging.

– more –

STUDENT INVOLVEMENT

Since the start of the academic year (January in SA), fifteen graduate EE students have been involved. They spend vacations and a third of their term time on the project. The remainder is occupied by graduate courses, homeworks, and ultimately their M.Eng project. Seven lecturers and four Professors (one at the University of Cape Town) take technical, schedule, and quality responsibility for the student work. Only the course work and M.Eng project, which we formally decouple from the Sunsat programme, are considered for academic credit. The Sunsat work provides practical engineering experience and technical growth early in the 2-year M.Eng programme, and makes graduate study financially possible for a number of the students.

A single large laboratory is being used, with desks, workbenches, and PC's attached to a campus-wide network and to Internet. A $12m^2$ control room contains an amateur satellite ground station equipped with tracking antennas, and 2m and 70cm transceivers. The facility enables the students, who all have amateur licences, to gain experience communicating via existing amateur satellites. A 4m tracking dish will be installed later this year for micro-wave work.

LOCAL AND INTERNATIONAL INTEREST

The launch of the programme, and the creation of the Advisory Board, received wide publicity, including South African TV, local and international technical press, and amateur newsletters (6, 7). Presentations have been made at numerous conferences.

British Aerospace Space Systems has given technical advice, including a week long design review at Stellenbosch, and other companies have offered to donate components.

- more -

SCHOOL INTEREST

South Africa is graduating 40 times fewer engineers per capita than England, and enrollments are dropping. It is critical for economic growth to attract many more children to technical careers, especially since early exposure to electronics markedly improves engineers' design ability. Generating school interest is thus important, and has been provided for, but will only be actioned once project financing is assured.

We are also a resource centre for SAREC, (Satellite and Amateur Radio Resource and Education Centre), an independent programme of the Amateur Radio Development Trust which aims to stimulate science interest in schools, through electronic and amateur satellite work. In its first six months, voice, fax and BELTEL (SA Telcom's Electronic Data Service) information facilities were established to carry technical news and bulletins.

SAREC has also arranged for school children to talk to the crew of the STS-50 Space Shuttle via amateur radio.

Sunsat will involve schools through SAREC. A school-developed, independent electronics experiment is planned for the tip mass on the satellite's gravity gradient boom, and a school communication requirement is included in the amateur payload specification.

TECHNICAL OVERVIEW

ORBIT

The launcher will place Sunsat into a circular polar orbit at 805 km altitude. During the 100.8 orbit period the earth rotates 25°, equivalent to 2770 km at the equator. The orbit plane at 98.6° inclination to the equator precesses a revolution per year to remain sun synchronous. A constant sun aspect is thus maintained which benefits imaging. Two satellite passes in the late morning and two at night provide nearly 40 minutes of communication time at a range of less than 2800 km.

- more -

Re-entry will occur in more than 20 years. Since the satellite needs no fuel, its operational life will be determined by slow component degradation. Other Oscar satellites in similar orbits have operated for many years.

POWER SYSTEM

This will be conventional, with fixed solar panels on four sides, NiCad batteries, and an optimum power point charger.

TELECOMMAND

Telecommand will normally be done by packet radio commands to the on-board computers. A hard wired backup telecommand system can override computer commands, select between two computers, reset them, or load new software.

TELEMETRY

Normal telemetry will be in packet protocols from the computer. The hard wired telemetry system is simple and intended only to help restore communications and correct computer operation.

COMPUTER

The on-board computer includes an 80C186 and a transputer to handle flight management tasks, digital communications and processing. Error corrected program memory, with memory washing for SEU's, and a 64 Mbyte RAM disk are included.

IMAGER

A 10cm diameter optic system will image the earth onto three linear CCD sensors, via spectral filters. Operation is analogous to a fax machine scanning the earth at 6624 m/s.

- more -

The high resolution data will be down-linked in real time to reception stations at Stellenbosch and Johannesburg. Use elsewhere is primarily a regulatory problem. Data for small areas can be stored in the RAM disk, for down-linking at much lower rates.

The pixel size goal is 20m by 20m, using optics specially developed by the Lasers and Optics Group of the SA Council for Scientific and Industrial Research (CSIR). The optic axis will aim 30° forward of vertical to permit stereo imaging as described later.

ATTITUDE CONTROL

A 2kg mass will be deployed from the top of the satellite on a 2m extensible boom. The gradient of the earth's gravitational field will cause the satellite to orient itself in an earth-pointing attitude. Controlable electro-magnet torque coils will use the earth's magnetic field to provide external moments to damp libration and to slowly yaw-spin the satellite for temperature equalisation.

When imaging, motor driven reaction wheels will stop the spin and re-orient the satellite with the imager looking forward. For stereo imaging, after a 200 km long strip is imaged, the satellite will be rotated through 180° in yaw within 90 seconds before the area is imaged again with a rearward view.

Attitude estimation will be redundant, using Kalman filtered 3-axis magnetometer data, linear CCD sun and horizon sensors (0.5mrad accuracy), and for redundancy and research, a CCD camera imaging the star background.

DATA COLLECTION AND TRANSFER

The footprint of the satellite (area where the satellite is 5° above horizon) is a moving circle of 5080 km diameter, that spans 45° in longitude. Radio range varies from 800 km to 2800 km compared to the fixed geostationary range of 36000 km. Data communication at 1200 baud is possible with 10 watt transmitters and dipole antennas, permitting data collection from, and data dissemination to, low cost terrestrial transceivers.

- more -

Since large quantities of data can be stored, data transfer between any two points in the world is possible where licencing is approved. AX25 data protocols will be used to ensure error free transfer. Frequency negotiations are in process for this commercial application.

RANGING SYSTEM

The position management function originally proposed will probably be omitted to save costs. Coupling ever smaller and cheaper OEM GPS receivers to the commercial data transfer system cqan provide a similar function.

WIDEBAND DATA RELAY

A 5-10 Watt S-band down-link is required for the imager. Adding an L-band receiver and appropriate switching creates a wide-band transponder capable of 1 MByte/s with 2 m diameter ground stations. Application of the system for amateur gateway service is being studied.

AMATEUR PAYLOAD

The amateur payload definition was approved at the SA AMSAT Spacecon 91 Conference (8). Store and forward digital packet radio will be provided, including 1200 baud AFSK for compatibility with terrestrial equipment common in SA. The 9600 baud standard pioneered by the University of Surrey on OSCAR 14 is also supported. Both 2m up/down and 2m-up/70cm-down options will be included, together with full bulletin board facilities. The Pacsat Standard Protocols being used on Oscars 16 and 22 are likely to be followed.

A 2m Parrot mode is intended especially for Novice category users (under 16). This will digitally store speech up-linked on the 2m Parrot channel, and then retransmit it on the same frequency. School users will thus hear their transmission being relayed to the whole of SA each time they get through. Learning the need for operating protocols will be a valuable part of the education!

- more -

The 2m down-link will also be used to distribute the SA Radio League's weekly bulletin country-wide and world-wide if required. SA AMSAT will also provide a linear 2m/10m transponder for the satellite.

Some of the above services are incompatible, so will have to be scheduled for different times.

PHYSICAL LAYOUT

The July 1991 concept layout shown in figure 1 will change with detail design starting in July. Design change was delayed till our thermal analysis capability and student familiarity with the system had improved.

WORK DONE TO DATE

RF SYSTEM

Initial student breadboard receivers, transmitters, VCXO's, synthesisers, modems, frequency multipliers, and diplexer filters have been built. These will be reviewed and updated before prototypes are made. Antenna patterns have been modelled with NEC, but more work is necessary.

ATTITUDE CONTROL

Attitude control simulations in (5) have been extended by WH Steyn to include the reaction wheels. The computer-driven reaction wheel controller, and horizon sensor breadboards are working. The magnetometer will be supplied by the SA Magnetic Observatory at Hermanus, using a well proven design.

TOTAL SYSTEM SIMULATION

A new Stellenbosch-developed, block diagram based PC simulation package, Simlab, is being used to develop a comprehensive dynamic system model. Figure 2 shows a screen display of one of the hierarchical modules.

-- more -

THERMAL SIMULATION

Figure 3 shows a plot of simulated +x panel and internal temperature for a spinning Sunsat. The non-spinning concept with two heat pipes has also been analysed and simulated, and found to be thermally feasible.

POWER SUBSYSTEM

Charge/discharge simulations have been done. Battery, solar panel, and solar cells choices are now being made.

TELECOMMAND

Command decoder breadboard work has been done. Changes after a first review are in progress.

COMPUTER

The computer and RAM disk design is complete. The prototype PCB will be laid out during July.

PUSHBROOM IMAGER

A CCD imager breadboard is working as a plug-in card in a PC with an external CCD head. The card has 96kB of data memory, which can be filled and then read and displayed via the PC.

The present CCD is a 5000 pixel, NEC device. Importance of maintaining sensitivity and device MTF (Modulation Transfer Function) at wavelenghts longer than 0.7 microns, is likely to cause a change to the TI TC104, even though it only has 3456 pixels. A longer device, with the MTF performance of the TC104, would be ideal.

- more -

The optical system is likely to be a derivative of the 600mm focal length, F/6 Telemacro 4 lens developed by the CSIR. The reflective optical design is short (200 mm), and of low mass (2.1 kg). Various concepts for the colour splitter are under consideration. An attractive option is to mount the 3 CCD's on faces of a penta-prism with internal dichroic layers. The CCD's could be aligned and permanently bonded to the prism to maintain perfect registration. Final optics design will begin after the CCD choice is finalised.

MANAGEMENT

Problems associated with establishing a unit of 15 people on a single project, in a university environment, have been encountered and largely overcome. Systems for cost accounting, project management, and systems engineering have been established. The networked computers are improving efficiency. Maybe we will even overcome the shortage of RF connectors and adapters!

ACKNOWLEDGEMENT

Sunsat is a project relying on time contributions by many people in the department, and by members of the Advisory Board. Their contribution is gratefully acknowledged. Professor JJ du Plessis in particular, has provided the activation energy that has been necessary for most activities to be accomplished.

Friendly advice from members of the Spacecraft Research Unit of the University of Surrey is greatly valued.

CONCLUSION

SUNSAT is an ambitious micro-satellite venture by SA Universities, Industry, and Radio Amateurs. It offers a means of both stimulating interest and training in satellite related science and technology, and marketing our electronics community. The programme has attracted local and international interest, and is seen as a statement of faith in a technological future for South Africa.

- more -

We have facilities and people necessary to make the programme a success. With all that has been set in place, we are determined that the project will get through to space operation. See you in 1994!

References

* Grinaker Chair of Earth Satellite Systems. ZR1AFH

\# Internet: milne@firga.sun.ac.za Fax +27-2231-774981

++ 7600 Stellenbosch, South Africa Tel +27-2231-774525

τ Analysis Management Systems, First National Bank, Geo Systems, Siemens

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(2) South Africans propose micro-satellite. Space News, Vol 2 No 29, August 26 1991

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(8) Sunsat - Stellenbosch, SA Amsat, and Industry. Garth W Milne, SA Amsat Spacecon 91 Conference, August 1991.

SUNSAT
Stellenbosch

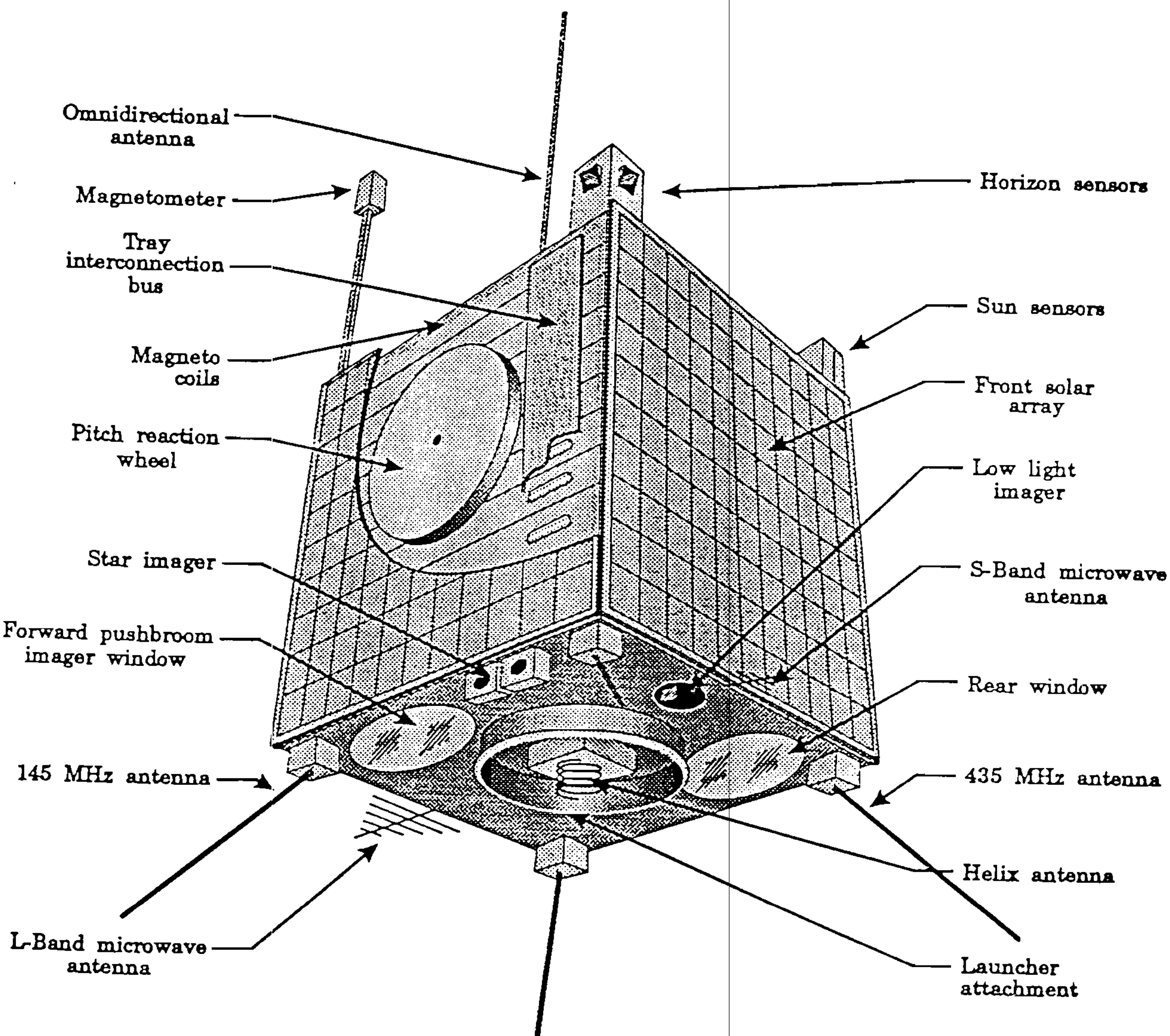


Figure 1. SUNSAT satellite concept. 27-6-91

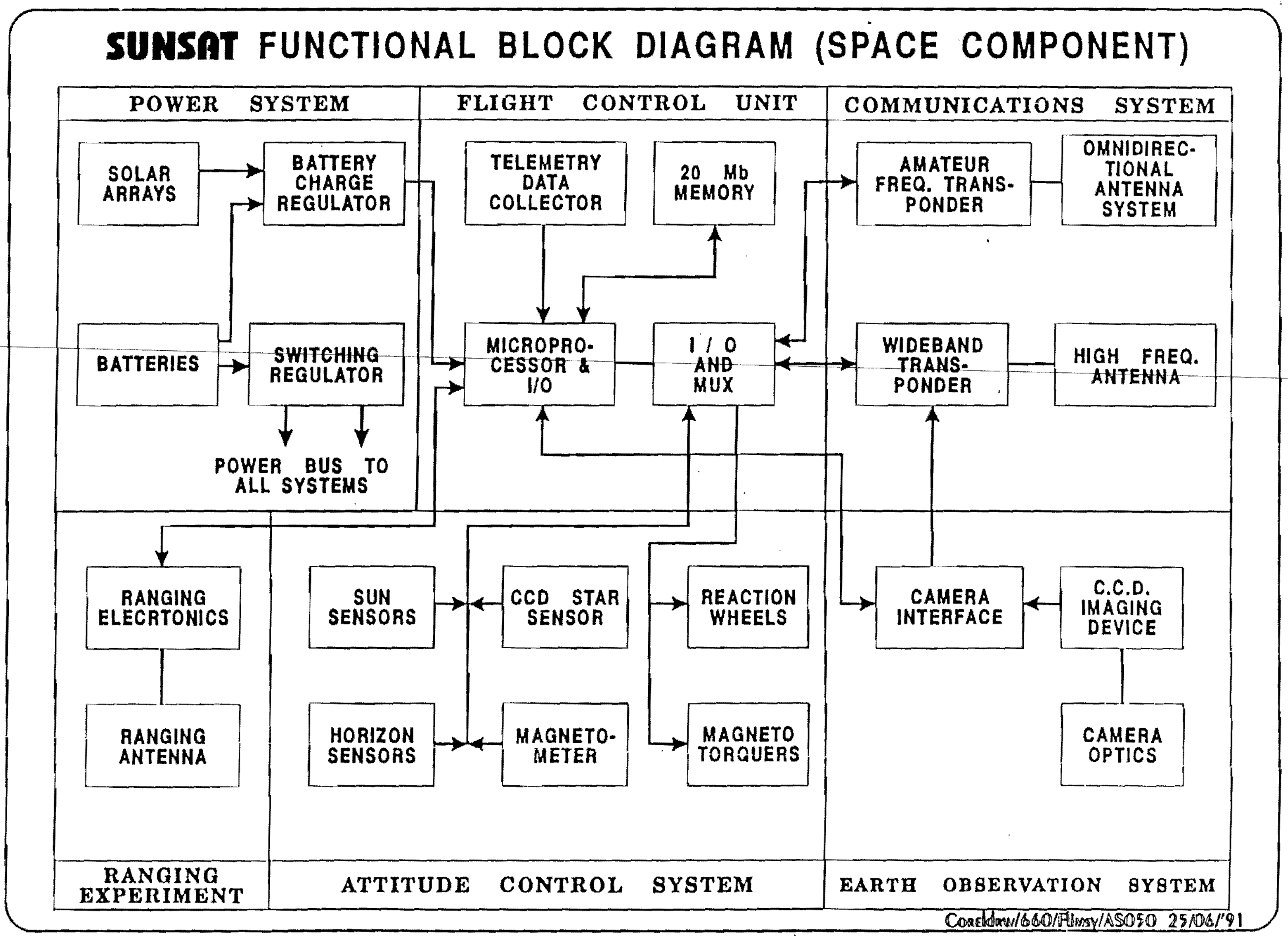


Figure 2. SUNSAT satellite block diagram. 27-6-91

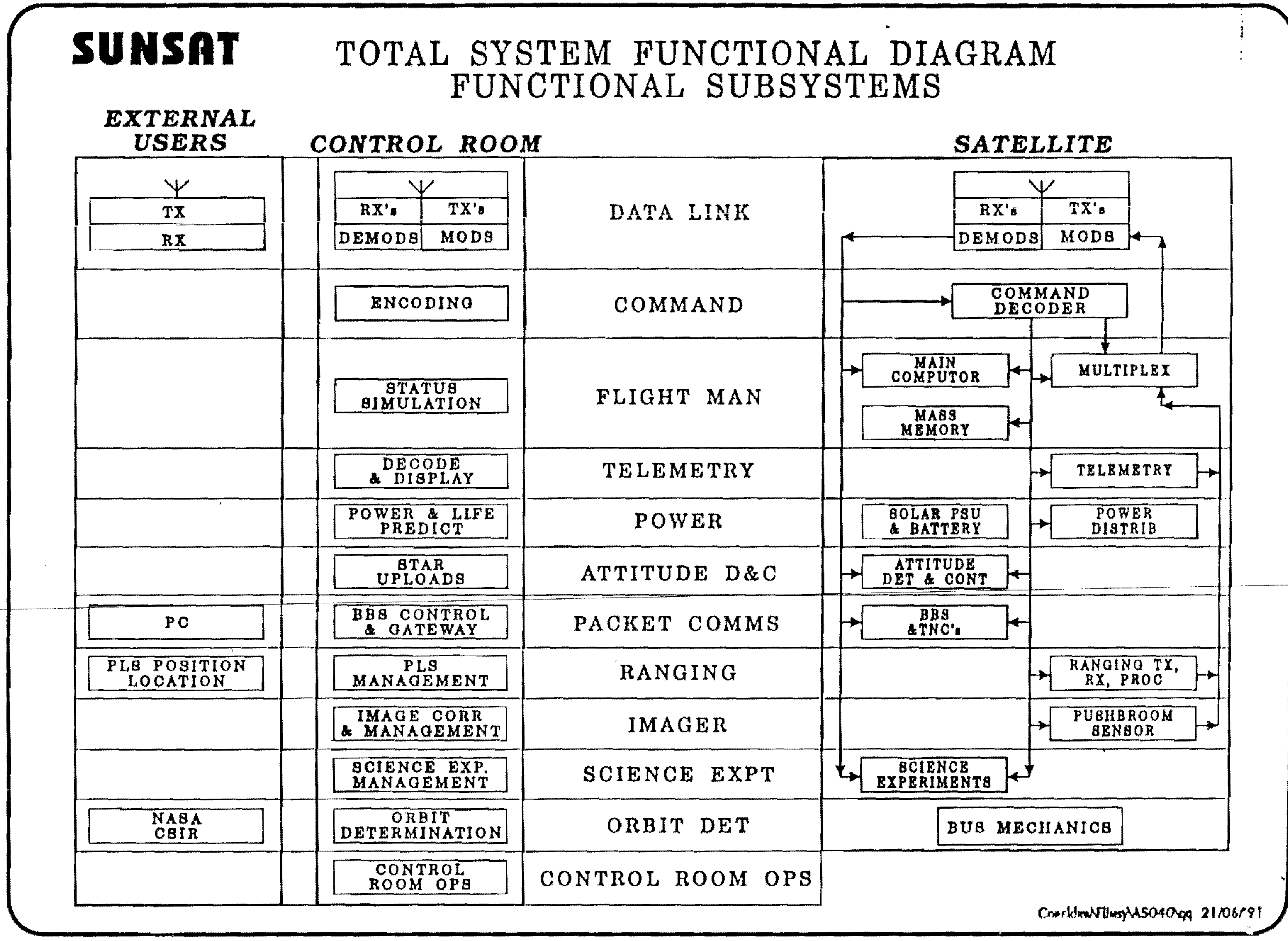


Figure 3. SUNSAT functional subsystems. 27-6-91

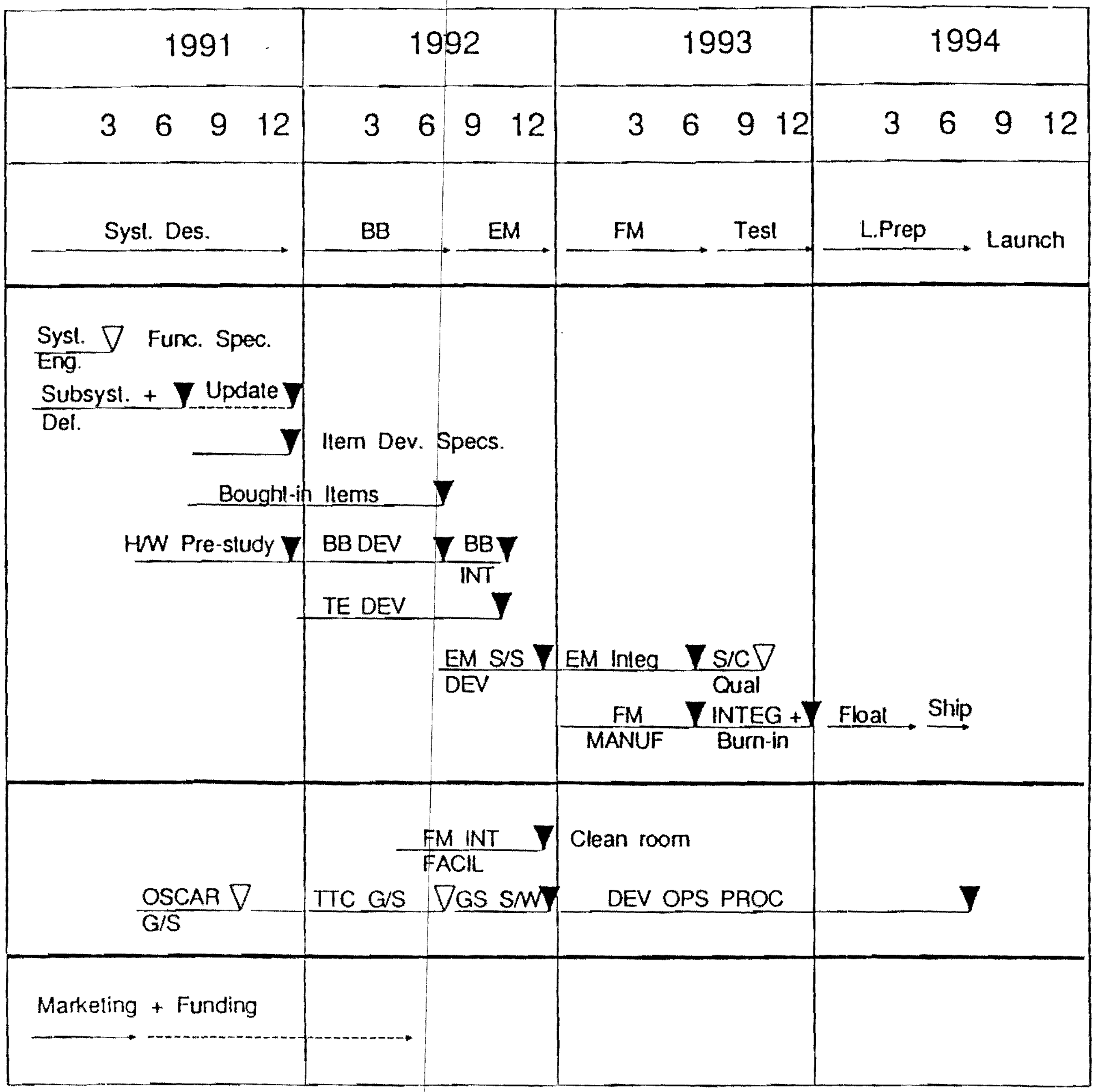


Figure 4. SUNSAT programme plan. 27-6-91

BASIC SATELLITE TERMINOLOGY EXPLAINED

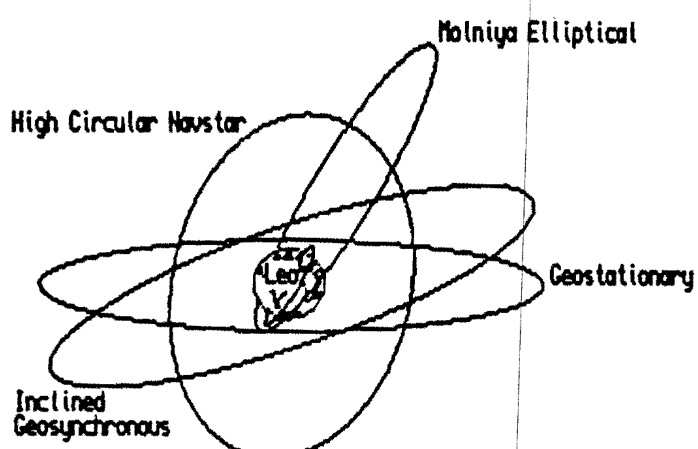
WILLEM NEL ZS6ALL*
SA AMSAT

Any new field in technology soon acquires it's own unique terminology. New terms get added as the need, caused by technical advances, arises.

Satellite technology is no exception. Many of the terms used, at first sounds strange but once they are better known prove to be quite harmless. Many of the terms used are borrowed from astronomy because any earth satellite is an artificial moon of the earth. The same laws of physics which govern the movement of celestial bodies are applicable to the earth-satellite system.

2.0 MOTION OF SATELLITES

Satellites are launched by means of a launch vehicle, normally a liquid fuel rocket, which carries it away from the surface of the earth to above the upper limits of the atmosphere. At a specific time it is separated from the rocket and it continues in it's path, orbit, at a certain velocity. Depending on the velocity and position of the satellite at release, the orbit will be either elliptical (eccentricity >0<1) or circular (eccentricity = 0)



2.1 CIRCULAR ORBITS (PHASE I AND PHASE II SATELLITES)

In a circular orbit the satellite goes round the earth with a constant velocity at a roughly constant altitude (Height above surface of the earth).

Low earth orbits (LEO) vary in altitude from 300 to 1700 km.

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PERIOD

The time taken for one compute revolution of the satellite around the earth is called the period. This is expressed in the formula as t and is proportional to the altitude of the satellite.

Visibility time is that time during which the satellite is above the horizon, in other words when it can be seen or heard.

The following table shows the relation between altitude, period, and visibility period for a fixed point on earth in the plane of the orbit. This means that the satellite must pass directly overhead.

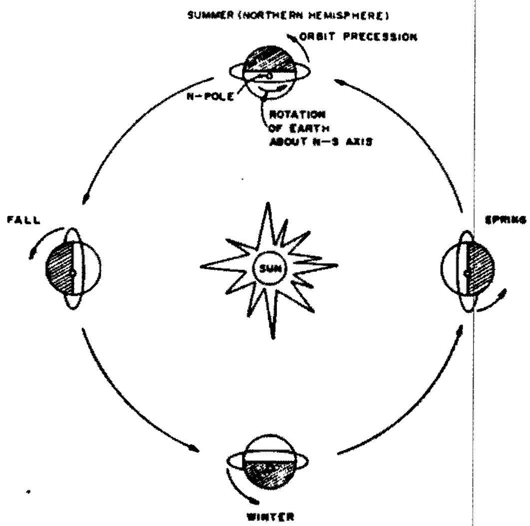
Altitude (Km)	Period	Visibility Period
400	01:32:00	10,1 min
800	01:41:00	15,5 min
1700	02:00:00	25,3 min
35800	24:00:00	24:00 hours

At any point in time there is a point on earth which is directly below the satellite and therefore nearest to the satellite, the **sub-satellite point.** At this point in time there is a circular area on the surface of the earth from which the satellite is visible (above the horizon) called the **footprint** of the satellite.

It is obvious that as the altitude of the orbit increases the surface area of the footprint increases. To illustrate the foot print, shine a round torch on a globe. The area illuminated is the footprint. Note as the torch is moved further from the globe the footprint increases. The same happens with a satellite in a higher orbit.

2.2 SPECIAL CIRCULAR ORBITS

There are a few specific circular orbits that warrant attention. Before these can be discussed the terms **equatorial plane** and **orbital inclination** have to be defined. The **orbital plane** of a satellite is a nearly constant plane in space in which the satellite moves. In the figure visualize the orbital plane and equatorial plane as perpendicular to the paper.



This orbital plane is positioned at an angle θ to the **equatorial plane** and is called the **orbital inclination.**

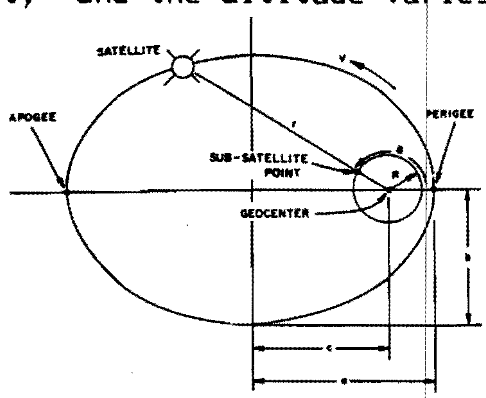
If θ = 90° then the satellite passes over both N and S poles and is in a **polar orbit.** If θ = 0°, the orbit is in the equatorial plane, and if the altitude of the orbit is 35 800 km the satellite stays directly above a fixed point on the equator for 24:00:00 min per day.

It therefore stays visible from any point on practically the whole hemisphere, E or W. This satellite is in a **geosynchronous** orbit.

If O is slightly greater than 90°, and the altitude of the orbit has been chosen correctly, the orbit will be **sun synchronous** (passes a point on earth at the same time every day).

2.3 ELLIPTICAL ORBITS (PHASE III SATELLITES)

A satellite in an elliptical orbit does not move at a constant velocity and the altitude varies greatly.

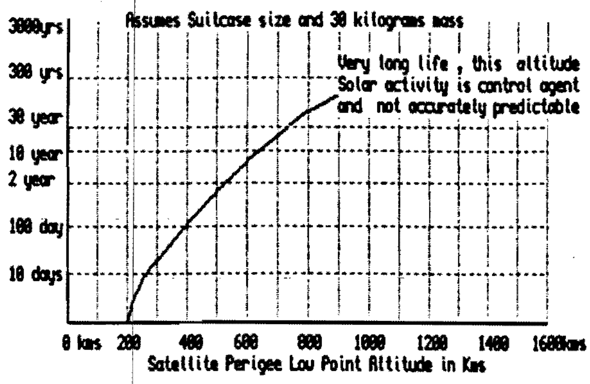


The motion of the satellite round the earth is similar to the motion of a planet round the sun and is defined by **Kepler's Laws.** From these laws it follows that when the satellite is closest to the earth, **perigee,** it is moving at maximum velocity. When it is at maximum distance from the earth, **apogee,** then it moves relatively slowly, with the resulting longer periods of visibility. Because of the great altitude at apogee, the footprint covers +- 40 percent of the earth's surface in the hemisphere below.

2.4 DECAY OF ORBITS

Due to atmospheric drag, anomalies in the earth's gravitational field, and radiation, orbits of satellites **decay** (satellite spirals in towards the earth). Eventually the satellite re-enters the earth's atmosphere, heats up due to friction and burns up.

The figure shows the expected lifetime of a satellite as a function of the orbit altitude.



3. TRACKING

In order to send radio signals to, and receive signals from a satellite, it must be above the horizon, as electromagnetic waves only travel in straight lines. It is therefore necessary to know where a satellite is at a particular time as they are not optically visible.

The position of an object in space can be expressed in terms of it's relationship with other bodies. Each orbit can be described in terms of a number of parameters which supply enough information to accurately locate the satellite. These parameters are called **orbital elements** or **Keplerian elements.**

Various PC tracking programmes are available which utilize these orbital elements to calculate the position of a satellite relative to specified point on earth. It will show the time when the satellite appears over the horizon (**elevation** positive), from which direction, **azimuth** (0° - 359° on compass rose with **True North = 0°).** Incidently, this time normally corresponds with the acquisition of signal. It will also show **azimuth** and **elevation** values at preselected time intervals for the whole **pass** (period when satellite is above horizon) up to the time when it disappears below the horizon, with the resulting **loss of signal.** The **optimum elevation** is when the satellite is nearest to the receiving station.

A typical set of Keplerian elements are shown below

Satellite : do-17
Object Number : 20440
Epoch Time, : 92 11.4068051
Epoch Rev, : 10274
Mean Anomaly, : 78.31170
Mean Motion, : 14.29622323
Inclination, : 98.65890
Eccentricity, : 0.00110520
Arg Perigee, : 281.68670
R.A.A.N., : 95.07800
Beacon Frq, : 145.8250
Decay, : 7.76000e-006

What do these figures tell us?

1. EPOCH TIME 92 11,4068051

This is the reference point in time to which the other elements refer.

The 92 obviously refers to 1992. 11,5068051 tells us that this point is 11, 4..... days into 1992. The date therefore is the 11th January and the time is 0,04068051 days after 00:00 UTC.

0,4068051	x	24	=	9,7633224	hours
0,7633224	x	60	=	45,799344	minutes
0,799344	x	60	=	47,9606	seconds

Reference time is 11th January 1992 09:45:47,96 UTC

2. EPOCH REV. 10274

The satellite is in it's 10274th revolution round the earth since launch.

3. MEAN ANOMOLY 78,31170 DEGREES

This figure defines the exact position of the satellite in it's orbit. The mean anomoly at perigee is 0°. During one complete orbit the radius vector sweeps through 360 degrees or 2π radians.

4. MEAN MOTION 14,29622323

This figure shows the number of revolutions that the satellite completes in a 24 hour period.

The period τ of the satellite $= \dfrac{24}{14,29622323}$

$= 1,678765$ hours

$=$ 1 hour 40 min 43,6 secs.

5. INCLINATION 98,6589 DEGREES

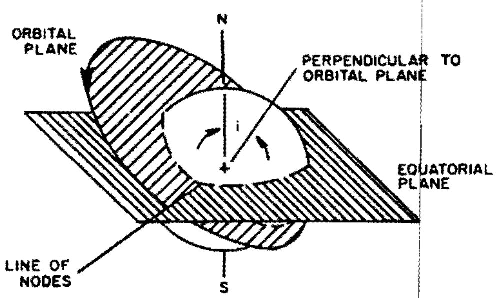
This shows that this satellite is in nearly polar orbit (Inclination 90° means that the satellite passes over the poles).

6. ECCENTRICITY 0,00110502

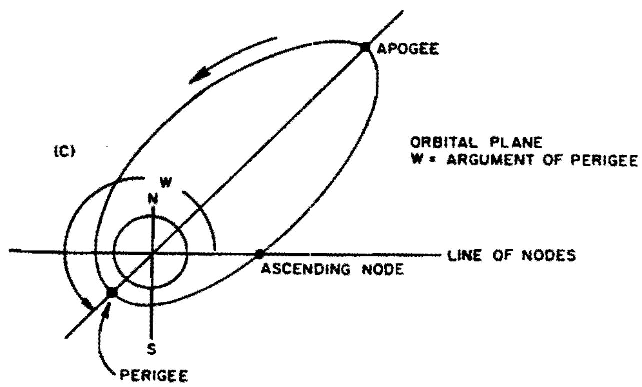
The very small value of the eccentricity of the orbit shows that the orbit is circular for all practical purposes. An eccentricity of 0 would indicate a perfectly circular orbit and an eliptical orbit would have an eccentricity of 0,2 upwards

7. ARGUMENT OF PERIGEE 281,6867 DEGREES

(A)



(C)



8. RAAN 95,078 DEGREES

Right ascension of ascending node fixes the orbital plane in space refering to a fixed point in space.

9. DECAY 7,76e-006

The decay rate of 7,76e-006 is a very small quantity. This means that the orbit decays very slowly and the expected lifetime of the satellite can be measured in years.

TYPICAL INSTANT TRACK PRINT OUT

Date/Time UTC	Azim/Elev	Range	Lat	Long	Doppler	Phs/M
11FEB92 090121	4/ -0	3271	+1	+30		247
11FEB92 090221	2/ 4	2873	-2	+29	+3224	250
11FEB92 090321	0/ 8	2480	-6	+28	+3192	253
11FEB92 090421	358/ 13	2094	-10	+28	+3127	255
11FEB92 090521	354/ 20	1724	-13	+27	+3002	2
11FEB92 090621	347/ 30	1383	-17	+26	+2760	4
11FEB92 090721	333/ 42	1103	-20	+25	+2275	7
11FEB92 090821	302/ 55	938	-24	+24	+1331	9
11FEB92 090921	254/ 53	953	-27	+23	-121	12

4. RADIO SIGNALS

4.1 POWER

Amateur satellites normally transmit relatively low power signals (a few watts) because of the limited power available from the solar panels. Receiving and transmitting antennas are in close proximity of each other and high power transmitter signals can reduce the sensitivity of receivers on board (de-sensing).

4.2 DOPPLER SHIFT

When the source of a signal moves relative to the receiver a **Doppler shift** of the frequency is noted. While the source **approaches** the signal is received on a **higher frequency** (about 3 KHz for a 2m signal from a low earth orbit satellite). When the satellite is directly overhead there is no frequency shift, and the received frequency is reduced by the same amount as the source moves away from the receiver.

4.3 SPIN MODULATION

Satellites often start tumbling in orbit. To stabilize the satellite it is spun at a few (30 - 100) revolutions per minute. This is heard on the signal as amplitude modulation impressed on signals.

4.4 ATTITUDE

The directional antennas on a satellite must point towards the earth for effective communication. Some satellites contain sophisticated **attitude control** systems to keep the antennas pointed towards the earth. **Bahn longitude and latitude** indicate the direction in which directional antennas are pointed.

4.5 BEACONS

Most satellites transmit a continuous beacon signal on a specific frequency in the band of interest to users. This signal is used to confirm the pass and to identify the satellite.

4.6 TELEMETRY

Once a satellite is in orbit the designers, constructors and ground controllers need information about the functioning of it's systems. This information is needed by the **ground command station** to send instructions to the control systems aboard the satellite.

Parameters like temperatures, state of the batteries, currents drawn by various circuits, etc. are measured by analog sensors, digitized and sent down as **telemetry frames.** These get decoded and supply the needed information about the state of the satellite.

4.7 TRANSPONDERS

The systems which are of most interest to the radio amateur who wants to communicate through the satellite are the transponders. A **transponder** is a device that receives radio signals in one segment of the radio frequency spectrum, amplifies them, translates their frequency to another segment of the spectrum and retransmits them. A rough comparison would be a repeater which receives in one amateur band and retransmits in another band. Contrary to repeaters, transponders are broadband devices. The **passband** (range of frequencies handled by a transponder) is in the region of 100 KHz. This allows multiple contacts through the same transponder.

Each **uplink frequency** (frequency on which signals are transmitted to the satellite from earth) in passband has a corresponding **downlink frequency** (the frequency on which signals are transmitted from the satellite to the earth)

Transponders can be **inverting** (changing LSB uplink signals to USB downlink signals).

Transponders are classified into Mode A, B, J, L, S, K or T with further refinements like Mode J digital, meaning the following :

Mode	Uplink band	Downlink band
A	2m	10m
B	70m	2m
J	2m	70cm
L	24cm	70cm
S	70cm	13cm
K	15m	10m
T	15m	2m

Most satellites have more than one transponder aboard but normally operate in one mode at a time according to a published **operating schedule** (segment of the orbit during which a specific transponder is operative). This schedule is normally given in terms of **mean anomoly** (orbit is divided into 256 equal portions starting with perigee as **MA 0** and apogee as MA 128). A number of tracking programmes show the mean anomoly values for a pass.

4.8 RECEIVING SIGNALS FROM SATELLITE

Low earth orbit satellites and elliptical orbit satellites during perigee portion of pass, are relatively near to the earth (400 - 1000 km) Passes are of short duration and it is difficult to manually track the satellite with long high gain antennas. There is no need for this as signals are strong and simple low gain, omni-directional antennas suffice. Automatic elevation and azimuth adjustment, driven by the tracking programme, will of course give the best results.

During the apogee portion of an elliptical orbit the satellite is far from the earth (+- 40 000 km) and **path losses** are great. This necessitates accurate pointing of high gain antennas. The use of a low noise high gain masthead pre-amplifier may even be required to receive the signal.

Signals transmitted from satellites are normally **circularly polarized.** The receiving antennas must be configured in the same **polarization sense** (left hand circular or right hand circular polarization) to avoid serious attenuation of the signal.

4.9 TRANSMITTING SIGNALS TO SATELLITE

Firstly the signals sent to the satellite must have the right polarization sense (RHCP or LHCP)

The next is the question of power to use. Different transponders require different levels of power and these are normally in handbooks for different satellites.

These are normally expressed as **dBW EIRP.** EIRP (Effective Isotropic Radiated Power) is a measure of the power radiated from an antenna system. It takes into account transmitter output power, feedline losses and other system losses, and the antenna gain as compared to an isotropic antenna. EIRP is best expressed in dBW (where dBW = 10 log power in watts).

The following example will illustrate the use of these terms.

100W transmitter output fed through 3 dB-loss transmission line to a 13 dBi gain antenna.

100W = 10 log (100) = 20 dBW

20 dBW - 3 dB + 13 dBi = 30 dBW EIRP

= 1000W EIRP

5. CONCLUSION

Hopefully SA AMSAT bulletins will now sound a little more like normal English and make more sense to the listener.

Recommended reading

1. **The ARRL Satellite Anthology (A selection of articles from QST).**

2. **The Satellite Experimenters' Handbook. Martin Davidoff.**

3. **Space Handbook John Branegan.**

SAREX GOES TO COLLEGE

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ABSTRACT

The Pennsylvania College of Technology is an institution in transition--a two-year Community College recently "bought out" by a State University. Faculty and administration are being challenged to retain our initial focus on vocational/technical training, while developing new Baccalaureate programs appropriate to the University environment.

The Electronics faculty, which currently includes four licensed radio amateurs (N6TX, W3SDZ, WB3CAF and WD9BBV,) is now developing a "two plus two" curriculum in Communications Engineering Technology. We are turning increasingly to Amateur Radio for means to bridge technology and engineering. SAREX (the Shuttle Amateur Radio Experiment) promises to be a guiding force in the development of that new curriculum. This presentation will show how SAREX, as well as the radio amateur satellite program, are being used to recruit and motivate students at the college level, how they provide unparalleled research opportunities, and how they can serve as a unifying thread through four years of study.

AN EDUCATIONAL BROADCAST TRANSPONDER FOR PHASE 3D

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ZS6AKV
PRESIDENT SA AMSAT*

INTRODUCTION

SA AMSAT (Southern African Amateur Radio Satellite Association) proposal for a broadcast transponder for the Phase 3D international Amateur Radio Satellite was well received at a recent meeting of Designers held in Germany under the auspices of AMSAT DL. At the meeting prototype equipment including a CAM transmitter and a high efficiency amplifier were presented.

This paper explains the system and reviews the progress made to date.

WHAT IS A BROADCAST TRANSPONDER ?

A broadcast transponder is a system that will store up to 15 minutes of digitized speech uplinked on a special service channel to the satellite. The unit will be capable of converting the digital data into speech and transmit this back to earth using compatible AM (CAM), a modulation system that allows the signals to be received on an ordinary AM receiver or a SSB communications receiver.

The downlink which is planned in the 29MHz band will allow simple converters to be used together with an inexpensive off the shelve medium radio.

The broadcast transponder will be used to transmit Amateur Radio and electronically based educational material for the newcomer to Amateur Radio, Novice Radio Amateurs and for use in satellite based projects for schools and other educational institutions.

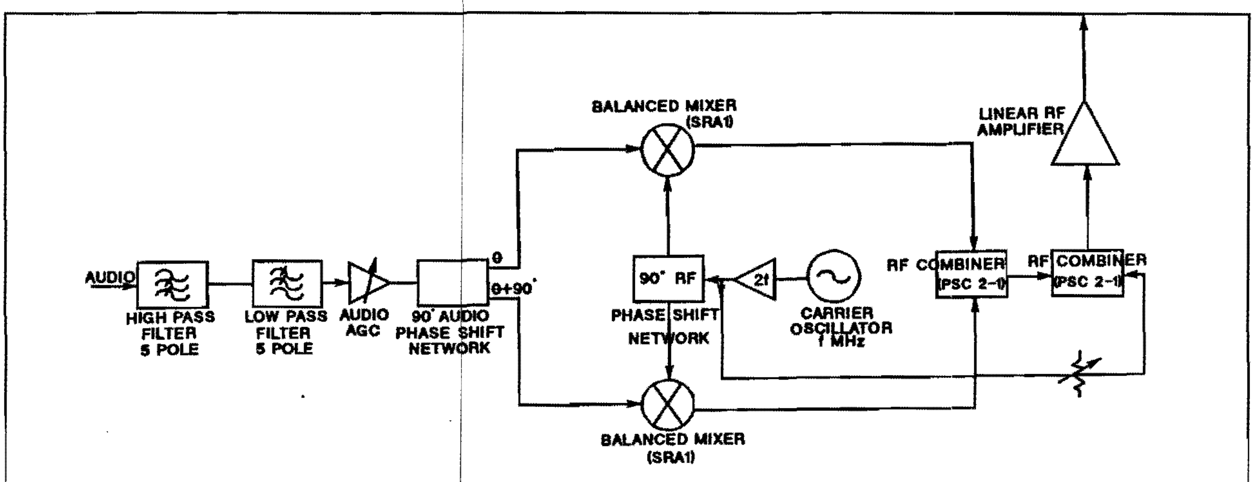
COMPATIBLE AM

Single-Sideband Full-Carrier telephony is the same as Single -Sideband Suppressed-carrier AM Telephony except that the carrier is re-introduced. It is also known as Compatible AM (CAM) because it can be received on an ordinary AM receiver with no beat frequency oscillator. CAM has a number of additional advantages:

- Receiver tuning is less critical than SSBSC.
- Band width is half that of Double Side Band AM.
- It is easy to generate using an SSBSC transmitter by simple insertion of the carrier.

There are also some disadvantages:

- Transmission of carrier reduces available power for sideband.



- Carriers produce unnecessary whistles in the phone band
- Reception on an ordinary AM receiver is a compromise and not as good as on a SSB receiver.

Not withstanding the disadvantages CAM has been chosen to give easy and more important inexpensive access to the signals by large groups of people. This is particularly important of the IARU's Promotion of Amateur Radio in Developing Countries programme.

Figure one shows the proposed circuit diagram of the CAM transmitter using the phase shift method of producing the signal.

High pass and low pass filters are used to act as a band pass filter at the audio input stage. This is followed by an automatic gain control stage to ensure optimum signal levels at all times.

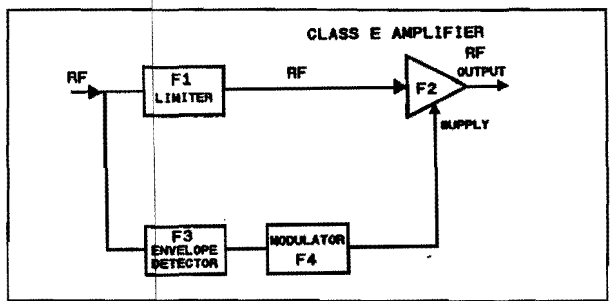
A 90 degree audio phase shift network is used to feed two balanced mixers. The output from a radio frequency carrier oscillator at half the final wanted frequency is doubled and fed to a 90 degree RF phase shifter. Outputs from the 90 degree RF phase splitter are used to feed the unaddressed input of the balanced mixers. The mixer outputs (a characteristic of a balanced mixer is the suppression of the input carrier frequency) are combined in a RF combiner where one sideband is reinforced and the other cancelled.

Another RF combiner is used for final carrier insertion to generate a single sideband with carrier.

The system has been extensively tested on 29,4 MHz and proved very successful. Later this year the cam transmitter will be used on 7 MHz for experimental transmission of the SA AMSAT News bulletins.

HIGH EFFICIENCY AMPLIFIER

The success of the broadcast transponder is very much dependant on the signal strength that can be achieved on the ground. Lots of time has already been spent on the development of a high effieciency amplifier. A proto-type demonstrated in Ger



many recently was a class E amplifier which is non-linear and requires to be fed and modulated by special circuits to affect linear amplification. (Block diagram 2)

The modulator circuit requires a Cuk (pronounced chook) topology and is a basic switcher power supply circuit for operation at 300 kHz. A switching frequency of 1 MHz or higher is ideal if suitable ferrite power transformer material is available. The material was not available for the proto-type hence a bandwidth of only 50 kHz was achieved.

A fairly low power VHF driver transistor (2 watt) was used in the proto-type delivering 3,6 watt into a 50 ohm load. The efficiency of the amplifier is 85% hence the ability of the transistor to survive. Only about 0,64 watt is dissipated in the device.

On a class E amplifier a RF switcher pumps an output tuned circuit in such as way that when the switcher is switched on by the incoming signal, no RF voltage can be present across the transistor due to the phase properties of a special, carefully designed output tuned circuit. Thus no power can be dissipated in the transistor.

In practice losses are experienced due to slight phase errors depicted by component quality as well as the time taken for the transistor to move out of saturation.

Various schemes are currently being looked at to further improve the efficiency to 90% or higher.

A further prototype class E amplifier (with additional circuitry towards achieving linear amplification) has been designed and constructed with the following performance :

- 28 MHz - Amateur Satellite band capability.
- 100 W or 50 dBm peak RF output for the following peak power levels at each of the following stages:
  - 1 mW or 0 dBm at the input to the pre-driver stage
  - 100 mW or 20 dBm at the input to the driver stage
  - 3.3 W or 35 dBm at the input to the output stage
- The limiter stage hard limits from -50 dBm.
- The envelope detector threshold is at 1 mW or 0 dBm.
- Efficiency (e) = approx. 80 %

THE DIGITAL SYSTEM

A common Cmos 286 type processor is envisaged mainly because it is commonly used in most computers which simplifies the software development. A very simple digital to analogue converter will be used on the output stage implicating that a large amount of memory will be required to store the speech signals. This route will allow almost any signals in the 300 to 3500 Hz to be transmitted such as packet signals and various experimental modulation schemes. A low 4 bit D to A converter is being looked at which will give approx 24dB signal to noise ratio.

On the digital input side it envisaged to use a simple fax modem chip. At this stage a breadboard design is being worked on. It is expected to have a working unit on the air for experimental purposes by the end of this year.

FUNDING

Funding of the project has up to now been done from SA AMSAT funds. However much more funding will be required . A serious appeal is made to Government Institutions and Industry to assist in this vital project which once circling the earth in another OSCAR satellite will do much to activate young people to make career choice in the Electronics and Communications fields.

Currently SA AMSAT members have been sponsoring orbits at R100 each. You are invited to do the same. Ultimately we hope to have between 7000 to 10 000 orbits sponsored.

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USE OF SATELLITES AND SATELLITE SIGNALS TO INSPIRE INTEREST IN NATURAL SCIENCES IN DEVELOPING COUNTRIES

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Abstract — Scholars and students with a science interest and background is what the world will need once it starts emerging from the current economic slump. In the developing world this need will be even greater and more pressing as a tremendous backlog has to be overcome. The use of satellites, satellite signals and amateur radio in the classroom is a unique way of developing interest in natural and communication sciences. It is easily accessible, even to educational institutions in the remotest parts of the world.

I INTRODUCTION

Satellites, satellite signals and amateur radio offer many exciting opportunities in the classroom for both curricular and extra-curricular activity. They introduce the youth to the vast world of science and technology and offers career path development from an early age. Natural Sciences are today still regarded as subjects for the so called advantaged students. This is particularly true in the developing world, where the main emphasis is on the teaching of the social sciences, a field where the supply often exceeds the demand.

The world is currently passing through a period of economic depression, but this will no doubt be followed by a period of economic growth and greater prosperity. In the developing world there is a growing awareness of the need to develop technologically so that it too may be part of this new growth and development phase. There is no better place to start than in the classroom!

The statistics show that in the developed world, the countries that have the most successful and thriving electronics industry, also have the largest number of licenced radio amateurs. In order of size these would be : Japan, USA, Great Britain, Germany and France. Although one should not generalize, it is indicative as to how this interest can influence career choices. With this as the premise, this paper explores the advantages that the developing world could derive from satellite and amateur radio activity at schools.

II SATELLITE BASED EDUCATION

There is a misconception as to what satellite based education and participative satellite education are. In the first case a satellite is used to transmit lectures or educational programmes to a large number of schools. This system utilizes highly skilled teachers to present lessons and semi-skilled teachers or facilitators in classrooms spread over a vast area.The Australian Outback Radio Classroom programme is a good example. The system utilizes a teacher in the studio with students in farm schools with facilitators.

A satellite based system would have many advantages but it is expensive and logistically more difficult to implement because in the rural areas of the developing world, mains power is not generally available. This poses a challenge to the industrial world to develop low cost receiving equipment and satellites with high power transmitters to allow for simple ground installations.

Another problem to overcome is political prejudices. Many governments would perceive global satellite based education as a threat to their national security and as outside interference.

III PARTICIPATIVE SATELLITE EDUCATION

This paper pursues this alternative of educational activities using various satellite resources available. Such resources include amateur radio satellites, scientific satellites launched by universities and weather satellites.

A Educational Aims

Satellites can be used in a number of educational activities across the curriculum, ranging from the physical sciences, to the humanities. Craig Underwood of the University of Surrey in his publication "Satellites in Education - a guide for teachers" lists a number of general educational aims. [1]

1. Encourages awareness of space, space science and the development of space technology.
2. Provides opportunities for technological activity, including construction of detecting apparatus, models, etc.

3. Illustrates an important example of modern information technology being put to a powerful use.
4. Provides a springboard to a range of thematic learning activities across a wide range of ability and age levels.
5. Encourages activities of a cross-curricular nature, incorporating many of the principles of mathematics, science and technology, and linking with work undertaken in the humanities, notably geography.
6. Provides a purpose and a real basis for experimental work involving data acquisition, information processing, interpretation and presentation.
7. Provides an example of scientific experimentation which closely reflects many aspects of "real" scientific research (the collection of large amounts of data, requiring interpretation and evaluation).
8. Opens up a wide range of possibilities for open-ended experimentation and project work.
9. Extends the range of educational activities based on the microcomputer, showing a computer in one of the roles which it commonly occupies in "real world" research and development contexts.
10. Can provide motivating and stimulating experiences in school science and technology.
11. May initiate a hobby interest in the area of radio communications and satellites.

B Satellites Available for School Use

A large number of satellites are available for use in the classroom. These satellites can be grouped as follows,

1 Amateur Radio Satellites OSCAR

The Oscar satellites can be sub-divided into various types

1. Satellites carrying Transponders for two-way communications
2. Micro satellites for digital communication and earth imaging
3. Educational satellites such as Dove OSCAR 18, the planned SEDSAT and OSCAR Phase 3D.
4. Scientific Satellites such as the UOSATs

2 Geostationary Weather Satellites

1. Meteosat

3 Polar Orbiting Weather Satellites

1. NOAA series
2. Meteor Series

4 Space Shuttle Missions

1. Planned school contacts
2. Adhock contacts

C Amateur Radio Satellites

Amateur radio satellites such as OSCAR 10, OSCAR 13 and the planned Phase 3D satellite offer opportunities for two-way communications between various educational groups on a world-wide basis. Equipment is however complex and expensive, and in the developing world often unobtainable.

The Microsats with their digital communication capabilities offer more opportunities for message interchange. The system is technologically advanced but simple and less costly to install, easily automated and software driven for easy use.

Organisations such as SateLife and VITA have proved the tremendous advantage these systems can bring at low cost.

SateLife offers a service to medical schools in several African countries giving them access to a vast medical information system. VITA (Volunteers in Technical Assistance) experimenting with an inexpensive system linked fieldworkers with VITA headquarters in the USA. Plans for an operational system are far advanced.

The educational and scientific amateur radio satellites can be grouped together. The basis of their use is to capture data and use the information in a series of classroom based science projects. Some of the projects include

- Radiation - Particle Physics
- Magnetism - The Earth's field
- Geodesy - Gravity
- Mechanics/Physics of orbits
- Geometry - Map projections
- Tracking

D Weather Satellites

Both the geostationary and polar orbiting satellites provide many opportunities in the classroom. Equipment, particularly for the low earth orbit satellites, is inexpensive and relatively easy to install and operate. Projects such as the following can be undertaken

- Interpretation of weather pictures

  The school could produce its own daily weather report. Weather watch can be extended to serve the local community and render a new service which may not have been available.

- Looking at IR images to determine temperature

- Spotting of ocean currents, urban and rural land uses
- The Weather satellites have a wide application in the study of geography

The use of the geostationary weather satellites can be further expanded by setting up a local receiving station and retransmitting the signals on the 2m or 70 cm amateur bands. This reduces the complexity and cost of the stations at each school. Such systems are in operation in several South African cities.

E Space Shuttle Missions

Many of the US Space Shuttle missions include amateur radio Activity in the SAREX programme. During many of these SAREX missions the shuttle crew take time off to communicate with scholars and students world-wide using amateur radio channels.

SAREX contacts are usually preceded by educational projects in the classroom. The ARRL makes a large amount of project material available which focuses on basic natural science principles. These projects cover a wide spectrum and can be used for many different age groups culminating in a real time contact with one of the shuttle crew.

During a typical 6 to 8 minute pass, selected scholars are given the opportunity to ask questions about space sciences.

A limited number of SAREX projects have involved schools in the developing world. NASA and the ARRL are urged to include more third world country schools in their SAREX programme and in a vivid way introduce young people to real science.

IV Amateur Radio - The Key Link

Amateur radio is the key link in many of these activities and can serve as a stimulus for the entire process of inspiring interest in the natural sciences. The development of amateur radio and Electronic clubs at schools is the first major step to be taken as it forms the communications base for many other science activities. It will often bring additional manpower and skills into the school system as many radio amateurs are willing and keen to assist school teachers, even to the point of supplying the initial equipment to get off the ground. In developing countries this may be more difficult as the amateur radio population is usually very small and in many countries non existent.

The International Amateur Radio Union (Region 1) has through its working group for the Development of amateur radio in Developing Countries, taken the first step by setting up an amateur radio station at the Sesekelo High School in Swaziland, the National University of Lesotho, Mozambique and other African countries are next on the list. The purpose of the PADC programme is to teach amateur radio and establish a local radio amateur base.

In Developing Countries the amateur radio base can serve as a nucleus of trained manpower in a positive attempt to train locals to become electronic technicians and to replace the transient ex-patriot labour force.

In South Africa a group called "SAREC" has been set up to assist with the establishment of radio and electronic clubs in schools and support them with the development of projects. SAREC supports the Southern African Region. SAREC was responsible for the coordination of the first Shuttle Amateur Radio Experiment on the African Continent and is currently planning SAREX events for Swaziland and Zimbabwe.

A UoSAT Educational Challenge

As part of ISY92 the University of Surrey has organised the UoSAT Educational Challenge, a schools project revolving around the UoSAT satellites. In the South African region SAREC supports schools with project material, technical advise and assistance to set-up receiving stations for interactive participation.

V AMSAT Phase 3D

The international amateur radio Community is currently building AMSAT Phase 3D, the largest amateur satellite to date.

As part of Phase 3D, an educational broadcast transponder will be included which will transmit regular information bulletins and details of educational projects. The transponder will transmit a compatible AM signal (CAM) on the 29 MHz amateur satellite band. Coupled with this project is an inexpensive AM receiver. The educational material will be uplinked and stored digitally, and converted into speech for transmission.

The broadcast transponder is being developed by the Southern African AMSAT group.

VI The Future

There is no doubt that education is the key to the future. It is now time for positive action by the international community. The following is proposed:

1. To develop and establish EDUSAT, a packet radio satellite dedicated to education much like SateLife and the VITA concept. This satellite, with ground terminals at schools, would give teachers in the developing world direct access to educational material and projects.
2. Sponsor more Shuttle based SAREX missions for the developing world to create interest in science.
3. Support world-wide AMSAT groups financially to develop, build and launch more satellites.

4. Setup up a world-wide "SAREC" organisation to develop satellite based education programmes and support for science teachers.
5. Expand the IARU PADC programme to include many more developing countries.

VII Conclusion

Satellites, satellite signals and amateur radio have unlimited resources to inspire interest in the natural science. In the words of author William Orr :

> 'The spirit of Adventure lies buried in every man's soul. Strike the spark and ignite the soul and the impossible is accomplished'

VIII Acronyms

AMSAT: Amateur Radio Satellite Corporation
SAREX: Shuttle Amateur Radio Experiment
SAREC: Satellite and Amateur Radio Resources and Education Centre
UoSAT: University of Surrey Satellites
VITA: Volunteers in Technical Assistance
ARRL: American Radio Relay League.

References

[1] C Underwood. *Satellites in Education*. University of Surrey, September 1985.