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RADIO AMATEUR SATELLITE
CORPORATION

PROCEEDINGS OF THE
AMSAT-NA

15th Space Symposium,
and **AMSAT-NA** Annual Meeting

October 17-19

1997

Toronto, Ontario
Canada

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WELCOME

I am glad that so many amateur satellite enthusiasts are able to attend the 1997 AMSAT—NA Annual Meeting and Space Symposium. It is especially gratifying to see so many Canadians, as well as those from overseas. Since the early 80's, we have been holding our meetings in various parts of the U.S. in order to permit as many people as possible to attend at least one meeting every few years. This year, we are expanding this concept even further by holding the meeting here in Toronto. I am glad to see that many Canadian members have availed themselves of this opportunity to attend one of these meetings.

This fine city has a special place in my heart as it was where my parents met and courted here almost eighty years ago. Who knows, without Toronto, I might be here! I am sure that the city has changed since then, but just as they found it, Toronto is still an interesting and vibrant metropolis, with lots of things to do and see.

For several reasons, this is an especially important year for AMSAT—NA. First, Robin Haighton, VE3FRH, has been appointed Vice-President for Canadian Liaison. This is a new post, aimed at strengthening the organization's bonds with its Canadian members and hopefully increasing VE membership. Robin will also be working with RAC and Canadian government people regarding regulatory and allocations matters.

This is also the year that Phase 3D was completed and is awaiting launch. Unfortunately, it was not able to be sent aloft on Ariane 502 as previously planned. But, rest assured, efforts are underway to identify another launch opportunity at the earliest possible date .

Phase 3D could not be where it is today without the help of many people and organizations. This includes those actually working on hardware and software, those looking after the management and business end of the project, and those who have so generously donated the money needed to make this most ambitious and capable Amateur Radio satellite, to date, a reality. AMSAT—NA members have come up with about \$800,000 and the ARRL, and its members, have put in another approximately \$530,000. Our European compatriots, with major inputs from the Germans and the British, have come up with an amount similar to that raised by AMSAT-NA and ARRL. Of course, expenditures have also been significant. To date, about \$1.2 Million has had to be expended by AMSAT-NA alone. The delay in the launch and the required structural modifications have caused a significant increase in our total outlay. So, if any of you would care to make further contributions to Phase 3D, I assure you they will be most welcome.

Although Phase 3D's completion is an important event, it also means that AMSAT must finally face up to what its role should be following a successful Phase 3D launch. Some of the papers at this Symposium deal with possible follow on projects. Decisions regarding our future course should begin to be made at the Board of Directors meeting which will convene immediately following this meetings, please listen to the ideas

presented in the papers and put them with any you may have: and, while we are gathered here together, take the opportunity to let various AMSAT-NA Board members know your views. Should we rest on our laurels and content ourselves with working Phase 3D? Bear in mind that this will mean closing the Orlando facility and attempting to store all the equipment, including the 20 foot by 20 foot clean room installed there. Also bear in mind, that a new satellite project, a few years hence, will entail re-establishing a similar facility there, or some other location. Should we, in the future, limit ourselves to small "fun-to-do" low earth satellites like the Microsats? Or, should we try for a more capable 24 hour per day communication capability? If we want to keep the Orlando facility open and operating, should we attempt to find some commercial business to pay the bills, while waiting for the opportune time to build another amateur satellite? These are some of the questions facing your Board of Directors. I know that all of them would like to hear your opinions on these important issues.

Although most of AMSAT-NA's energies have been devoted to Phase 3D, we have also been active in SAREX, as well as devoting attention to planning for amateur participation on the International Space Station. You will hear more about these plans during this Symposium.

I hope you enjoy the 1997 AMSAT-NA Annual meeting and Space Symposium, as I will; and that your attendance will prove to be productive to you, and to the amateur space community.

73, and thanks for coming,
Bill Tynan, W3XO.

Design And Implementation Of Internet-Linked Ground Stations For The Amateur Satellite Community

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Abstract

Widespread distribution of data gathered via amateur satellites poses two significant problems. The first relates to the difficulty of downloading large amounts of data given the short access windows (roughly an hour a day) typical of amateur satellites. The second arises once the data is downloaded, as there is no practical means for distribution. Enter the Internet-connected amateur ground station. Client ground stations for a given satellite will be connected, via the Internet, to a remote server, which maintains a master database of everything downloaded from the satellite. When the satellite is in view of a client ground station, the server is given the current directory contents of the satellite, and is queried regarding which file should be downloaded. Once the data has been downloaded and forwarded to the server, it is then accessible to anyone with Internet access. Such a client/server architecture is the goal of the SEDSAT Ground Station Client/Server (SGSC and SGSS, respectively) design.

Design And Implementation Of Internet-Linked Ground Stations For The Amateur Satellite Community

By Christopher Bond

And Dr. Mark Maier

1. Introduction To Digital Amateur Satellites.
2. The Digital Amateur Satellite Access Problem.
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 - 3.3. Client Software.
 - 3.4. Server Software
 - 3.5. Legal Issues
4. Advantages Of Frequent Access
5. Conclusion And Further development

Introduction To Amateur Satellite Communications

For over two decades, Amateur satellite communications have been growing in popularity and availability. Groups such as AMSAT have designed, developed, and launched several small satellites, mostly with scientific or educational payloads. These satellites are typically orbiting such that an ideally placed ground station is in line-of-sight communication for ten to twenty minutes at a time, two or three times a day. Most of the functionality of the AMSAT-class satellites (and their accompanying ground stations) stem from the legal issues resulting from their use of the Amateur Radio bands. The relevant regulations include:

- Each station must be run by a licensed Amateur Radio operator.
- No commercial business may be conducted over amateur bands.
- Encrypted data is not permitted (this excludes public-domain compression methods, such as GIF or JPG)

The amateur satellite community has adopted several standards in an effort to make communication with their digital satellites file systems accessible to anyone with the required equipment. The AX.25 broadcast standard is used for binary transfers to and from the satellites. These transfers have traditionally involved short ASCII correspondence between amateur radio operators unable to connect point-to-point, and thus the satellites were essentially mail carriers. Increasingly, however, satellites with imaging capabilities, and users desiring to transfer images or other large binary files, are creating a new role for the amateur satellites.

Ordinarily, an amateur satellite does not communicate with a single user at a time. Instead, it maintains a queue of requests from users, to which it responds via a public broadcast which all users may 'overhear'. For example: if there are currently ten users within transmit range of a satellite, and each of them requests some data, then each user will be able to listen and record each file as it is transferred. Multiple requests of the same data are removed from the queue by the satellite. Note that security over the broadcast channel is not an issue, as amateur radio is insecure by definition. Those desiring a more secure channel over which to transmit their data should not use the amateur wavelengths.

The Digital Amateur Satellite Access Problem

The most significant obstacle to amateur Radio communications has always been that radio waves are reliable only when an unobstructed path exists between communicating stations. This problem exists also for users of the amateur satellites.

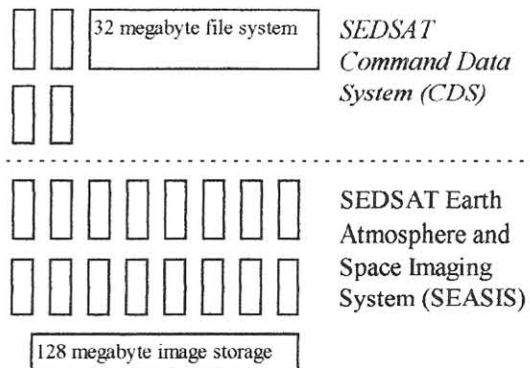
General Case

As a satellite orbits the Earth, it is able to communicate with only a small area at a time. As 9600 baud radio modems have only recently been adopted by the average amateur radio user, the ability to transfer large amounts of data is necessarily limited. The amount of data which operators desire to transfer, however, has been increasing exponentially as more satellites with cameras and other instruments which generate large amounts of data are launched. The difference between the rate at which data is generated and the rate at which that data can then be transferred to the ground clearly represents a problem facing the amateur satellite community.

SEDSAT Mission

The SEDSAT mission will clearly demonstrate this problem. SEDSAT is the secondary payload on a Delta II rocket scheduled to be launched in the summer of 1997. The primary payload, A deep space probe, will leave SEDSAT in a less than optimal orbit, making communications windows shorter than the typical amateur satellite.

SEDSAT carries 128 megabytes of RAM onboard specifically to be used for storage of image files generated by its two cameras. This memory is separate from the 32 megabytes which will be used by the file system, meaning that the satellite could store 160 megabytes of image data. At 9600 baud, even given constant contact, it will take nearly two days to download every image file. Obviously, given its larger amount of storage capacity, SEDSAT would benefit greatly from higher accessibility than is available to the typical amateur satellite.



A Solution

As stated before, the average amateur ground station is only able to communicate with an individual satellite for roughly an hour a day. At speeds of 9600 baud or lower, transfer of large amounts of binary data clearly require more access. Ideally, any user of the satellite would be able to at least access the data being transmitted over it's broadcast channel at any given time, and to also have access to the current directory of the satellite, as well as the queue which the satellite uses to decide what data to transmit next.

One possible solution is to somehow link all of the ground stations of a particular satellite together, so that whenever a satellite is in view of one station, all other stations may communicate with it. As there already exists a base of ground station operators who might be willing to provide download services in exchange for access to new satellites, and the cost of setting up new ground stations is minimal, this seems an effective strategy. It remains, however, to choose a method by which to connect these stations.

Design Of Internet-Linked Ground Stations

Internet access has become widely available in the past decade, making it possible for anyone with a computer and a phone line to dial up a provider. To make use of this widely available access to the benefit of the amateur satellite community is the goal of this design.

Assume that two ideally placed ground stations wish to communicate with a given satellite. Each station, as stated above, is able to communicate with the satellite for roughly an hour a day. If these two stations were connected by a wire, than either one could communicate with the satellite by proxy via the other. Furthermore, it is readily obvious that as the number of stations connected to each other increases, so does the ability of any single station to access the data from the satellite. Of course, this would perforce require a huge amount of wire to be strung between ground stations. Luckily, this wire already exists, in the form of the Internet.

Ground Station Requirements.

A traditional amateur station with the ability to communicate with the amateur satellites has always consisted of the following equipment:

- A personal computer running the software necessary to communicate with the file system onboard the satellite (A shareware program called WISP is most commonly used, and is available from the web site of the amateur radio organization, AMSAT: www.amsat.org).
- A Terminal Node Controller (TNC) and modem package, to handle the translation of the serial output of the PC into AX.25 packets, and vice versa.
- A radio capable of communication with the amateur satellites (this includes a properly configured antennae).

Such a station would be able to detect the amateur satellites as they flew overhead, download the contents of the directory onboard the satellite, place requests into the broadcast queue of the satellite, and download data as it was sent over the broadcast channel. There are literally thousands such stations across the world - the Huntsville amateur radio community alone has almost a hundred members. With such a user base, it would seem to be possible to achieve constant communication with a satellite, if the users were given some means to communicate with each other.

Additional Requirements.

We will add to the above list this list hardware, be it modem or network card, to provide the ability to transmit and receive packets over the Internet.

With this addition, implementation of an Internet-connected Client-Server design becomes possible. Essentially, there would be some number of ground stations sufficient to provide constant communication with the satellite. These

stations would also be connected, via the Internet, to a central station, which would be dubbed the server. This server would be the source of every request for data from the satellite, and the clients would be anyone who wished access to data from the satellite. All data downloaded by a ground station would be forwarded to the server for archival.

Client Software Functional Description

Client software would run on local ground stations, and would provide the functionality for communicating directly with the amateur satellite. Communications capabilities would include:

- Reading the directory contents of the satellite.
- Insertion of file requests into the satellites broadcast queue.
- Reception of requested files over the satellite's broadcast channel.

All of these functions would be available to a licensed operator of a ground station.

The client software would also include the ability to communicate over the Internet with a remote server. Essentially, once the directory contents of the satellite had been obtained, the client would forward them to the server. The server would then respond with a request for a particular file, a request to upload a file (see below), or with a 'no requests' message. If a file was indicated, the client would then begin downloading it. The server would continue downloading until either the file completed or it lost communications with the satellite. In either case, the data downloaded will be forwarded along with a status message. Valid status messages include:

- Download complete, satellite still in sight.
- Download interrupted, lost sight of satellite.
- Download complete, lost sight of satellite.

If the client is still in contact with the satellite, the directory contents will again be downloaded and forwarded to the server, and the server will again send either a file request or a 'no requests' message.

Finally, the client software has the ability to upload files to the satellite. Files may be local (i.e., on the computer on which the client is running), or remote (residing somewhere on the Internet). A file upload may be initiated by a command from the server.

Server Software Functional Description

The server provides a web-based interface to a database of files downloaded from the satellite. Essentially a file browser, the following functionality is also provided:

- The ability to upload files to the satellite

- The ability to command select hardware (cameras, for example)

The server is also responsible for determining the order in which files should be downloaded. When making this determination, the first consideration is the importance of the data in the file. Telemetry data is given a higher priority than image data, and image data that has been requested is given higher priority than image data that was generated automatically by the satellite.

Finally, the server will provide the capability to make web-based queries into the telemetry database for the satellite. A typical query might be "Find all time/date stamps in which the temperature on sensor TS05 exceeded 50 degrees Celsius."

Query	Response
Face+x temp > 50	6/7/98 6:03 - 13:05, 6/8/98 0:21 - 12:56, 6/12/98 13:09 - 6/18/98 2:09
Motherboard_DC/DC current >= 2.5	No data matches query
Actuator_A temp > 100	6/7/98 6:10 - 6:15

Example queries into SEDSAT telemetry database

Legal Issues

FCC regulations concerning amateur radio bandwidths prohibit remote control of radio transmissions except in certain situations. Whether or not commands that tell a computer to initiate radio transmissions (note that the transmission is not generated remotely, but the command to generate the transmission is) fall under these guidelines seems to be an open issue. The obvious situation such operation resembles is a repeater. Whereas a repeater is simply mimicking signals, however, the client software is actually interpreting the commands it receives and generating a transmission on an amateur frequency. The situation may be likened to a licensed operator being asked by someone without a license to say something on the air. It is my contention that if the client station is being monitored by a licensed operator, then the client/server system described here is legal. I am not aware of any precedents, however, and a discussion with the FCC is pending.

Benefits of Increased Access

A Client-Server design using Internet connectivity for amateur radio satellite ground stations has many benefits:

- It requires only a finite number of ground stations to be maintained.
- It allows universal access to the satellite - no radio is needed, only an Internet connection.
- It implements data archival within the design, so that no external means of archiving data is needed.
- It can be fairly autonomous - the only maintenance needed would be that required legally by the FCC while operating the station actually in contact with the satellite.
- It allows the controllers of the satellite constant access for system maintenance.
- It provides for a more comprehensive means of distribution of data gathered by the satellite.

Conclusion And Further Development

The evolving role of the amateur radio satellite clearly points to a need for a more efficient means of data retrieval. Correctly implemented, a client-server scheme connected via the Internet could provide an incredible amount of access to satellite data, and more efficient use of the satellite's broadcast channel. Further development could show that the amateur satellites could even be useful as Internet access providers for users outside of normal areas of communication. The growth of the Internet and the continuing advancement of communications technology promise dramatic changes in the world of amateur radio.

Using Broadcast Protocols On Terrestrial Links: A New Approach To Digital Satellite Gateways

by John Hansen, WAØPTV
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ABSTRACT

This article describes a new software package that allows users who do not have satellite stations to access the amateur digital satellites. This package differs from previous software designed to perform this function in that it is fully integrated with WiSP and utilizes a broadcast protocol for transfer of satellite files to end user computers. Thus, the end users get a better "feel" for operating digital satellites, because they access satellite files with programs like WiSP or PB/PG running on their own computers.

1. Background

When the group of digital satellites known as the "microsats" was originally conceived, the planners envisioned an orbiting bulletin board system that would work pretty much like the then standard WØRLI terrestrial system. However, at the Des Moines AMSAT meeting, Harold Price, NK6K, one of the microsat's designers, announced that the WØRLI-like system wouldn't work. He had performed some calculations about the number of potential users and the fact the satellites would only be visible for a maximum of about 15 minutes per pass and concluded that if everyone was to try to connect to the satellite individually, very little data would actually get through. This realization gave rise to a system of broadcasting files that has been used on most of the digital satellites launched since then.

The basic concept of broadcasting files is fairly simple. Files that are requested by groundstations are transmitted in a continuous stream of unconnected packets, where they may be received by multiple stations at the same time. Each groundstation keeps track of the pieces of the file that it is still missing (called "holes") and then requests the satellite to retransmit only the parts that it needs. Thus, aside from uploading files, no one actually connects to the satellite and everyone receives the files simultaneously. This greatly increases the efficiency of data transmission for two reasons. First, the transmitted data stream does not have to pause to receive the acknowledgement packet from the ground station. Thus the transmit/receive turnaround time is eliminated along with the time that is required to send the ack packet. In short, the file server transmitter is always on, sending a continuous, uninterrupted stream of data. Secondly, files are received by many stations at once, thereby saving the time it would take to retransmit them to each ground station. A series of papers by NK6K and Jeff Ward, GØSUL, describe the broadcast protocol in detail.¹

¹ These are available at <ftp://ftp.amsat.org> in the subdirectory /amsat/satinfo/pacsat. The complete set of documents is contained in a compressed archive file called PACDOC.ZIP

At the 1993 AMSAT Symposium I presented a paper that argued that this same "broadcast" approach could be usefully applied to terrestrial links as well as satellite links.² The scheme that I proposed would have existing BBS's set up broadcast file servers on dedicated channels that would respond to file requests submitted to the BBS. The files would then be transmitted using a protocol similar or identical to the one used by the microsats.

Also in the early 90s I developed a software suite called Gateway Node software.³ It permitted an interconnection between an F6FBB-type terrestrial bbs and packet satellites. BBS users who had no satellite capabilities themselves could access the digital satellites by interfacing with their local BBS, if that BBS either had a satellite groundstation itself, or had a forwarding relationship with a BBS that had a satellite groundstation. Thus, individuals who had satellite capabilities could obtain directories of what was on the satellites, could request that specific files be downloaded and delivered to them, and could even upload messages they had created themselves using this software.

While a number of stations around the world adopted the Gateway Node software and provided access to many other amateur stations that were not groundstation equipped, there were a number of problems with the early version of this software. Most notably, the software only ran under DOS and thus would not interface well with WiSP or WinFBB when those packages became available. Secondly, the Gateway Node software used the basic file transmission mechanisms of the F6FBB software. That is, all files were transferred in connected mode to one station at a time with transmission being interrupted (and slowed down) by acknowledgement packets.

When WinFBB was released, I began to work on a version of the Gateway Node software that would run under Windows. I was about three fourths of the way through the development of the new package when I realized that the requirements of Phase 3D were likely to make this software obsolete shortly after it was released. The problem is that Phase 3D will make much larger quantities of data available than any packet satellite that preceded it. This is partly due to the anticipated higher data transmission rates, but also due to the fact that Phase 3D will be visible a much greater percentage of the time and consequently will be able to serve up much more data, even at the initial data rate of 9600 bits/sec. Even with existing packet satellites, large files, such as images, are very difficult to download over 1200 baud terrestrial data links. Thus in order to have a workable Gateway Node (especially with Phase 3D) it was going to be essential to speed up the delivery of data to end users.

It is, in my judgement, unrealistic to think that this increased speed will come about in the near term by end users all acquiring radio based data communication equipment capable of 19,200 bit/sec or faster speeds. Instead, I came to believe that the answer lies in applying a broadcast protocol to terrestrial circuits.

² Hansen, J.A., "Implementing the PACSAT Broadcast Protocol on Terrestrial Networks" *Proceedings of the AMSAT-NA, Eleventh Space Symposium, Arlington, TX.* (Newington, Ct: ARRL, 1993).

³ Hansen, J.A., "Digital Satellite Automation: Gateways and Gateway Nodes" *Proceedings of the AMSAT-NA, Tenth Space Symposium, Washington, D.C..* (Newington, Ct: ARRL, 1992).

2. The HamWeb Server

I paused work on the new Gateway Node software to begin work on a more generic project, a terrestrial fileserver that would use a broadcast type approach to transfer data to large number of end users at once. I originally envisioned this as a means of transferring HTML documents among amateur stations with the idea that a WWW browser would become the basic packet radio terminal program, hence the name *HamWeb*. As I was building the server, however, it became clear to me that this would turn out to be a much more generic tool. It is designed to replicate the files (or whole directories of files) from one computer to many others. The filenames are preserved and the subdirectory structure is also preserved as the transfers are made from the server computer to the client computers. In short, everything appears exactly the same on the client's computer as it is on the server. In addition, because the file dates are preserved, the system keeps track of which files have been updated on the server and automatically updates those files on the clients as well.

In its current design, this system does not allow the client stations to request hole fills. Instead, the files that are to be sent are placed on a carousel and retransmitted periodically. The client station that has missed part of a file will fill in the holes the next time the file is transmitted. I designed the system this way to make it as easy as possible to set up a client. To request holes, a client would have to have a separate connection to the server. I believe that HamWeb servers will generally be placed on clear frequencies and the number of holes that occur should be much less in terrestrial service than with spacecraft. In theory a useful groundstation client could be set up with only a receiver (even an ht or a scanner) and a TNC.

An amazing amount of data can be transferred using this system... even at relatively modest data rates. Using standard 1200 baud packet equipment, this system will transfer 6-7 K per minute or about 400K per hour uncompressed. Compression, of course, could double that rate. Assuming the server and clients were left on 24 hours per day, the clients could receive up to 10 megabytes per day (20 if compressed). This is surely enough to provide copies of virtually every file on KO-23, KO-25, etc to every client station. It would even begin to put a dent in the data stream that could be expected from Phase 3D. Increasing the data rate to 9600 baud will increase the throughput by a factor of 8, since there are no transmit/receive turnaround times to worry about. This could conceivably provide clients with close to 100 megabytes of data per day... enough to fill up most people's hard drives fairly quickly.

The HamWeb server does not use the standard pacsat header system. There are a number of reasons for this. When the pacsat header system was created, it included a number of fields that were infrequently or never used. Thus it seemed like a good idea to revise this system at this time to eliminate portions that were unneeded. In addition, the HamWeb system does away with the pacsat file numbering system altogether. Files are identified on client computers not by number, but by the same name by which they appear on the server. Duplicate file names can exist, as long as they are in separate subdirectories.

3. Creating a New Gateway Node

The HamWeb file server is the basic building block for the Satellite Gateway Node. The Gateway Node station runs the HamWeb server and specifies that the entire satellite subdirectory structure be broadcast. Thus all of the satellite files, including directory files, are replicated on the client computers exactly as they appear on the server. The client stations, then, can simply run a satellite groundstation program like WiSP to access the files. Thus, in addition to giving end users without satellite stations access to the digital satellites, it also gives them more of the "look and feel" of operating a satellite groundstation since they will be running real satellite groundstation software to access the files. It is probably worth mentioning that this might expand the potential market for groundstation software sold by AMSAT as well.

Client users will not, of course, be able to use a program like WiSP to automatically upload files to the satellite or to mark specific satellite files for download. This could be implemented, however. It would be possible to write a program that monitored the WiSP files that request downloads or result from uploads being prepared and automatically communicate those requests to the server. The reason that I have not implemented that at this time, is that it would require that the client stations have a separate connection to the server to provide it with this information. I think most stations using this system will be relatively modest in size, and are unlikely to have this capability. Thus marking files for download and uploading files using the new Gateway Node system will occur in much the same way as with the old system... It will require a regular packet connection to the BBS. When a marked file is received by the server, however, it will automatically be placed in the broadcast queue and transferred to the client stations.

The HamWeb software is now complete and available for distribution. It is available free of charge for amateur radio applications only. More information about HamWeb can be obtained at: <http://www.tapr.org/~wa0ptv>. The software itself is available by ftp from: <ftp://ftp.tapr.org/pub/wa0ptv>. The file that contains both client and server software as well as documentation is HWFILES.EXE. It is a self-extracting file. This software (both server and client) is designed to run under Windows95 and will not run under Windows 3.X.

As of this writing (July, 1997) the revised Gateway Node software (which would be required in order to allow users to mark files for download and upload their own messages) is not yet complete. I hope that it will be completed shortly. Interim versions of this partially completed package have been used by a number of satellite groundstations. A couple of HamWeb servers have also either been established or are in the process of being set up. As yet, no one that I know of has set up a Satellite Gateway Node based on a HamWeb server. If you are interested in doing so and require assistance please feel free to contact the author.

Mobile and Portable Operation of Voice Mode Satellites

By

Chuck Duey, KI0AG

Abstract:

Large tracking arrays and high power radios are not needed to work the Analog mode satellites currently in operation. With a few small portable antennas and QRP to moderate power the satellites can be worked from a variety of locations, coast to coast and the mountain tops in-between. This can be as simple as QRP operation from a city park with an HT and short Yagi, to a small array of antennas on a vehicle parked at a Yellowstone campsite. The setups range from a couple of mobile whips for RS-10 (RS-16) and RS-12 to a short 70 cm and 2 meter Yagi pair for AO-10. With a little planning and common sense, just about any trip can become a satellite DX-pedition.

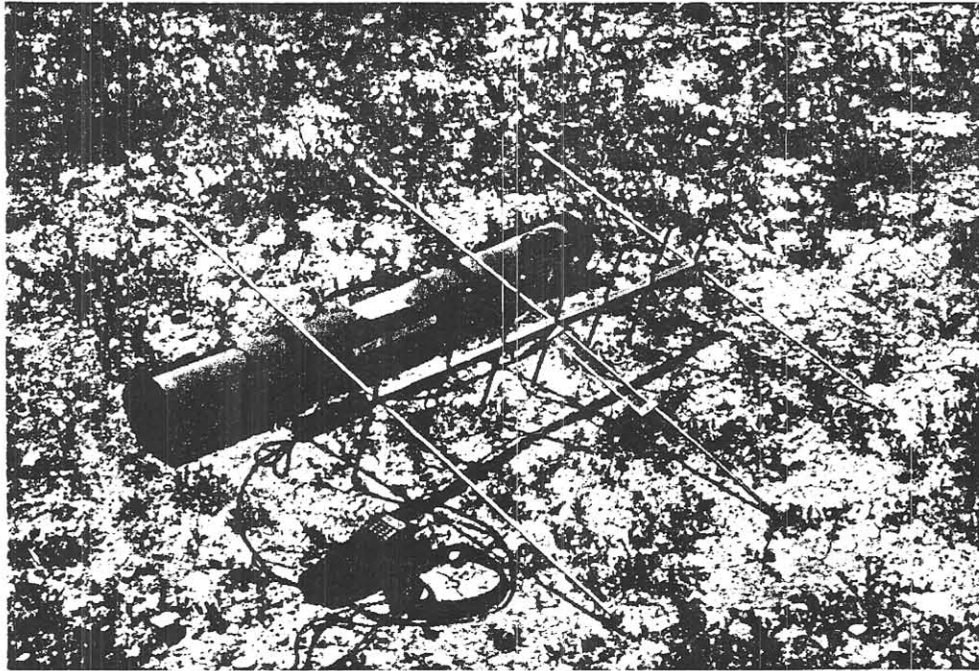
Introduction:

Mobile and Portable satellite operation can be done from a variety of exciting locations coast to coast and the mountain tops in-between. Adding a few satellite contacts on a cross country trip makes the journey that much more pleasurable. Satellite operation can also add some excitement to camping trips. Mobile and portable operations can also provide many contacts when restrictions prevent a station at home. With the right equipment and a little planning satellites can be operated from just about any place away from the old QTH.

Just a quick word on my operations. Due to restrictions in my neighborhood, I could not set up the station like I would. Rather than fight the home owners association lawyers and the ire of neighbors, my operations are either very low profile or away from home. This has led to many discoveries on how easy most analog birds are to operate. I now carry some satellite gear along on just about every trip by car or airplane. So far I have logged 68 grid squares that I've worked from including both coasts and a few mountain tops between.

AO-27:

AO-27 is my favorite bird for portable operation. All it takes is a good dual band HT, a 5 elements 70 cm Yagi or better, and headphones. The real key to AO-27 is the down link. To hear the bird horizon to horizon an antenna with the gain of a 5 element Yagi is needed. Sure, AO-27, can be heard with a rubber duck, or mobile antenna, but these windows of operation are usually short. It can be very frustrating to hear a mobile station in some rare grid square, and they can't hear the bird well enough to make contact. In contrast to the down link the up link antenna does not need to be high gain. As long as there is no other stations transmitting a rubber duck at 5 watts gets in well. However, there is often some interference on the Southern part of the pass that might need a little more gain.



AO-27 Satellite Equipment: Arrow 146x437-10, Yesu FT-530, headphones, and fly rod case.

The current 'classic' antenna for portable operation is a dual band Yagi. These range from a 70 cm and 2m antennas placed in the same boom to the ever popular Arrow Antenna 146x437-10. The Arrow Antenna consist of 7 elements on 70 cm and 3 elements on 2m. This configuration gives very clear down link signals and a little extra gain for the up link from your HT. With a dual band HT, dual band Yagi and headphones, it is quite easy to operate from mountain tops and remote locations.

The radio or radios for AO-27 operation can also make a big difference. The up link can be operated from just about any HT or mobile that can transmit on 145.85 MHz FM. Side band and CW do not work well on AO-27, it is an FM bird. The down link at 436.800 MHz is the most important aspect to focus on. Many scanners do not have the receive sensitivity and have 12.5 KHz steps. The sensitivity can be compensated for by a preamp. However, steps greater than 5 KHz cause a shortened operating time. Dual band HT's can also have the same sensitivity problems, however many newer models are quite good and don't require a preamp. The other feature to look for in the dual band HT is 'Full Duplex' operation. That is the ability to hear the satellite on 70 cm while the 2m up link is active. Full duplex operation on AO-27 lets you hear your own signal and verify your getting in.

Getting on AO-27 can be a daunting task. With many QSO's flying back and forth, getting a word in edge wise can be difficult. The trick is to listen and get the style of operation. Listen for a blank space and call one of the call signs that has been working the bird. Many new stations cannot hear the bird and start calling 'CQ' for the whole pass. What happens is after a few attempts to call these stations back, this station is usually ignored. The worst case is an inexperienced operator who uses 100 Watts and cannot hear the bird. Up link power is not the answer to hear the bird. A 100mW up link and a 1KW up link have the same down link power!!!

Currently AO-27 is on during daylight passes over the Northern Hemisphere. At the start of the pass tune the 70 cm radio to 436.805 MHz and point the antenna towards the satellite as it rises from the North. At first the receiver will quiet down, but WAIT!! The initial quieting is the receiver getting the carrier, but the modulation may not be heard yet. It takes a couple more seconds to hear the QSO's going on. Once voices can be heard clearly, it is safe to try to make contact using the 145.85 MHz up link. Beware of feed back. If the speaker and the microphone are close together, feedback through the satellite can be heard. For HT operation headphones are almost a requirement when in full duplex operation. 3 minutes after the rise of AO-27 tune the down link receiver to 436.800, it should sound better. As the bird goes to it's peak the receiver should be at 436.795, and then 436.790 about a minute after the peak. At about 3 minutes before setting the receiver should be tuned to 436.785. After the pass write down the call signs contacted and answer the questions of the curious bystanders watching.

The RS Birds:

The Russian birds RS-10, RS-12, RS-15 and RS-16 can be worked quite well on the road. At the time this paper was written RS-10 is off the air to return at an un-known time. RS-16 will be a mode A bird, but has not yet been activated. RS-15 has battery problems, and is slowly getting tougher to work. RS-12 is strong and healthy. RS-12 is the easiest to work from a mobile station, however the up link is in the Advanced and Extra class band of 15 meters. The mode A birds RS-10, RS-15 and RS-16 have strong down links and can easily be received from a good location.

With a lowly 10 meter Hamstick, out way from the city noise and under clear skies all of the Russian birds can be copied. RS-15 can some times be a little more difficult, but with some practice, it can be heard. A wire turnstile antenna can be string up to give a better signal on RS-15. Unlike RS-15 the other three birds RS-10, RS-12 and RS-16 come booming in frequently S9 on the old 10 meter whip. The 2 meter down link from RS-12 simultaneously runs with the 10 meter down link. Both bands, 2 m and 10m have the same information, so if 2m side band is available, it is better. The 2 meter down link can also be copied using a 5/8 whip. The up link antennas on the RS birds can also all be whips. A 15 meter whip on the RS-12 up link works quite well horizon to horizon with 100 watts.



RS and FO Satellite Antennas: 2m Eggbeater, 70 cm Eggbeaters 10m Hamstick and 5/8 wave 2m.

A 5/8 wave whip works quite well on RS-10 at 40 watts SSB. RS-15 needs a hair more power, with the whip at 100 watts it gets in for most of an overhead pass. RS-16 has not been turned on as of yet, but with the lower orbit and the past history, it should be very easy to get in off a mobile whip. So with a few whips and moderate mobile power all the RS birds can be worked.

The radio can make a big difference on reception. Some 10 meter rigs are not very sensitive. Quite often the older units need a good preamp. The newer multi-band mobile rigs are just the ticket for some on the road QSO's. With a 2 meter side band radio and a 10 meter/15 meter HF radio, these birds can be worked from a wide range of locations.

The location for operating can make a big difference in down link signal. Other AM signals, heaters, running cars and neon signs tend to cause a large amount of noise on the down link. Even some seemingly quite locations can be bad. For example while I was in Yellowstone, I found the heaters in the restrooms caused a considerable amount of noise on 10 meters. At the start of the pass on RS-15 all was quiet, then a small group of folks walked in to the restrooms, and the heaters started up. The next morning, I paced off the distance and found the closest one was 120 yards off! Very noisy heaters!!

One of the best things about the RS birds and mobile whip operation is there are no antennas to set up. Just stop and talk. Just pull up in a clear spot and give the weather report to some one that can be a thousand miles away. As long as the SWR is good it is a lot of fun sitting in a snow storm talking to some one in warm sunny Phoenix AZ.

FO-20/29 Voice Operations:

The Fuji Oscar birds can be temperamental at times, but they are well worth working from remote locations. They have a nice 15-25 minute pass just enough time to hold a good QSO and move on. Even in the Mountains of Montana and Wyoming, European contacts can be made. There are a few tricks however to make these birds work well.

Even with a good radio, the gain of a mobile whip is just not enough to hear these birds for a good QSO. However, you don't need to resort to long Yagis on an Az-EI rotor. I use the humble Eggbeater with a minor modification. FO-20 and FO-29 work well on the normal Eggbeater most of the time, however some times they switch polarity RHC to LHC. That's the modification: use two Eggbeaters and a switch to select which one is better. The stock M2 70 cm Eggbeater is Right Hand Circular on top. To make a Left Hand Circular, just open it up and flip the phasing loop 180 degrees. (I.E. Unsolder the wires from the phasing loop and connect the one end backwards from the original design). On the horizon the two Eggbeaters work the same, but over head quite often it switches, so be ready. The up link is also best with an Eggbeater and 50 watts. One other trick is to be sure the ground radials do not touch the vehicle, or else the up link interferes with the down link.

With the gain of the Eggbeater a preamp is helpful with most radios. The preamp built in to the average amplifier works well. The FT-736, TS-790 and the IC-821 work well for FO-20 and FO-29. A little extra up link power at the horizon helps to get in early, but as it goes over head, the power can be reduced down to 25 watts and still work well. The configuration I run is a Yeasu FT-736, a 2 meter amp / preamp and a 70 cm amp / preamp.

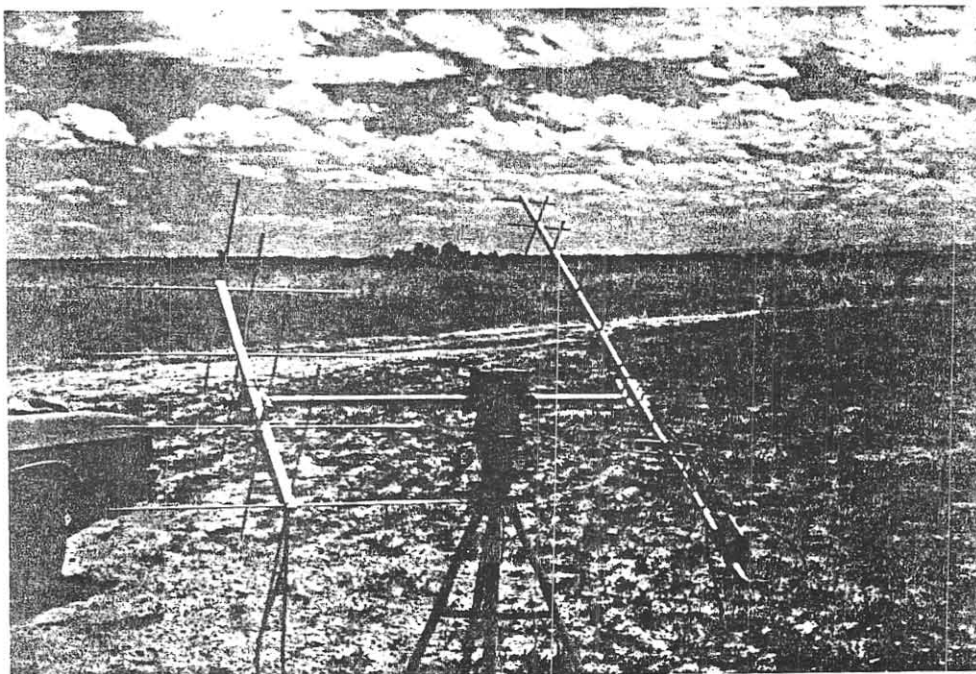
The operation of FO-20 and FO-29 does take some practice, but can be mastered with in few QSO's. If software is not available to calculate the Doppler shift, it can be done manually as long as the down link can be heard. At the start of the pass a FO-20 up link / down link pair are 145.933 MHz LSB and 435.870 USB. FO-29 when it is in analog mode is slightly different at 145.937 LSB and 435.870 USB. These number are for the start of the pass. As the pass progresses, the frequencies decrease. The COMMON practice on FO-20 and FO-29 is to tune the higher frequency I.E. the down link. Towards the end of the pass the up link will still be at 145.933 or 145.937 but the down link will be around 435.858.

The FO-20 and FO-29 down link on 70 cm is much less susceptible to noise and can be run even with the engine running. However, due to the complexity of the Doppler shift and size of the 2 meter Eggbeater, operation while moving is difficult. A good camping spot and a warm vehicle can be just the ticket on a quiet vacation.

AO-10:

AO-10 is still functional and can provide the best DX and the longest QSO's. Its high orbit gives it a great foot print. It does come with a cost, much higher gain antennas are needed. When AO-10 is at Perigee, yes whips work but not for long. There is a very short window for about 1 hour long that low gain antennas work. From perigee to 12,000 Km, 70 cm and 2 meter Eggbeaters will work. After that a higher gain antenna system is needed. Between perigee and 25,000 Km a 8 element 2 meter crossed Yagi and 22 element 70 cm crossed Yagi seems to work well. At distances greater than 25,000 Km even better systems are required. A 22 element 2 meter antenna is not that easy to set up on the fly, but can be done in remote locations given enough time.

On AO-10 there is plenty of time to sit back and talk. Even with the lower gain antennas, the useable pass is typically better than all the other Amateur birds. If your in a rare location, you can get quite the pile up, so be ready with a good log and lots of patience.



AO-10 Antenna Array: KLM 435-18C, Arrow Antenna 146-8X and Yeasu G5400 Rotor

Locations:

Sometimes the best location is not on top of a mountain. Mountain peaks give a good view and are great for VHF/UHF DXing, but they quite often have transmitters there also. One thing to look for in a location is other antennas. There can easily be a pesky pager a couple hundred meters away that totally over loads the front end of your receiver. They never seem to be there until the satellite comes up. Another interesting problem is IMOD (Inter-Modulation). The video carrier of channel 7 at 175.25 and the up link of RS-10 at 145.880 mix to get 29.37 MHz on one product. Some locations close to a powerful channel 7 transmitter cannot work parts of the RS-10 band. So pay attention to the transmitters around.

The ideal location has no obstructions in any direction, and unless your out on the Plains, it can be difficult. Mountains, valleys and hills cause a sudden loss of signal as the satellite drops behind it. Look at where the hills are and it is easy to see how much sky is left to work the birds. Trees are a mixed blessing; while they provide protection from the sun and wind, they do attenuate the signals. Pine trees tend to attenuate less, but it is better to find a wide open location. Buildings are the worst obstacle of all. Not only do buildings block the satellite signals, but they also have transmitters and quite often noisy computers.

Computers carried along are also a mixed blessing. The satellite can be tracked the contact logged, but quite often the computer hits a couple of important bands. Many computers hit the 10 meter band making RS-15 that more difficult. Some others put birdies all over 2 meters. Only a few bad computers hit 70 cm. The best advice is to listen to the band of interest with and with out the computer to find out where it causes interference.

Speaking of interference, watch out for bystanders when operating with any power over 5 watts. All you need is some one looking at your 2 meter Eggbeater on the car touching it as you transmit. A location where the transmitting antennas are away from the radio and roped off or cut off from possible bystanders is best.

Weather can also cause another severe safety problem. Lightning can be hazardous to your health. (I'm sure the Surgeon General Agrees). Antennas are great lightning rods. Even a close strike can hurt you and or your equipment. During a storm stop operating and disconnect the antennas, and stay in the vehicle. I have seen the whips on my car start to glow just before a strike 1/4 mile away. It would not have been good to have the equipment hooked up.

Planning:

The nice thing about Whips and Eggbeaters is no pointing is required, so no computer needs to be hooked up. Getting a print out of the pass times and the azimuth of the rise and set of the bird works quite well. Even AO-27 can be worked by knowing the direction it rises and then tracking it by hand or ear as the case may be. A laptop helps out for those far off locations where the predictions are more difficult to come by. It is also a great supplement to plan the next passes coming up.

A laptop or computer can be used to point the antennas. A tracker such as FOD Track can be used with the Yeasu G5400 Rotors. (FOD Track is on the AMSAT shareware FTP) To power the rotors a simple power inverter available from Radio Shack does the trick. So with a Laptop and an inverter to power the rotors, the station can have the same ability as a big home station. The draw back is all the equipment that is required, but nothing is like the look of fellow campers when the antenna moves by itself.

Moving down the road chasing grid squares can be quite fun. Each square is 67 miles wide North to South and about 100 Miles long East to west at Colorado latitudes. Between passes it is easy to hop across a grid square boundary and hit another one. For AO-27, the FO birds and the RS birds it is easy to move one whole degree (67 miles) North-South in one pass, however even with the 'Safe and Prudent Speeds' 2 degrees (100 Miles) East-West is not advisable. Some of the best grid square chasing can be done on the many North-South Intestates in the U.S.

The next time there is a trip planned for a cross country trip, consider bringing along a few antennas and radios for the birds. Working a few satellites can break the monotony of the road and make a few fellow hams happy to hear someone from that rare grid.

Catch Ya' on the Birds

73

Chuck (KI0AG)

Equipment:

Arrow Antenna 146x437-10
M2, 2 Meter Eggbeater
M2, 70 Centimeter Eggbeater RHC
M2, 70 Centimeter Eggbeater LHC
Hamstick, 10 Meter
Hamstick, 15 Meter
Radio Shack, 5/8 Wave 2 Meter Whip
KLM, 435-18C
Arrow Antenna, 146-8X

Yeasu, FT-530
Yeasu, FT-736
ICOM, IC-706
RF Concepts, 2-417 2 Meter Amp/Preamp
RF Concepts, 4-310 70 Centimeter Amp/Preamp
Yeasu, G5400 Rotor
Compaq LTE 25
FOD Track, Software and Hardware
Garmin, GPS-45

WATOO: An Internet Access Software to a Satellite Tracking Station*

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Abstract

The goal of the project presented in this paper is to provide means to share the resources of a satellite tracking station via the Internet. Being costly and cumbersome, this kind of installation is not affordable to everybody. But with the outreach offered by the Internet, it is possible to share this material. In particular, we hope that this project will make easier participation of students to communication programs with astronauts (such as SAREX).

The project itself can be divided into two main areas: the client application and the satellite telecommunications server. The client application is the user interface. Using this application, an internaut is able to connect to a satellite telecommunications server and talk on a satellite frequency (an amateur radio license is required). The server manages the control information exchanges, antennas, and radios. Both the client and server designs are object-oriented. The client is programmed in Java and the server is implemented in C++. Our software is called WATOO which stands for World wide Access To Orbiting Objects. This paper presents the user interface of WATOO and briefly reviews the design of the client and server.

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1 Introduction

This paper presents a novel software providing access to satellite telecommunications stations via the Internet. Installation of a satellite telecommunications station is not affordable to everybody because it requires a certain investment of money, expertise with satellite telecommunications equipment, and adequate space for antennas. Our goal is to develop software that enables distant access and sharing of this kind of material through the Internet. In particular, we hope that with such software, participation of students to communication programs with astronauts (such as SAREX) will be more accessible. Our software is called *World wide Access To Orbiting Objects* (WATOO).

The software is divided in two parts: the client application and the satellite telecommunications server. The client application is the user interface. Through this application, a radio amateur internaut may get connected to a satellite telecommunications server and talk on a satellite voice radio frequency. The server controls the antennas and radios and sends/receives voice over the radio channel.

The satellite telecommunications server comprises the following pieces of equipment. Outside the station, there is a system of crossed yagi antennas for the 2 m and 70 cm bands. Their length is approximately 10 feet. There are azimuth and elevation rotors to maintain the direction of antennas toward

a satellite. Inside the station, there is a Yaesu FT-736R radio covering the 2 m and 70 cm bands. The satellite telecommunication server runs on a Pentium personal computer executing the Linux operating system. The computer has a hardware interface with the rotors of the antennas and a hardware interface with the radio, so they can be automatically controlled by software. The computer also has a sound card connected to the radio audio in an out.

This paper presents the user interface of WATOO (Section 2) and briefly reviews the design of the client and server (Section 3).

2 User interface

The user interface of the software is illustrated in Figure 1. In the top left corner of the window, the name of a tracked satellite is posted. On the left side, there is a panel of four numeric values indicating the current satellite latitude, longitude, and altitude, and antenna direction, in terms of azimuth and elevation. For the sake of simplicity and readability by non-experts, all numeric values are displayed as rounded integers, although computations within the server are done using double floats. In the middle, there is a map showing the ground location of the server and the point directly below the satellite (the subsatellite point (SSP)). An ovoid figure is drawn around the subsatellite point that delimits the coverage area. Of course, the location of the satellite telecommunication server, and not necessarily the one of the client, has to be within the coverage area to make communication possible. On the right side, there is a panel of four buttons. A click on the button *Connect (Disconnect)* triggers the client to server connection establishment (release) process. The button *Talk* launches a voice over the Internet communication software. The software that we use for this purpose is named *Speakfreely* [6]. The last button on the bottom allows selection of a language in which names

of fields and buttons as well as messages are displayed (presently, English and French are supported).

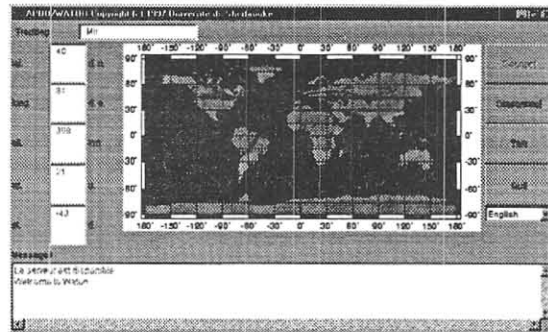


Figure 1: User interface

3 Design

The design has been devised using the object-oriented development method of Booch [1].

3.1 Client application

One of our main goals was to develop a client application that can run across several platforms. At first, we turned our attention to the Java language [3] that aims to have the portability property. Development in Java means re-use as much as possible of Java components, from a rich collection of classes, and Java architectural patterns. Adoption of Java has therefore considerably influenced the structure of the interface. However, we were not able to do everything in Java, while investing a reasonable amount of efforts. Hence, we achieved the portability goal to a certain extent.

The architecture of the client application is pictured by the class diagram of Figure 2. Every class is represented as a rectangle with its name in a top subrectangle and list of methods and in a bottom subrectangle. Edges between classes represent has by-value relations (solid diamond on the component

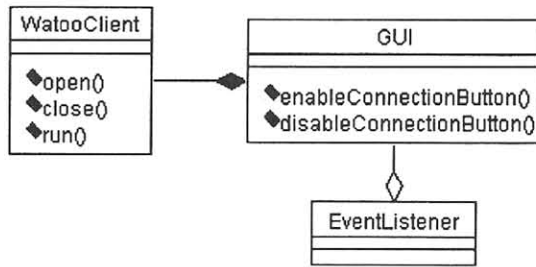


Figure 2: Architecture of the client application

side) and has by-reference relations (hollow diamond on the referee side).

In our diagram, there are three main classes of objects: *WatooClient*, *GUI*, and *EventListener*. This architecture follows the event delegation architectural pattern of Java (JDK 1.1). An important point is the fact that the application logic is separated from the graphical user interface, giving to them a certain independence. The application logic is in class *WatooClient* and the graphical user interface is in class *GUI*. An other important point is that there are sources of events and listeners of events. A source of event is typically a graphical user interface object (instance of *GUI* in our case). A listener is an object that provides a method called by the event source in response to a specific event that occurs at the interface (e.g., the click of a button). In our design, there is specialized (subclass) event listener for every type of event. The method called when an event occurs is polymorphic. An event listener may dispatch work to other components of the application. Hereafter, we describe two key mechanisms of the interface: connection establishment and voice communication.

The mechanism for the connection establishment with the server is illustrated in Figure 3. First, a user clicks on the button *Connect*. An event emerges from the graphical user interface that triggers an event listener. The event listener calls method *open()*

on an object of class *WatooClient*. This method opens a stream transport connection with the server (using TCP), sends to the server the name of a satellite to track, requests disabling (enabling) of the connection (disconnection) button on the object of class *GUI*, and threads a copy of itself which, by definition, executes the method *run()*. The method *run()* embeds an endless loop that periodically receives from the server a message giving the coordinates of the tracked satellite.

Presently, not much is available in Java for supporting real time duplex voice communication [4]. The voice communication mechanism of the interface simply launches the communication freeware called *Speakfreely*. The executable code of *Speakfreely* is platform dependent. However, it is available for several platforms (Windows, various Unix systems). Therefore, the *WATOO* client application is portable to a platform as long as an executable of *Speakfreely* is available for that platform.

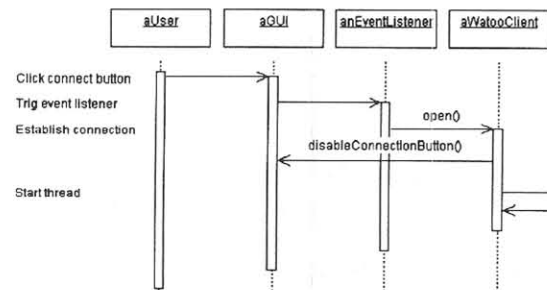


Figure 3: Connection establishment mechanism

3.2 Satellite telecommunications server

The server is responsible for:

- Determining the position in space of a satellite (the SSP and altitude) at a given time using Keplerian orbital elements data.

- Determining the direction in which the antennas should point, expressed in terms of azimuth and elevation.
- Positioning the antennas according to the computed direction.
- Tracking a given satellite, i.e., making that the antennas point towards a satellite.
- Setting the communication mode and frequency of the radio.
- Accepting a connection from a client.
- Periodically transmitting to a connected client the SSP and altitude, of a tracked satellite, and direction of antennas.
- Serving a voice connection with a client.

Since the satellite is constantly moving (for non geostationary orbits), the antenna rig needs to be repositioned periodically. A continuous update of the frequency is necessary to compensate for the Doppler shift effect.

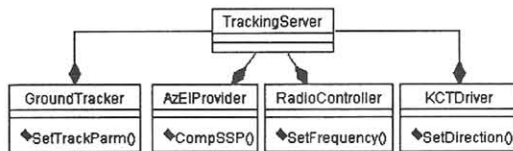


Figure 4: Architecture of the server

The architecture of the server is pictured in Figure 4. In the run time environment, every class is instantiated once. At the heart of this architecture is the TrackingServer that controls all related classes. The GroundTracker class is a computation center for the SSP and radius (distance between geocenter and satellite). The AzElProvider class is another computation center. It calculates the direction of the antennas, the altitude of the satellite, and the center angle¹ based on the

¹The center angle is defined as the angle between two vectors originating from the geocenter, one di-

rected toward the satellite and another one directed toward the ground station. The RadioController class is the interface used to set the radio modes and frequencies, which is done using the parameters computed by GroundTracker and AzElProvider. The last abstraction is KCTDriver. It controls the antenna rotors. Given positioning parameters, it is responsible for moving the antennas in the proper direction.

A typical tracking session goes as follow. The object of class TrackingServer accepts a client Internet socket connection. Next, it receives a selected satellite name from the client. Afterwards, it reads the corresponding Keplerian orbital elements from a file and sends them to the object of class GroundTracker (using message SetTrackParm(), see Figure 5). Then, it enters and executes a loop until the socket connection with the client is broken.

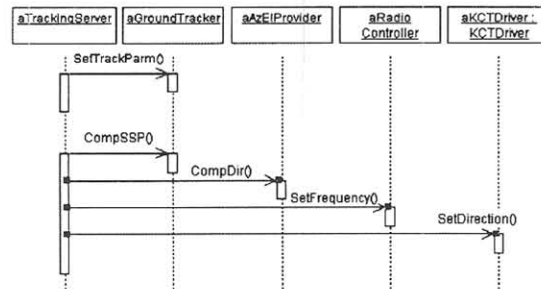


Figure 5: Main loop of the server

The loop of the server is illustrated in Figure 5. The participating objects are aTrackingServer, aGroundTracker, aAzElProvider, aRadioController, and aKCTDriver. There are five main steps. First, aTrackingServer sends message CompSSP() to aGroundTracker. It triggers computation of the current subsatellite point and radius. Second, aTrackingServer sends this information in message CompDir() to aAzElProvider that computes the current azimuth, elevation, and frequency. Third, aTrackingServer sends SetFrequency() to aRadioController that sets the radio frequency. Fourth, aTrackingServer sends SetDirection() to aKCTDriver that moves the antennas in the proper direction.

tion, altitude, and center angle. This second block of information is sent in message Set-Frequency() to aRadioController (that sets the radio channel taking into account the Doppler shift effect) and, in part, in message SetDirection() to aKCTDriver.

Note that in this design, the control flow of the application (put in TrackingServer) is separated from objects that performs specific computations or tasks. This design has two advantages. The control flow is easier to grasp. And, controlled objects can be easily substituted by objects that offer the same services but in different ways (e.g., more accurately, faster, for a different hardware).

The server is implemented under the Linux platform using C++. We selected the free-ware Linux for its performance and wide distribution. We selected C++ because the object-oriented design was easy to map this implementation language with good performance. Most of the top level objects are implemented as Unix processes communicating through Unix sockets. Although, this single user version of the server is essentially a sequential process, we went for a multiple processes structure because this server is the first phase of a more elaborated project. We have foreseen development in a near future of a multiple users, radios, and antennas server that will require parallelisms within its components.

Keplerian orbital elements are automatically gathered daily through the FTP site at the Air Force Institute of Technology (AFIT). This feature has been implemented using the *cron* mechanism of Unix. All calculations are based on the two body model and equations described in Ref. [2].

4 Conclusion

We have presented the interface and the design of a software that provides access through the Internet to satellite telecommunications stations. The current version is single user and supports solely voice communi-

cation. Note that we are currently supporting only one type of rotor hardware interfaces (Gracilis Grace) and solely one type of radios (Yaesu). More work is required to support other makes of equipment.

We are presently working on a second client-server software that will support multiple users, various digital modes, and video. We are also sketching a network of distributed, interconnected, and cooperating satellite tracking stations. When a client will log on this system the latter will automatically switch him to a station that will provide the earliest available communication window with the desired satellite. And, upon closure of this window, the system will switch the client to the server that provides the next available communication window. Hence, the client will have access to longer communication time, automatically managed by the system.

Acknowledgments: The authors would like to thank Andre F. Lamothe, Gaston Sirois, and Denis Thibault whom precious collaboration has greatly contributed to the realization of this project.

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Satellite Technology for Newcomers: The "Weather Channel" Model

by Rich Moseson, W2VU
Editor, *CQ VHF* magazine

If you can tune in the Weather Channel on your TV, then you've got a built-in tutor for explaining satellite technology to new and prospective satellite operators.

Introduction

Since its earliest days, the amateur satellite program has faced three parallel but distinct—and ongoing—challenges. First and foremost is the technical challenge—designing, building, launching and controlling ever-more-sophisticated, ever-more-innovative, amateur radio satellites. The second challenge has been to build and maintain public, political and financial support for amateur satellite programs. And the third challenge—the one on which this paper concentrates—is the challenge of making amateur radio satellites accessible and understandable to the average ham, and of teaching the average ham how to find, track and use these technological marvels that have been built and launched for their benefit.

The Technical Challenge

The technical challenge has always been met superbly, placing and keeping the amateur satellite community at the cutting edge of communication technology—a fact well-known and appreciated outside as well as inside of amateur radio (just look at the "Little LEO" industry—building a business

based on amateur microsat technology and then trying to take away our bands since it's proven that the technology works on these frequencies!). I hope that the amateur satellite community is prepared to continue facing and meeting this challenge in the years ahead, and to continue building on its tradition of innovation and leadership.

The technical challenge has always been met superbly, placing and keeping the amateur satellite community at the cutting edge of communication technology...

In addition, our links with the University of Surrey in England, Weber State University in Utah, the Korean Advanced Institute of Science and Technology, and other universities in Mexico, Israel, South Africa and elsewhere, are allowing new generations of space scientists to learn and innovate by building and launching amateur radio satellites, and—in keeping with ham radio's traditions—spreading our knowledge and experience around the world.

The Political/Financial Challenge

The challenge of building and maintaining support for amateur satellites is another one that, somehow, always seems to be met. Our public, of course, is the world's hams, and the vast majority—even those who have no interest in using satellites themselves—have needed very little convincing to believe that a strong amateur satellite program is important, if not essential, to a strong amateur radio service. They have been generous with their financial support as well, both individually and through other amateur organizations, from local and regional clubs to national societies.

The challenge of political support—the cooperation of government agencies around the world to launch and track our satellites—has also been met with great success. And while we can no longer "hitch rides" for free on military or commercial launches, our organizations have developed excellent, and mutually-beneficial, working relationships with the world's space launching agencies.

The Educational Challenge

Encouraging and educating potential users about satellite communication is, it seems, the most difficult challenge. And it would seem, on the surface, that it shouldn't be. After all, satellites have become part of our everyday lives. TV news reports, entire TV programs and many long-distance telephone calls are relayed by satellite. It's become so commonplace on TV that the networks long ago stopped superimposing "via satellite" on reports from remote locations. It's just assumed.

But, unless you work at the TV station or the phone company, all of this satellite use is passive. The end user doesn't have to do anything special. Even if you have a satellite dish in your yard, it's generally a "set-it-and-forget-it" type of device. You don't have to do much tracking of a satellite in geostation-ary orbit. Amateur satellites are different, though, and therein lies our education problem.

Who's Interested?

The first question we have to ask ourselves is, "How many hams are really interested in learning about satellites?" The answer may surprise you. Two years ago, we at CQ commissioned a professional survey of newly-licensed hams—the survey that ultimately led to the creation of *CQ VHF* magazine.

The good news is that 58% of the hams responding (to a CQ survey) said they'd like to try amateur satellites someday.

One of the questions asked these new hams to rate their involvement in various amateur activities. And the "never tried it" category was broken down into two possible answers—"never tried it but would like to someday" and "never tried it; no interest." Well, the bad news is that only 3% of those newly-licensed hams described themselves as either "very active" or "occasionally active" on amateur satellites, and another 30% said they have no interest (actually, the 30% "no interest" response was about average for most categories). The good news? The good news is that 58% of the hams responding said they'd like to try amateur satellites someday.

That was the *only* activity which drew an interest rate above 50% in the "wanna try it someday" category. So there are lots of people out there who are intrigued by amateur satel-lites, who think it might be fun to operate them, and who, someday, want to be-come satellite operators. So how do we reach them? How do we turn "someday" into "today"?

A Matter of Perceptions

A major part of the problem is one of perceptions—using satellites is perceived by many hams to be complex, difficult and expensive. And to some extent, it is. It's certainly a lot more complicated than dialing up your local repeater, keying the mic and saying, "*W2VU listening.*" It's even more complicated than getting on 20 meters and calling CQ (and, hey, you need to know code at 13 words per min-ute to do *that!*).

...the mystique of "rocket science" has made it seem that using amateur satellites is more complex, more difficult and more expensive, than it really is.

To use an amateur satellite, you have to locate it, track it, tune around to adjust for Doppler shift, and be there at the right time for passes of limited length. Plus, you need to be able to operate simultaneously on two bands, meaning two radios and two antennas that have to be able to move in two directions at once. And you can't really "work" the digital satellites at all. You have to tell your computer what you want it to do and let *it* make the contact!

But, to a greater extent, the mystique of "rocket science" has made it seem that using amateur satellites is more complex, more difficult and more expensive, than it really is. After all, is keeping track of uplink and downlink frequencies on two bands *really* that much more complicated than working "split" on 40 meters so you can work the DX stations below 7150 on phone? No, not really. Is the expense of setting up a satellite station *really* much greater than what you'd have to spend on equipment for any other specialized part of our hobby, whether it's DXing, con-testing, ATV or VHF weak-signal work? No, not really. Is satellite terminology *really* that much more difficult than packet terminology, with its ACKs and FRACKs and commands like AXHANG, not to mention KISS mode and PMS? No, not really.

So what's the problem? The real problem, again, is in perceptions. Face it, your average ham—if there is such a thing—tends to be a little insecure about the unfamiliar. And in "satspeak," even things that seem familiar aren't. Take the word *mode*, for example. To most hams, it refers to the type of modulation you're using. In "satspeak," it tells you which bands to use. And then you get into words like *mean anomaly*, *argument of perigee* and *right ascension of the ascending node*. Which has nothing to do with a packet node. And which leads the average ham to say, "Hold it right there. This stuff is *way* over my head. I'm not a rocket scientist. I can't possibly do this."

A complicating factor is the fact that many leading satellite users *are* rocket scientists, who *do* understand all the ter-

minology, and who forget that what's familiar to them is a foreign language to many others. And unless you have a knack for explaining things in plain language, you'll go to a club meeting or demonstrate your station to a prospective user, and it's usually only a matter of minutes before their eyes start to glaze over and you've lost your audience.

Educating Ourselves to Educate Others

If we're going to do an effective job of educating new and prospective satellite users, we need to educate *ourselves* first—not only in how satellites work and how to work them (you should already know that if you're going out recruit-ing!), but in how to present this information in an easy-to-understand form.

The first instinct is to turn to the professional educators among us for help. And sometimes, that may work. But most teachers are used to dealing with a) children or teenagers, and more importantly, b) a captive audience. Our audiences, on the other hand, are generally made up of adults who, first of all, can get up and leave anytime they want, and who don't especially enjoy being reminded of how much they didn't learn when they were younger. Also, being older, they are often more set in their ways and have more difficulty than children in absorbing new concepts. On the third hand, our audiences tend to be more mature and more motivated. The point, though, is that what works for a schoolteacher in a classroom won't necessarily work for a ham in a club meeting room. Corporate trainers might

be a better choice, but they're not exactly commonplace among the ranks of hams (or if they are, they haven't come forward and identified themselves).

Making it Sound Easy

Now, there are *some* people who truly have a knack for explaining complex material in a way that makes it sound downright easy. Some of them may be familiar to many of you.

I remember Ed Krome, back when he was KA9LNV, explaining to me how he designed and built the transverters he uses on every band from 50 MHz to light. It all made so much sense. I remember saying to myself, "Wow! I actually understand this. Maybe I can build one of these, too."

Then there's Paul Shuch, N6TX, who spends most of his time these days showing people how easy it is to become amateur radio astronomers, listening for signs of life in other parts of the cosmos. He cracks jokes and sings songs, but you come away thinking, "yeah, I follow that. I just might try to do that."

"Gee," I thought. "This stuff really isn't that complicated after all."

And earlier this year, I listened to Mike Owen, W9IP, give a talk at the Central States VHF Society conference titled "Rocket Science 101." It was all about his specialty of locating and tracking satellites in orbit, and, according to the conference program, was supposed to show you how to use tracking software—including his, of course—to do this. Instead, though, it was the clearest, easiest-to-understand discussion I've

ever heard on the science behind the numbers that get plugged into those programs that then tell you when and where to find the satellites of your choice. "Gee," I thought. "This stuff really isn't that complicated after all."

These are the kinds of responses we should be looking for from our own audiences. And if you want to be an effective teacher about amateur satellites, you should make a point of seeking out people like Ed, Paul and Mike when they're on a program someplace, listening to *how* they present their material, and learning from them. I, for one, seek out people like them to write for *CQ VHF*, as ham magazines can be an excellent tool for recruitment and education in all aspects of the hobby. But there must be one-on-one follow-up for the effort to be fully effective.

Unfortunately, not everyone can be where Ed, Mike and Paul are. And there's always the danger that you'll get so absorbed in *what* they're talking about that you'll forget to concentrate on *how* they're presenting it. So where can you turn for tutoring? The answer may be as close as your TV set.

The Weather Channel Model

Meteorology is at least as complex a science as rocketry, with the added variable of unpredictability. The laws of physics work the same way all the time, and if you've done all of your homework correctly and if nobody's missed anything like a leaky gasket, then a rocket or a satellite will behave in a predictable manner. And two rocket scientists working with the same data will nearly always come to the same

result. Randomness rarely plays a role. Not so with weather.

The world's best meteorologists can use all their skills and all their computing power to predict what a storm or other weather system *might* do and when it *might* do it, but there will always be disagreements among forecasters and the weather is going to do what it wants to anyway, even if it doesn't fit the computer models. But understanding the processes that go into making the weather do what it does is just as important as understanding the forces that determine where a satellite will be at any given time, and whether you're likely to be able to work it. And with a few local exceptions, no one does a better job of explaining how the weather works than the folks you can dial up on your TV set at the Weather Channel.

In addition to giving you the forecast for various parts of the world, they devote a lot of time to explaining how those forecasts are made. You learn about the jet stream, about tropical waves coming off the coast of Africa that sometimes develop into tropical storms and hurricanes in the western Atlantic; and about upper-level winds that can shear the tops off of tropical systems and prevent them from getting organized into major storms. You learn the terminology, such as what it means when a hurricane becomes "extra-tropical," the differences between watches and warnings, and the forces that mix together in the Midwest every spring and summer, often leading to tornadoes and severe thunderstorms.

NOAA Weather Radio is, with all due respect to both, the *QST* of weather ... The Weather Channel is more like *CQ VHF*.

You can also get this same information from the weather map discussion that airs a couple of times an hour on NOAA Weather Radio, but the presentation is different. NOAA Weather Radio is, with all due respect to both, the *QST* of weather. All the facts are there. Everything is technically correct. But the presentation is often dry (even if the weather isn't) and you sometimes feel like you have to be a meteorologist to understand what they're talking about. The Weather Channel is more like *CQ VHF*. *Explaining* is at least as important as *reporting*. And they try to keep things upbeat and interesting because they realize you won't learn *anything* if you hit the remote and switch to MTV. Well, anything about the weather, that is.

How do they keep things upbeat and interesting? For starters, they use a lot of pictures—it's television, of course, so you see winds ripping roofs off of buildings, people being plucked from flood waters, etc.—but a lot of time is also spent with the weathercaster standing in front of a weather map, talking about the weather and *showing* you things. Showing you how this system might interact with that system and what should result if one thing happens instead of another; or showing you how different factors actually came together to make the weather behave differently from what they'd previously forecast. Especially helpful are the regular features, such as "Tropical Update" and the "Five-Day Business Planner," which deal more with

trends than with up-to-the-minute forecasts, and which often go heavy on the explanations, with weather terminology put into everyday language. Plus, there are periodic special programs that look in greater depth at various types of weather, at specific storms, or at people involved in weather research, such as the storm chasers who go out looking for tornadoes or hurricane hunters who fly into the eye of a massive storm. These delve deeply into the technology and terminology of weather forecasting, again with an emphasis on making it all make sense to the average viewer. All of this serves to keep you interested and keep you tuned in, but it also provides a tremendous education for the amateur meteorologist. Imagine what a ham could learn from the *Amateur Satellite Channel*.

The Amateur Satellite Channel?

There is no Amateur Satellite Channel, of course, although help is available in print from articles in all of the major magazines and on the TV from *CQ*'s slightly out-of-date but still very useful "Getting Started in Amateur Satellites" video. Once the interest is sparked, though, it's up to individual satellite operators to invite people to their stations or go out to club meetings, set up a station if you can for live demos, and then explain in simple terms, in plain language, everything that's going on. Use your props (which can include a PC with a tracking program, QSL cards and anything else relevant) to *show* as well as *tell*, and follow up on any interest that is

shown. That may be the most important part—the follow-up.

But before your talk, before you write anything, before you organize anything, take some time to tune in the Weather Channel if it's available where you live; concentrate less on content than style and approach, and try to absorb what you can of their proven style of explaining the complexities of weather to an audience that's even more general than the one you'll find at your local ham club.

One final note—I know the Weather Channel is *not* available everywhere, and it's used here only as an example. Some other TV options that can help you learn to teach effectively about amateur satellites include *Bill Nye the Science Guy* on public television—I think he's the best since Mr. Wizard in the 1960s at explaining science and technology to kids or anyone else (I think Bill is a ham, by the way, but I'm not sure)—and several programs on the Discovery Channel, including Henry Tannenbaum's *Beyond 2000* and another future-technology program called *Next Step*. And once you've got it down pat, if you notice an aspect of satellite operating or technology that hasn't been well-covered or well-explained in the amateur radio press, I want to hear from you!*

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They Never Told Me Not To

an innocent is seduced by centimeter waves

Laura Halliday VE7LDH

Abstract

Microwave communications on Phase 3D promise unprecedented performance and ease of use, but to the vast majority of radio amateurs, microwaves are totally mysterious—even irrelevant.

This paper is the story of how one amateur learned a bit about microwaves, from 1296 MHz to 10.5 GHz, with the help of new and used components, classic designs, straightforward application of modern components, and, for good measure, the occasional stupid design.

Résumé

La satellite Phase 3D nous promettra des communications à micro-ondes des performances élevées, plus facile que jamais à utiliser. Mais selon le plus grand nombre des radioamateurs, les micro-ondes sont des choses mystérieuses, sans grand intérêt.

Voici l'histoire d'une radioamateur, et comment elle a appris un peu des micro-ondes. En effet, toute la gamme de 1296 MHz jusqu'à 10 GHz, assistée par des composants neufs et d'occasion, des montages classiques, des réalisations simples des composants modernes, et bien sûr, de temps en temps, des montages stupides.

Introduction: Why microwaves?

Are microwaves the future of amateur radio? I'd sure like it if they were—just think of what you could do with them. *Really* high-speed data. Local chit-chat with high-quality audio and nifty control capability. Applications nobody has thought of yet. Heck, those AMSAT folks are even launching a satellite with microwave capability.

But few amateurs have any experience above 450 MHz. For microwaves to be useful, people need the same sort of easygoing familiarity that most hams have with 2m FM, or 20m SSB. The only way to achieve this is to try it and see. Play with microwaves. Put things together. Enjoy the fact that they work, or figure out why they don't. Break them. Fix them. Modify them. Understand them. Absolutely standard amateur radio, in other words, except that the wavelengths are measured in centimeters, and not tens of meters. I set myself this learning experience as a piece of personal research, and this is a report of some of the trouble I've caused.

This paper has several sections: getting information, getting parts, wideband 10 GHz equipment, no-tune transverters, simple applications of modern components, and a summary of the lessons I've learned.

Getting information

Information is key to any activity, and amateur microwave communication is no different. The main sources of information on microwaves are reference books, conference proceedings, specialized books, magazines, the Internet, and Elmers. Only by accessing most (if not all) of these sources can you find the information you need.

Reference books: These are often professional books, and sometimes out of date. They can be expensive. They are written for professionals, and the technical level may intimidate some amateurs.

Conference proceedings: These include the excellent *Microwave Update*, regional conferences like the Central States VHF Society, and collections like *DUBUS*. They are an accessible source of information, written by amateurs for an amateur audience. In the past these have been highly specialized documents, going out of print quickly. Perhaps it's time for some reprints. Or for a collection of articles. This information is too good to waste!

Specialized books: These include publications like the RSGB's *Microwave Handbook* [ATUR—All The Usual References—please see the *References* section of this paper] and the ARRL's *UHF/Microwave Projects Manual* [ATUR]. These books, while sometimes expensive, are necessary background material.

Magazines: General amateur radio magazines have little microwave content, with the exception of the *Above and Beyond* column in *73 Amateur Radio Today*, written by WB6IGP. The RSGB publish the *Microwave Newsletter*, and have a *Microwaves* column in *Radio Communication* written by G3PFR, editor of the RSGB's *Microwave Handbook*. More specialized magazines include *DUBUS* and *UKW Berichte*, which may be more familiar in its English edition *VHF Communications*. The professional magazines like *Microwaves and RF* are fascinating and highly educational. They are also ultimately heartbreaking when you consider the price tag of the test equipment in the ads.

The Internet: The net is growing explosively, and it is particularly useful to a far-flung lot like amateur microwave enthusiasts. Useful resources include the Ham-Microwave mailing list, various web sites, and so on. Since the addresses change from time to time, please do a search to find current information.

Elmers: While this has been a traditional way of sharing information, microwave radio amateurs are so rare that I mention in-person Elmering for completeness only. Elmering via the Internet (see above) can be very effective, however.

Getting parts

Amateurs have been complaining about the availability of components for decades. I am mystified by this: parts are easier to get than ever before, and offer unprecedented performance and convenience. They aren't even very expensive after allowing for inflation. The issue appears to be that electronic components are no longer sold in every shop: other than Radio Shack, only major cities have comprehensive electronic component dealers. In practice, all this means is that I buy components by telephone, and wait a few days for a parcel to arrive. In all my amateur radio work, one parcel has gone missing, and when I notified the supplier, they shipped a replacement that day, no questions asked.

I have never had any difficulty purchasing components from suppliers in other countries. The worst Canada Post have ever done to me is charge me GST, plus their handling fee, which tends to be greater than the tax I'm paying on the shipment. This is sometimes the only convenient way to obtain "European" components, like BF961 transistors (a very nice VHF dual-gate MOSFET). Different countries have their own peculiarities: suppliers in the United Kingdom tend to take every credit card known to commerce; Visa was until recently called "Carte Bleue" in France; suppliers that take American Express (outside of the U.K. and U.S.A.) are extremely rare.

If you travel, try visiting some of the local firms. To me, Paris is a city of amazing electronics stores!

I have tried to avoid an excessive dependence on surplus equipment. The supply is at best erratic. It may be drying up. Few areas have any decent surplus dealers, though I have visited some brilliant shops in places like Silicon Valley, Dallas and Orlando.

Bands and modes

My microwave experiments have had two goals in mind: to learn something about microwaves, and to have equipment ready for Phase 3D. These goals coincide with 1296 MHz and 2304 MHz no-tune equipment that can be easily retuned to 1269 and 2400 MHz. These goals do *not* coincide with 10 GHz Gunn-based equipment—which has no application to Phase 3D communications, but which is an excellent way to get started with microwaves. Some choices have been based on equipment availability—like the two C band Frequency West brick oscillators that I purchased at a swap meet. They will eventually become the LOs of 3456 MHz equipment.

I have not attempted S or C band uplink equipment. The techniques are specialized, and the components (barring good luck at surplus dealers) are expensive. For the moment I will stick to 435 and 1269 MHz uplinks, where uplink power is inexpensive and idiot-proof. My terrestrial microwave work involves tens of milliwatts, which is plenty for what I want it to do.

I have no preference on the modes I use. Some have satellite applications. Some don't. This is not an issue on the lower bands (e.g. 2m FM vs. SSB); why should it be so on microwaves? "Appropriate modes" will change with the passage of time. Professionals use many modes, including wide-band FM and PSK. So can we: with satellites that look increasingly like bent-pipe repeaters, why not (other than power budget concerns) use any mode that will fit in the satellite's passband?

10 GHz: the easy band

My first microwave communications were in this band. I set an initial budget of 100 dollars for two stations (to make sure that I would have somebody to talk to), and came in substantially under budget. Here's how I did it.

Getting going

My first real microwave gear came from the usual source: a swap meet. I noticed a box full of ex-intruder alarm Gunn diode oscillators, with detector diodes in their feed horns. I bought two units as cheaply as I could and happily carted them home.

My primary reference for 10 GHz wide-band equipment remains *Practical Transmitters for Novices* [Case95], a book aimed at U.K. Novice licensees, who have access to a segment in this band. Following the instructions in the book I verified that the Gunn oscillators both worked, and estimated their operating frequency. This turned out to be approximately 10.6 GHz, typical for Doppler intruder alarms. I retuned one unit to 10.2 GHz by adjusting the its tuning cavity, and after convincing myself that it was on the correct frequency, adjusted the other one to 10.3 GHz.

My "test equipment" makes the accuracy of these figures debatable, but the 100 MHz difference between them is accurate, since they are operating like Gunnplexers, where the Gunn oscillator that you transmit with does double duty as the receive LO. I chose an IF of 100 MHz to make use of available FM transistor radios, but IF breakthrough caused me to change my IF to 90 MHz. The modulator is trivial, adding a few millivolts of audio to the well-regulated Gunn diode power supply. For good measure I added an MMIC preamplifier to the receive side, using a MAR-6, a MAR-3, a 7808, and some components salvaged from junk cellular telephones. I laid out a little microstripline PC board with a ruler, drafting tape and guesswork. It works fine.

Does it work?

Of course! The audio quality rivals FM broadcast, and with small dishes or horns, these units can work any non-obstructed terrestrial path. Since very little of the circuitry is frequency-sensitive, the choice of modulation is open. I want to try X band ATV!

What now?

I'm starting to experiment with more elaborate receive equipment. Among other things, the Gunn unit detector diodes are grossly overdriven, limiting their performance. Also, low-noise preamplifiers are not possible. I purchased a pair of converted Ku band TVRO LNBS from a source in England. They have GaAsFET front ends, with noise temperatures in the 80 to 100 K range. They are already converted to 10 GHz with 9.0 GHz LOs, for an L band IF of 1000 to 1500 MHz. They are intended for use with a surplus satellite television receiver, but for experimental purposes I tacked together a very simple converter with some Mini-Circuits components from my junkbox: a MAR-6 preamplifier, a TUF-5 mixer and a POS-535 VCO. I didn't have anything in my junkbox that would oscillate at 1100 MHz, but knew that the diode mixer would respond on the 3rd harmonic of its LO. So I tuned the oscillator to 366.66 MHz, converting 10.2 GHz signals first to 1200 MHz in the LNB, and then to 100 MHz in my little converter. I initially christened this the Stupid Converter, because it cuts so many design corners, but still works. Sort of. Others have suggested the Geoduck Converter, because the input coax (a cut-down CATV cable) is white, and looks like a geoduck's foot.

One day I may move to a more benign IF like 70 MHz, popular in professional circles. While I may modify a faithful transistor radio, it may be easier to build a simple FM receiver. The only way to do this today is with subsystem ICs, an approach that does not seem to be well covered in the amateur literature. Other than the datasheets for the ICs themselves, the only useful references I've found on the subject all seem to come from Europe, for example, [Bajcik92], [Bajcik94] and [Lemmens96]. Others report success with even simpler receivers, like X band superregenerative receivers [Janet97]. I wouldn't mind better frequency stability, and know a number of ways of achieving it (injection locking, AFC, etc.).

My X band setup is less than optimal, but *does* work, it worked the first try, and, stupid though it may be, it's a place to start. A system that works, however inefficiently, can always be a tool for testing and evaluating systems that work better.

No tune on 1296, 2304 and 2400

A really good idea

It seems so simple: by designing filters for 50 ohm input and output impedances, and interconnecting them with 50 ohm mixers and MMIC amplifiers, you can assemble systems out of building blocks that have very little reason not to work. But it took several developments to happen: hairpin filters on PC boards that can be etched precisely. Those 50 ohm MMICs, at a price amateurs can afford. And somebody to pull it all together.

Now that this is done, we amateurs can benefit from the work done by the no-tune transverter designers. Since the critical part is done once the PC board is etched, all that we need to do is add the remaining parts to the board, test it, and use it. Since the filters are already matched to 50 ohms, we can use *any* 50 ohm components between them. Since the boards are dimensionally stable, we can cut them up, use the components to make other things (or test stages in isolation), and fit the pieces back together.

It all sounds like a dream come true. Books for beginners recommend the no-tune transverters as an easy way to get on microwaves [Case94], [Campbell92]. Best of all: it's true. These things work.

I tried it

My no-tune transverter experience extends to KK7B's 1296 MHz transverter, and to WA8NLC's 2304 and 2400 MHz versions [ATUR]. The 2400 MHz version is the LO and receive side of the 2304 MHz converter. Not knowing what I was doing, I bought one complete kit, and a second set of boards. In this way I could build a transverter from a proven design that would have a very high probability of working. I could then use it to test the results of my own experiments on the victims...ahem, other boards.

The only component that has ever given me any difficulty is the KK7B local oscillator board [ATUR], which starts with a crystal oscillator in the 90 MHz range and multiplies it by 6 to around 540 MHz. I've built three of them on various frequencies, and while the crystal readily oscillates on the correct frequency, I seem to get odd frequencies (and low output) out of them until I tweak the diode multipliers. It is, however, pretty

obvious when they work. I have found an older UHF television receiver (the continuous tuning variety) to be a handy broadband relative power indicator. The 576 MHz output of the 1296 MHz transverter LO board, for example, comes in on channel A31, and you can easily see changes in signal strength.

My assembly technique is good enough that I have never fried any components. Nor have I ever lifted any traces off the boards—a concern on the teflon 13 cm boards. Not at all bad for somebody who had never worked with this technology before.

Updates

The no-tune transverters date back to the 1980s, and in the meantime people have gained a great deal of experience with their strengths and weaknesses. Experience has taught people how to make better transverters. Some updates are based on new technology, like MMICs that were not available at the time of the original design [Kostro95]. Others are based on engineering and operational experience, like regulated MMIC power supplies [Ward93], and shielding things that radiate RF [Campbell94]. Some have pushed no-tune technology to X band [Orban96]. An important new technology is prepackaged computer clock oscillators, some of which are available in useful frequencies. These oscillators are simpler to use, cheaper than an equivalent circuit made out of discrete components, and work every time [Campbell95]. They're even more compact. Campbell's article is also a useful overview of design decisions in the no-tune transverters, with indications of future directions.

My no-tune transverters all have cut traces and additional components, little daughterboards and shielded filters. Some have LOs based on computer clock oscillators. Do they work any better? They appear to; I don't have test equipment for anything more than qualitative comparisons. Bragging rights are, of course, another matter entirely.

Simple stuff

Commercial interest in microwave communication is producing a steady flow of interesting new components. These components are aimed at mass-produced consumer products, so they are cheap, robust, and easy to apply. These components include low-noise amplifiers, power amplifiers, mixers, phase locked loops, and more. Examples include the ERA series of MMICs from Mini-Circuits, MMIC amplifiers internally matched to 50 ohms, with useful gain to X band. Mini-Circuits make a wide variety of other components, including mixers. National Semiconductor make PLL chips useful to 2.5 GHz. Hewlett-Packard make GaAs MMICs useful to X band. *Everybody* makes various chips for S band applications.

The simplest S band downconverter I've been able to come up with uses an HP MGA-86576 GaAs MMIC [Ward94] and a Mini Circuits SKY-5G mixer on a little PC board. I simplified the circuit by considering just what image response the converter needs, knowing that I will use it with a directional antenna. Since the antenna is pointing at the sky most of the time, the odds of anything other than noise being on the image frequency and in the antenna's pattern are remote. Since we are dispensing with image filtering, the choice of IF is open. Noting that we are receiving a 2400 MHz signal (24×100), if we choose an LO frequency of 2376 MHz (24×99), we have an LO frequency that can be generated from a standard 66 MHz computer clock oscillator module ($24 \times 99 = 36 \times 66$). For compatibility with available PC boards my LO uses a 74AC04 tripler to 198 MHz, an additional tripler to 594 MHz, and a final quadrupler to 2476 MHz. The circuitry will be familiar to users of the KK7B and G4DDK microwave LOs [ATUR], also [Campbell95].

The 24 MHz IF affords no image rejection with any reasonable filter, and so carries the price of a 3dB degradation in the signal-to-noise ratio. How will this work with Phase 3D?

You can approach this in one of two ways. Obtain the information on Phase 3D's orbit and S band transmitter and do formal link budget calculations. Or compare the known performance of OSCAR 13 S band equipment (for example, [Miller92]) and extrapolate to a very simple converter receiving Phase 3D signals. Either way, don't take my word for it. Please try it yourself. Even better: try both ways, and compare the results. Best of all: build it and get on Phase 3D.

Another simple to use device is Motorola's MRFIC2401, a complete low-noise amplifier and down-converter in a single SO-16 package. It requires very few external components to make a 2400 to 144 MHz converter (the recommended IF range is from 100 to 350 MHz) of respectable performance. Having been designed for portable telecommunications equipment, its current requirements are miniscule. The performance is much the same as the MGA-86576/SKY-5G converter, which is to be expected, because the LNA in the MRFIC2401 has similar specifications to the MGA-86576.

The RF portions of both these converters are extremely simple, but their local oscillators are complex. Is there a better way?

Lessons learned

What have I learned? A summary:

It works: Microwave communications provide efficient, reliable, highly predictable communications with modest antenna and power requirements. They will be a delight to use on Phase 3D.

Parts are available: There are many suppliers of generic electronic components, and a handful who sell more interesting RF components. Cherish them! In this age of direct international dialling and credit cards, I define a "local supplier" as one on the same planet as myself. While they are geared toward OEMs, I have often found local industrial distributors to be receptive to friendly, polite requests.

New and neat parts: Commercial interest in wireless communications is growing explosively, and we can benefit from this. Since designers want to be able to make money for their employers as quickly as possible, the new components are easy to use, and are often already matched to 50 ohms. All you have to do is string them together, like the building blocks they are. All semiconductor manufacturers have their datasheets online now, making it easy to obtain information. Do it!

The HUH?! factor: I sometimes feel like I have just arrived from Vega when I try to discuss microwave amateur radio with other hams, whose usual response is blank stares. What is the origin of this disconnect? What can we do about it?

The Narrowband Preoccupation: While we can send and receive SSB and CW on the microwave bands, and these are sometimes the best modes, they are not *always* the best modes in all circumstances. The microwave bands are tens—even hundreds—of megahertz wide, room for all kinds of useful and interesting signals. Some are starting to express concern that the steep learning curve of narrow-band equipment is hampering the growth of microwave amateur radio [Dixon97]. I routinely receive email informing me that WBFM is Just Not Done Anymore. I beg to differ.

Use what you have: I made my first X band frequency measurements with a ruler, a piece of unetched PC board and a multimeter. While this is not the most accurate measurement, it is far better than no measurement at all. I made my first L band power measurements by counting the number of paces until the transmitter would no longer break the squelch on a hand-held scanner. Again, not a perfect measurement. But it's a place to start. Don't be embarrassed. I'm not.

Band occupancy: With commercial interests eyeing our bands, we *must* make use of them to have any justifiable claim.

Just do it! What are you waiting for?

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Production note

I created this paper with Donald Knuth's typesetting system T_EX, running on a 66 MHz 486 PC under the Linux operating system. The fonts are from the ITC Souvenir family.

An EZ-Sat Proposal

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ABSTRACT

This paper outlines plans for an EZ-Sat project. This satellite would provide additional entry-level amateur communications capability, using some of the most commonly-owned HAM equipment. This project benefits the AMSAT community by adding a new satellite that can be operated with modest equipment and from a portable or mobile station. The design, construction, and operation of such a system provides a practical telecommunications curricula supplement to several Undergraduate-level programs. The ultimate project goal is to develop a series of simple, yet effective spacecraft carrying amateur radio communications payloads.

INTRODUCTION

This EZ-Sat project intends to provide a basic orbiting amateur communications capability from a spacecraft built and controlled by Undergraduate students. The educational benefits are that an amateur satellite project with real technical obstacles can provide the students with a practical and interesting application of classroom material. AMSAT benefits by getting a new entry-level satellite with potential to spur new interest in amateur satellite communications.

The authors were first introduced by Dick Knadle K2RIW, following Fred N2XOU's successful bid for a scheduled SAREX contact at Suffolk County Community College, Long Island, New York. An excellent working relationship developed between N2XOU and N2WWD while planning and coordinating this SAREX contact during STS-71, the first docking of the Space Shuttle Atlantis with the Mir Space Station. The smooth execution in which all 20 local students spoke with Atlantis Commander "Hoot" Gibson impressed Suffolk Community College President, John Cooper, enough to offer continued support for incorporating other amateur space communications projects in the school's technical curricula.

Suffolk County Community College now has a permanent satellite communications station and is assembling the equipment necessary to support SEDSAT command and control. The EZ-sat project provides the real technical challenges that match the subject matter covered in the communications technology syllabus.

GOALS

The primary goal is to build and orbit a working amateur communications spacecraft. We believe a new "EZ-Sat" accessible with common and affordable amateur radio equipment would be a welcome addition to the amateur satellite "fleet."

Other important goals include:

- The spacecraft must be simple in design and construction, reproducible by undergraduate students in the community college environment.
- Develop a base of expertise in spacecraft design, analysis, construction, and project coordination and management.
- Develop a satellite Command and Control (C²) infrastructure capable of handling multiple satellites.
- Maximize the applicability of these projects to the telecommunications and other curricula at the college.
- Make the experience rewarding (some students might actually enjoy their lab projects).

CONCEPTUAL DESIGN

We propose a single frequency satellite using a communications payload with a 2 meter FM uplink and a 10 meter SSB downlink. The reasons we chose this frequency arrangement are:

- The popularity of 2 meter FM amateur radio transmitting equipment.

- Availability of 10 meter SSB receiving equipment in general HF transceivers, 10 meter single-band transceivers, and communications receivers.
- Low satellite power drain using SSB transmit.
- Manageable antenna sizes.
- Relatively low Doppler frequency shift simplifies operation.
- Usability by most amateur radio license classes including the US "no-code" Technician license.

We also propose the use of a small, inexpensive microsat spaceframe, using passive thermal and attitude control designs.

This satellite will operate in a Low Earth Orbit (LEO), but will be capable of operating effectively in virtually any orbit. Because of the single frequency operation, the satellite's transmitted energy will be concentrated on a single, communications channel with a relatively strong downlink signal.

The spacecraft's 2 meter FM receiver will be designed to be as sensitive as possible; analysis of the link margin will determine the exact sensitivity goal for the receiver. However, the initial goal is to allow for enough margin for an uplink signal of 5 watts of ERP, assuming a satellite elevation of 30° and a 1000 km orbital altitude. Because of this sensitivity and the popularity of the FM band, the receiver will require sharp filters to reject adjacent signals and will likely use CTCSS tone squelch to reject on-frequency signals not intended for the spacecraft.

TECHNICAL SUPPORT REQUESTED

We are seeking technical support in two basic areas: a basic microsat design and methodization of spacecraft assembly.

A basic microsat design would, at minimum, provide an example that could be adapted as necessary to accommodate our particular spacecraft. This would include any details on the spacecraft's Command and Control (C²) design. Our ultimate hope is that few, if any, modifications would be necessary. Toward this

end, the AMSAT microsat is a most welcome option.

For spacecraft assembly, we are seeking advise on construction methods for both mechanical and electronic assemblies. Some specific areas include the choice and application of thermal coatings and solar arrays as well as the use of epoxies or other stiffeners for electronic assemblies to ensue they survive the launch or other mission-related mechanical stresses.

OTHER REQUESTED SUPPORT

One of the most important considerations is finding a ride to orbit. We are very interested in learning the process by which amateur radio spacecraft get a "free ride" as balast on space launches. Specific individuals to contact and any advise in this area would also be welcome.

Another important area in which we seek AMSAT expertise in securing donations of "scrap" material such as solar cells and storage batteries for the construction of the spacecraft. Again, names of specific individuals to contact would be very helpful.

SUMMARY

The ever more fascinating world of satellites is at or doorstep. We wish to invite it into the guest room for a while in order to experience its many facets much like that of a fine diamond. We seek guidance from the experts and have determined them to be the professionals at AMSAT.

ABOUT THE AUTHORS

Frederick J. Winter, Ph.D., holds a Technician Class license and has enjoyed a career as an Engineering Consultant, a Microwave Communications Engineer, and most recently a Professor of Engineering Science, Electrical Technology, and Telecommunications. Teaching at the undergraduate level at Suffolk Community College and at the graduate level at Polytechnic University (formerly "Brooklyn Poly") provides Mr. Winter with students who are interested in advanced technical projects.

Kenneth J. Ernandes, BS, ME. holds an Extra class license and was formerly a USAF Captain,

an Air Force Flight Instructor, and an F15 Eagle pilot. Achieving Scholarship status, Mr. Ernandes has enjoyed a career as an Engineer and a Satellite specialist who is well known to AMSAT as well as NASA.

An Object Oriented Approach to Automatic Radio Tuning

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Introduction

A major obstacle in operating through satellites, especially polar-orbiting, LEO satellites, is in tuning the earth-station receiver and transmitter. Because of the constantly and often rapidly changing *Doppler-shift*, determining and maintaining the proper frequency relationships can be quite troublesome. Losing contact with a station that has momentarily faded is a common consequence of this and even finding one's own down link signal can sometimes be a challenge. These difficulties often lead to unintended interference.

By automating the radio-tuning task with a computer, operating through satellites can be made dramatically easier. With automatic tuning, the computer predicts the Doppler-shift, calculates the proper frequencies, and sets the radios. It is no longer necessary to hunt for the down link signal or to tune constantly to stay on frequency. The *hands-free* satellite contact can become a reality and the accidental interference to other stations can become a thing of the past.

Modern object technology can help in the development of the software needed to automate this radio tuning. In this paper, the fundamental principles and application of object technology will be illustrated by stepping through the analysis of a basic automatic radio tuning system.

Review of Radio Tuning

If the satellite were not moving, tuning would be straightforward. The operator would first tune the receiver to find a desired station or unused frequency. Then the satellite's transponder translation equation could be used to calculate the required transmitter frequency. For a non-inverting transponder, the equation is:

$$f_{input} = k_{transponder} + f_{output}$$

And for an inverting transponder, the equation is:

$$f_{input} = k_{transponder} - f_{output}$$

Where:

f_{input}	=	frequency at transponder input
f_{output}	=	frequency at transponder output
$k_{transponder}$	=	transponder translation constant

Doppler-Shift

Unfortunately the situation becomes more complicated when the satellite is moving. Due to the relative motion of the satellite, a receiver sees the radio signal at a different frequency than that sent by the transmitter. This occurs on both the up and down radio links.

This difference in frequencies is called the *Doppler shift*. The relationship between the transmitted and received frequencies is given by:

$$f' = f_0 \cdot (1 - v/c)$$

Where:

f_0	=	the originally transmitted frequency
f'	=	the frequency seen at the receiver
v	=	the relative velocity between the transmitter and receiver
c	=	the speed of light

The relative velocity of the satellite is negative as it approaches the earth station so each receiver sees the corresponding transmitter signal at a higher frequency. As the pass progresses, the relative velocity increases and becomes positive so the receivers see the transmitted signals at lower frequencies.

Since the relative velocity of the satellite and hence the Doppler-shift, is not the same for each earth station, the radio tuning must be calculated locally at each station.

Manual Tuning

Ideally, satellite operation should be similar to terrestrial operation in that the stations involved in a contact would pick a transponder frequency pair to use and would keep that pair for the duration of the contact. However, this requires maintaining a constant frequency pair *at the satellite*. At the earth station, we do not know the frequencies at the satellite. What's more, it is not easy for a person to calculate the satellite's velocity or Doppler-shift in real-time, even *with* a calculator! But, without some guidance the operators could easily "walk" the frequency all the way up or down the satellite pass-band causing all sorts of interference as they go.

To reduce this frequency drift, most stations follow the guideline of *tuning only the highest frequency link*. On mode A satellites this means only tuning the *transmitter* whereas, on mode J satellites this means only tuning the *receiver*. Following this guideline helps to *reduce* the frequency drift with a method that is possible for a human operator to manage. It does not, however, eliminate the problem.

Automatic Tuning

While a human operator cannot easily do the needed calculations to maintain the frequency pair at the satellite and compensate both the up and down links in real-time, this task is quite easy for a computer. With computer control, the frequency drift problem can be completely eliminated.

In addition to Doppler shift compensation, the tuning process can be made much easier by automatically calculating and setting the required transmitter frequency based on the receiver frequency. This eliminates the need to find your own down link signal in the pass-band after changing the receive frequency. By completely automating the tuning process, satellite operation can be made almost as easy as terrestrial operation.

A Real-World Scenario

It is most helpful to start by walking through a hypothetical real-world scenario as if the earth station operator had a friend who was willing to take on the radio-tuning task. This

friend has a calculator, knows how to tune the radios, and can determine the relative velocity of the satellite at any time.

First, the operator would tune in a desired station or clear frequency on the receiver. The friend then goes through the following steps:

- Read the receiver dial to determine the receive frequency
- Using the relative velocity of the satellite, calculate the Doppler shift on the down link
- Using the Doppler shift, calculate the frequency of the signal at the output of the satellite transponder
- Using the translation equation, calculate the frequency seen at the input to the satellite transponder
- Record the transponder input and output frequency pair
- Using the relative velocity of the satellite, calculate the Doppler shift on the up link
- Using the Doppler shift, calculate the required transmitter frequency
- Set the transmitter tuning dial to this frequency

The operator is now ready to transmit. The transmitter has been set to the required frequency so there is no need to find the down link signal. Since no signals have been sent, there has been no opportunity to cause interference.

Once the transponder frequency pair has been established, the friend needs to keep the earth station radios on-frequency. Every second or so, the friend looks to see if the operator has re-tuned the receiver. If so, the previous steps are repeated to re-tune the transmitter. If not, the friend goes through the following steps to maintain the transponder frequency pair:

- Using the new relative velocity of the satellite, calculate the new Doppler shift on the down link
- Starting with the recorded transponder output frequency, use the Doppler shift to determine the required receiver frequency
- Set the receiver to this new frequency
- Using the relative velocity of the satellite, calculate the new Doppler shift on the uplink.

- Starting with the recorded transponder input frequency, use the Doppler shift to determine the required transmitter frequency
- Set the transmitter to this frequency

If the operator had a friend who was willing and able to do these steps quickly and unobtrusively, they would be all set! Fortunately, with some software, a computer can become this friend.

The Object-Oriented Approach

With traditional software development techniques, the programmer is tasked with trying to understand the problem using the language of the real world and converting this into the language of the computer. As these languages are dramatically different, bridging this gap is difficult and error-prone.

An *object-oriented* approach starts with an analysis of the real world problem using the language of the real world and uses step-by-step refinement to arrive at an implementation. This approach is substantially easier and more robust because the programmer can think in terms of real-world concepts rather than trying to think like a computer.

The key element in this new approach is the *object*. An object is a simplified representation of a real-world thing or concept. It is simplified in that any characteristics that are not important to the real world problem are simply ignored.

An object's characteristics are captured by identifying its *operations* and *attributes*. Operations are the things that can be *done to* an object. For example, if an object represents a radio receiver, its operations might include setting its VFO frequency, selecting an IF filter, or checking its S-meter reading. Attributes are the things that an object *remembers* or more formally, its *internal state* information. Again using the radio receiver example, its attributes might include the currently selected band, the currently selected mode, or the current VFO frequency.

Object-Oriented Analysis

In object-oriented analysis, objects are used to build models of the desired real-world system. These models address the behavior and structure of the system. The purpose of this analysis is to create a clear and concise specification for the system. Therefore, design and implementation details can and should be ignored. The focus is on "What do we want to accomplish?" rather than "How will we accomplish it?"

While the complete analysis process is generally messy, intuitive, and iterative, a good place to start is by examining the real world to identify the objects. From the previous real-world scenario walk-through, the things that are important to the radio tuning system are the radios, the frequencies and relationships of the satellite radio links, and the hypothetical but very helpful friend. These things shall be modeled with objects.

Object Behavior Analysis

Behavior analysis is primarily concerned with what the objects *do* and how they *interact*. In this respect, behavior analysis provides a model of the *dynamic* aspects of a system.

An easy starting point is to define an object that models the radio transmitter. An appropriate name for this object is "Transmitter." This object shall be responsible for tracking the tuning of the real radio transmitter. Looking back to the real-world scenario, the thing that can be *done to* a radio transmitter is to *set* the transmit frequency. The important internal state information that the transmitter *remembers* is the actual transmit frequency. These are the only characteristics that are important to the radio tuning system so the Transmitter object is defined as follows:

```
Name:
    Transmitter
Responsibilities:
    Tracks the tuning of the real
    radio transmitter
Attributes:
    TransmitFrequency
Operations:
    SetTransmitFrequency()
```


The Transmitter object was not difficult to define and the "Receiver" object is also fairly easy. The Receiver object will be responsible for tracking the tuning of the real radio receiver. The things that can be *done* to the real-world receiver are to *set* and to *get* the receive frequency and the receiver *remembers* this frequency.

Additionally, the human operator can manually change the tuning of the receiver so a method for determining if this has occurred is needed. It is convenient to make the Receiver object responsible for detecting and remembering this event. The definition of the Receiver object is then:

Name:
Receiver
Responsibilities:
Tracks the tuning of the real radio receiver
Attributes:
ReceiveFrequency
ManualTuneIndicator
Operations:
GetReceiveFrequency()
SetReceiveFrequency()
HasUserTuned()

Now that the easy parts have been tackled, it is time for a more difficult one. The most complicated part of this system is modeling the frequency relationships of the radio links.

It helps to recall that this problem was actually quite simple if the satellite was not moving; the transponder translation equation provides the relationship.

One can think of the satellite as a vehicle for carrying the transponder. Due to the satellites' motion, it acts like a "Doppler-shifter" on the transponder frequencies. This point of view provides valuable insight. To model this, two objects will be used; a "Transponder" object to track the frequencies at the real transponder and a "Satellite" object to provide the Doppler shift.

The definition of the Transponder object is straightforward. Since it is responsible for tracking the frequencies at the real transponder, it must have operations to *get* the current input

and output frequencies and it must remember the input-output frequency pair. Since tuning the earth station receiver on the output side of the transponder dictates the operating frequency; an operation is needed to *set* the frequency on the transponder *output*. The Transponder object is then defined as follows:

Name:
Transponder
Responsibilities:
Tracks the currently used frequency pair at the real transponder
Attributes:
InputFrequency
OutputFrequency
Operations:
GetInputFrequency()
GetOutputFrequency()
SetOutputFrequency()

Now it is easy to define the Satellite object. From the previous discussion, the Satellite uses its Transponder object to get the basic frequency pair and then applies the Doppler shift to this pair. To calculate the Doppler-shift, the Satellite object needs the velocity of the real satellite so it also needs an operation to *set* it.

The Satellite must also have operations to *get* the up and down link frequencies. Since the human operator *sets* the down link frequency by tuning the receiver, the Satellite object needs an operation to *set* the down link frequency as well. The Satellite object is then defined as follows:

Name:
Satellite
Responsibilities:
Tracks the up and down link frequencies of the real satellite as seen by the earth station.
Attributes:
Velocity
Operations:
SetVelocity()
GetUplink()
GetDownlink()
SetDownlink()

Finally an object is needed that models the behavior of the very helpful friend. Since this object will be controlling the interactions of

the other objects, it will be called the "Controller." The Controller adjusts the frequencies of the radios to track the ever changing up and down link frequencies of the satellite. It gets the frequencies by invoking the GetDownlink and GetUplink operations on the Satellite object.

The Controller needs to be triggered by an external event. This event will be a once-per-second message that provides the new satellite velocity. There are a variety of ways to provide this message and it will be assumed to come from an external source. (The OrbitDRV TSR supplied with AMSAT's InstantTrack software can provide this function for example.) The Controller is defined as follows:

Name:
Controller
Responsibilities:
Controls the radio tuning
Attributes:
Operations:
UpdateVelocity()

Using the objects that have now been defined, a model of the dynamic behavior of the system can be created. This is represented with a *Collaboration Diagram* as shown in Figure 1.

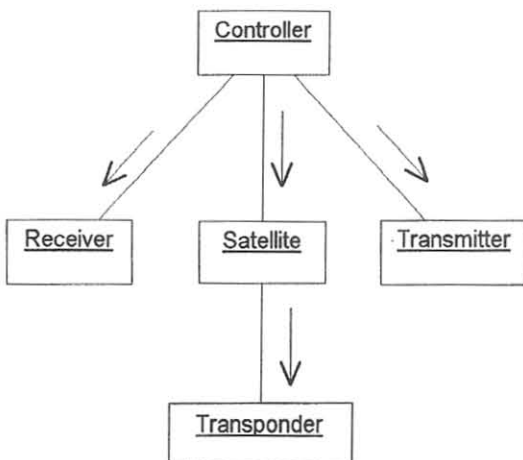


Figure 1. Collaboration Diagram

The diagram shows the objects and the links between them. Objects interact via these

links. The arrows show the direction of the links and this diagram shows that the Controller invokes operations on the Transmitter, Receiver, and the Satellite. Also, the Satellite invokes operations on the Transponder. There are no other interactions between the objects.

Once a second, the Controller goes through the following set of actions to set and maintain the proper radio tuning:

1. Update the Satellite velocity. This causes the up and down link frequencies to change due to the new Doppler-shift.
2. Check the Receiver to see if the user has manually changed the receiver tuning. If user *has* changed tuning:
 - Set a new down link frequency at the Satellite to be the Receiver frequency. This in turn sets a new transponder frequency pair based on the Doppler-shifted receiver frequency.
 - Otherwise:
 - Adjust the Receiver frequency to match the new Satellite down link frequency. This compensates for the new Doppler-shift to maintain the existing transponder frequency pair.
3. Adjust the Transmitter to the corresponding up link frequency.

This completes the basic dynamic behavior analysis of the system.

Object Types and Relationships

The structure or *static* aspects of the system are modeled by identifying the *types* of objects and their relationships. Objects that *behave the same* are considered to be the same *type*. For example, all inverting transponders behave the same in terms of the specific way the input and output frequencies are related (i.e. the translation equation) but non-inverting transponders behave differently. Therefore, inverting transponders are of one type and non-inverting transponders are of another type.

In the real world it is often useful to ignore these differences and instead refer to transponders as a general type of device. When someone uses this generalization they are

referring to the aspect of all transponders that is common, namely the translation of input to output frequencies. Humans intuitively understand that an inverting transponder is just a specific type of transponder.

The ability to capture this *generalized-specialized* relationship is one of the most powerful concepts in object technology. In object parlance this is called the *inheritance* relationship. The inheritance relationship provides a systematic way to address the common parts of related but different types of objects.

Another important relationship between objects is called *aggregation*. An aggregate object is one that is made from one or more other objects. In the real world, a satellite *has* a transponder. This property is modeled by making the Satellite object *have* a Transponder object. The Satellite object is then an example of an aggregate object.

A third relationship is the *using* relationship. When one object invokes operations on another object it is *using* that object. For example, in the behavior analysis section, our Controller object *uses* a Satellite object to get the up and down link frequencies.

While other types of relationships are possible, the *inheritance*, *aggregation*, and *using* relationships will be the only ones needed for the analysis of the structure of the radio tuning system.

Object Structure Analysis

In behavior analysis, the real world radios were modeled using generic Receiver and Transmitter objects. This allowed us to specify the behavior of the radio objects as well as the Controller without regard to the specific type of radios. When one actually uses this system however, they will want to control *real* radios that are going to be of some specific type, such as ICOM R7000 or Kenwood TS-690. These real radios require different system behavior to control them. How then can a system be defined and built using a general radio type yet still allow it to behave differently as needed for each specific type of radio?

The *inheritance* relationship provides the solution to this problem. What is needed is a general radio type that captures the common characteristics of all types of radios. The specific radio types will *inherit* these common characteristics yet behave as needed to control specific radios. This general type is called a "super-type." The Controller object will interact with all specific radio types using only the common part defined in the super-type.

Since real radios may include a receiver, a transmitter, or quite commonly both. The super-type, which will be called "RADIO," must include all the operations and attributes required to support this. The Controller must also be able to interact with the radio objects when the Transmitter and Receiver are in the same box as well as when they are distinct. The RADIO super-type is then defined as follows:

Type Name:
RADIO
Responsibilities:
Tracks the tuning of a radio
Attributes:
ReceiveFrequency
ManualTuneIndicator
TransmitFrequency
Operations:
GetReceiveFrequency()
SetReceiveFrequency()
HasUserTuned()
SetTransmitFrequency()

All of the specific radio types in the system will inherit the characteristics of this general type. Specifically, this means that all radio objects in the system will have common operations and attributes regardless of the specific type of real-world radio. The Controller object can treat all radios the same and so it does not need to know anything about the specific type of radio currently in use. The specific radio types differ only in how the operations are *implemented*.

This implies (correctly) that we can use any type of real-world radio in this system by just providing a proper type for it. *Subject, of course, to the limitation that there has to be a way to control it from a computer!*

Assuming that one would like to be able to control at least ICOM, Kenwood, Yaesu, and "Mic-button" radios; Object types need to be provided for these radios. The structure of the object types and relationships is represented through a *Class Diagram*. The basic Class Diagram for the radio object types is shown in Figure 2 below.

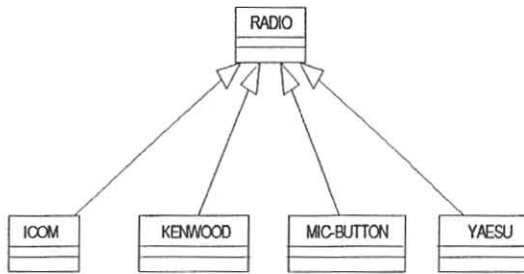


Figure 2. Class Diagram of RADIO types. The arrows indicate inheritance and point towards the parent or more general type.

Like the radios, general types of Satellite and Transponder objects were used in the behavior analysis. But in the real world, an operator will use a specific satellite with a specific type of transponder. Since the Doppler-shift is only dependent on velocity, from the standpoint of radio tuning, the difference between satellites is *only* in the transponder. Thus, there is no need to have more than one type of Satellite object but there is a need for different types of Transponder objects.

The Satellite object needs to invoke operations on *its* Transponder but since all Satellite objects are the same type we would like to make the Satellite type independent of the specific Transponder type.

Here again, *inheritance* provides the solution. Creating a super-type called TRANSPONDER that provides a definition of the operations and attributes common to all types of transponders solves this problem. The real transponders commonly used include inverting, non-inverting, and fixed frequency (i.e. "digital" and "FM repeater") types. These specific transponder types inherit the characteristics of the super-type. The TRANSPONDER type is defined as follows:

Type Name:
TRANSPONDER

Responsibilities:
Tracks the currently used frequency pair at the real transponder

Attributes:
InputFrequency
OutputFrequency

Operations:
GetInputFrequency()
GetOutputFrequency()
SetOutputFrequency()

The Class Diagram illustrating the SATELLITE and TRANSPONDER types is shown in Figure 3. In this figure, SATELLITE objects have a TRANSPONDER, whose actual type is FIXED, INVERTING, or NON-INVERTING.

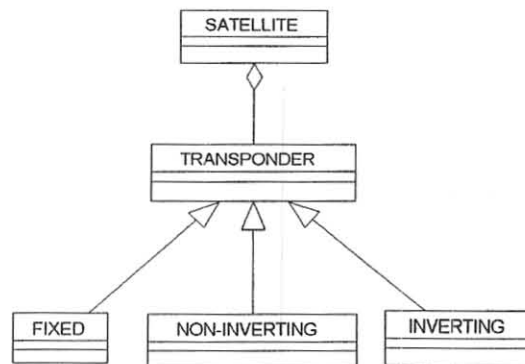


Figure 3. Class Diagram showing SATELLITE and TRANSPONDER types. The arrows indicate inheritance and point towards the parent or more general type. The diamond indicates the "has-a" relationship.

This completes the basic static analysis of the automatic radio tuning system.

The Models

The complete static and dynamic models are provided in Figures 4 and 5. A *Class Diagram* is used to show the static model. A *Collaboration Diagram* is used to show the dynamic model. The static and dynamic models are not independent but complement each other to provide a complete view of the system.

Automatic Radio Tuning System

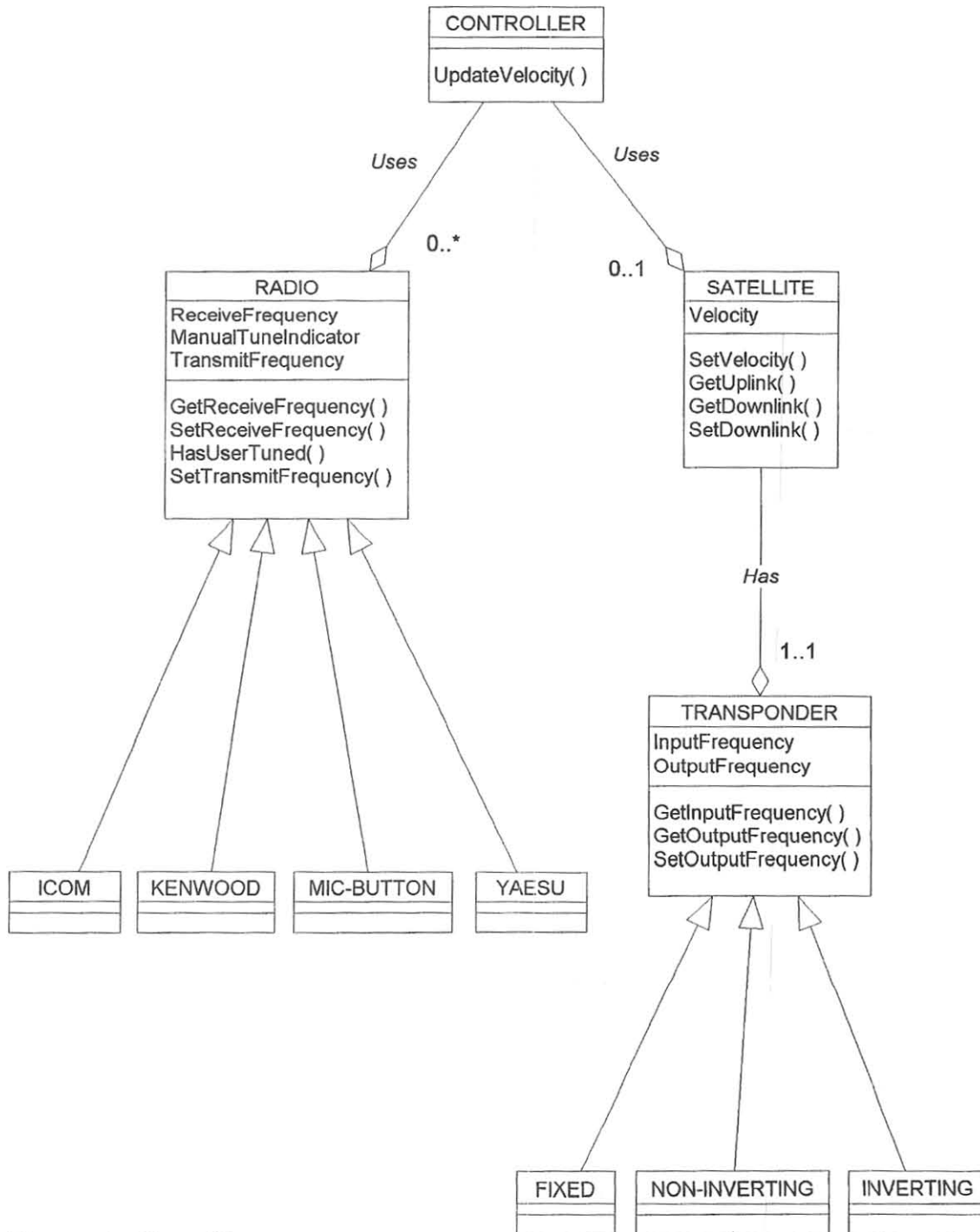


Figure 4. Class Diagram.

Automatic Radio Tuning System

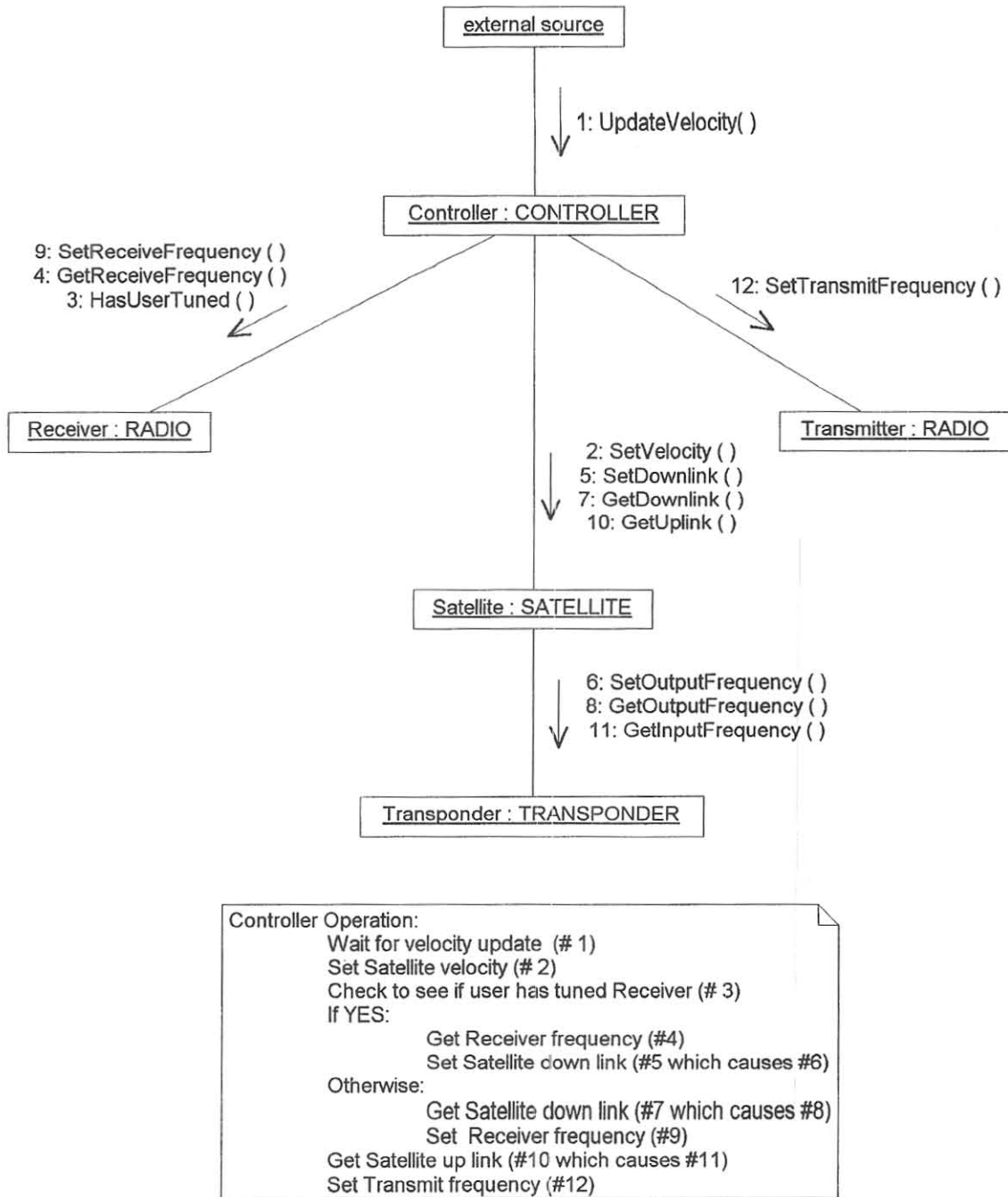


Figure 5. Collaboration Diagram.

Conclusion

The diagrams in Figures 4 and 5 follow the *Unified Modeling Language (UML)* guidelines. UML is a proposed industry standard and is available for free on the World-Wide-Web. Please see the references. UML provides guidance on the types of diagrams and their presentation. Many types of diagrams are available beyond those used in this paper.

This paper presented an object-oriented analysis of a basic automatic radio tuning system including frequency tracking and Doppler-shift compensation of the radio links.

In addition to the basic tuning and Doppler-shift compensation, a number of other features would contribute considerably to ease of use and operator convenience. Some examples of these include:

- Automatic setting of receiver frequency and mode (CW, USB, LSB, FM, etc.) to satellite beacon.
- Automatic setting and tracking of transmitter mode.
- Support for up and down frequency converters
- Support for satellites with multiple transponders like RS-12 mode K/T.

Enhancing the diagrams to incorporate these and other advanced features is relatively straightforward. The same approach would be used of starting with the real-world scenarios and using objects to model the desired behavior and structure. This approach is what distinguishes object technology from more traditional software development techniques.

While the software industry has widely adopted object-oriented approaches for developing graphical user interfaces, many complex real-time applications, such as automatic radio tuning, are also candidates to benefit from this technology.

Acknowledgements

The author would like to thank Ann Hagerman and Mary Lou Monteiro for their help in reviewing this article.

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A Simple BPSK Software Modem
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Abstract

At times, DSP modems have been discouraging to beginners because of the initial expense and the required hardware. This software approach allows amateurs to use their existing computers and a sound card to emulate a BPSK modem and a TNC. This paper is intended for the amateur radio operator with an interest in digital communications.

Keywords

BPSK, digital signal processing, DPSK, DSP, modem, PSK, software, sound card.

Background

In November of 1996 in Tucson, Arizona, I attended the Amsat Symposium and listened to a lecture by Phil Karn, KA9Q, on a software based modem which used a sound card. (Karn, 1996). Inspired by hearing about his staggered quadrature phase shift keying (SQPSK) software, I began to write my own version of a regular phase shift keying (PSK) modem. This paper discusses the modulator and demodulator and some of my ongoing efforts towards a more fully functioning PSK sound card modem.

Why use a sound card based software modem?

As others have already noted, sound cards are inexpensive, versatile, and widely available. (Karn, 1996) Besides amateur radio, DSP modems have many other uses such as games and voice communications over the Internet. It's nice to know that if it were necessary to actually go out and buy a new sound card, the owner would not have a useless piece of hardware if their interests changed.

Most recent computers (486 or better) are probably fast enough to be used with a sound card to emulate a modem, especially at slow speeds such as 400 and 1200 baud. DSP modems only require a software upgrade, which is usually easier than a hardware upgrade. When someone develops a new modulation or coding scheme, the DSP modem user just needs to run a different program. A DSP based sound card modem/TNC does not necessarily have to occupy a communications port like a regular TNC, which could free it up for some other uses such as GPS. Using an internal sound card eliminates another power supply, a power cable, and a few connecting cables. In addition, a sound card DSP modem allows anyone with the inclination to get a taste of satellite communications by having them receive real satellite signals without the usual large financial investment in hardware exclusively used with satellites. (In all honesty, how often are amateur terrestrial contacts made by using Manchester coded BPSK?)

And now the bad news, perhaps...

Performing the digital signal processing on the main computer's CPU requires a recent fast processor such as a fast 486 or a Pentium. The sound cards in a typical computer were not designed for digital signal processing: they are not ideal analog to digital converters; their internal clocks can drift; their sampling rate is limited to about forty-four thousand samples per second, and there exists a wide variety of similar, but very different, standard sound cards. Their use as modems is not widely known nor accepted in the amateur community. Finally, the computer's operating system can introduce a delay between the time the samples are taken and the time they are made available to the modem software. This delay can cause problems for communications protocols with strict timing requirements (Sailer, 1996).

Why a 1200 BPS BPSK software modem?

There are several functioning satellites already in orbit which exclusively use 1200 baud BPSK. Why not use the existing hardware in orbit to its fullest potential, not only in terms of the hardware's usage, but also by having it used by as many amateurs as possible? At 1200 baud, the data rate is slow enough that the sound card and computer can emulate a hardware PSK modem and a TNC without too much trouble, and yet it's fast enough to exchange information at a tolerable pace. In addition, a BPSK signal can be easily demodulated in software without a lot of complicated math or digital signal processing algorithms. Lastly, a BPSK modulated signal is very easy to synthesize.

Part of my motivation for this project was that I couldn't find any existing software that already did BPSK on a sound card. Other groups and persons have done work on many other modulation methods (including WEFAX, RTTY, slow scan television, and regular packet radio), but apparently no one, to my knowledge, has done 1200 baud PSK.

About my BPSK software modem

My BPSK modem is made from a sound card, a modulator program, a demodulator program, and some supporting programs. My computer programs were written using Borland's Delphi programming language and run under Windows 95. The computer's sound card is used only to perform the analog-to-digital and digital-to-analog conversions while all of the signal processing is handled by the computer's CPU. The incoming audio is sampled by the sound card several thousand times per second at eight bits of resolution per sample. The samples are passed to my demodulator program using the Windows 95 WaveIn set of API calls. Using these API calls insulate the programs from the low level details of the communicating with the sound card hardware, but it also can introduce a delay between the time when the samples are taken and when the modem actually receives them. This is only a problem when the protocol demands some action within a limited amount of time from some other event and the software is unable to receive the samples and perform all of the necessary work to transmit the reply within that time limit. As Karn has already pointed out, the simple solution to this problem is to relax the protocol so that more time is available.

The Demodulator

The samples from the sound card are passed to my demodulator which uses a differential phase shift keying (DPSK) algorithm. The name sounds complicated, but all it really does is compare each of the samples of the current bit to the samples from the previous bit. To understand how this works, it helps to know a little information about the BPSK signal itself. BPSK modulation uses two different signals to convey information. These two signals are one hundred eighty degrees out of phase with each other and are as different from each other as possible. Regular BPSK uses the first signal to send a binary one and the second signal to send a binary zero. However, the actual BPSK signals used in amateur packet radio are also differentially encoded, using a method known as Non-Return to Zero Inverted (NRZI). In NRZI encoding, the first signal is sent when the current data bit is the same as the previous data bit and the second signal is sent when the current data bit is different from the previous data bit. All of the information in the signal is contained in the transitions between the two signals.

This actually makes the job of the demodulator easier because it doesn't need to compute the actual phases of the signal or try to determine which of the two signals is being sent. It only needs to determine if the signal during the current bit is the same as or different than the signal of the previous bit. Therefore, if all of the samples taken during the current bit are the same as (or very similar to) samples from the previous bit, then the current bit is a one bit. Otherwise, if the samples are all different, then the current bit is a zero bit. When there is noise present, the demodulator examines all samples during the current bit period and decides whether the bit is a one or a zero by counting whether there are more samples the

same or more samples different. I use a couple of simple criteria for what constitutes "similar" and "different," including one method which just checks whether both samples have the same sign (both positive or both negative) and another method which computes the slope of a line from sample number n to sample number $(n-1)$ and then compares it to the slope of a line from the two samples exactly one bit prior.

One advantage of DPSK demodulation is that it does not require a locally generated carrier. The actual phase of the incoming signal is never computed. The samples are merely compared to the samples of the signal from one bit period ago. Another advantage is that it can directly decode AX.25 data bits. This avoids the need to demodulate the signals to some intermediate bits and then decode those bits to the data bits. However, in order for DPSK to work properly, the audio signal needs to be tuned so that an integer number of cycles occur during each bit period. This means that a 1200 baud signal has to be tuned to 1200 hertz for my demodulator instead of the more common 1600 hertz used by other PSK modem designs.

According to communications theory, DPSK has a slight performance disadvantage over other methods of demodulating PSK. Also, if noise corrupts one bit of the received signal, the demodulator will decode two bits incorrectly: the corrupted bit, and the bit when the corrupted bit was used as a reference. For AX.25 this isn't as bad it seems because it doesn't matter how many bits are received in error. If any of the bits are wrong, even just one, the entire packet is discarded.

Bits and Bytes

Since an AX.25 packet could begin with more than one flag byte, the demodulator scans the digital samples for a flag byte followed by a non-flag byte. When this is found, it tries to demodulate the rest of the AX.25 packet, assembling the bytes one bit at a time and performing the necessary zero bit unstuffing and CRC calculations along the way. When it sees the flag at the end of the packet, it knows that it's done and that the previous two bytes were the CRC. It checks to see if the CRC is valid. If the CRC isn't valid, the demodulator discards the packet. If the CRC is valid, then the packet was received correctly and is passed on to the next higher level program. The modem doesn't understand high level protocols and doesn't even care who the packet is from, who it's for, where it has been, or what it contains. It only checks that the packet is valid. This leaves the job of actually interpreting and handling the packet for the higher application level program (APRS developers take note!).

Tuning the receiver

The receiver tuning is somewhat critical in the current modem; however, I hope to make the tuning requirements less demanding in a future version. In one version of the modem, I use a tuning method based on a technique used in a hardware PSK modem (Magliacane, 1994). By full-wave rectifying the received BPSK signal, the PSK modulation can be removed and a pure carrier signal can be obtained at twice the frequency of the original signal. My modem computes the received frequency on each buffer of digital samples by taking the absolute value of a couple hundred of the samples and running a Fourier transform. The process of taking the absolute value doubles the frequency but removes the PSK modulation, which simplifies the task of the Fourier transform. No fancy windowing algorithms are used in the transform and in the interest of simplicity, the earliest versions of the modem used the slower Discrete Fourier Transform (DFT) rather than the more efficient Fast Fourier Transform (FFT). In either case, the frequency bin from the transform with largest amplitude corresponds to a frequency which is twice the actual received frequency. This information is used to update a frequency display for the user similar to a TAPR PSK modem tuning display. The display can also be used by the user to manually tune the received signal. By carefully choosing the number of samples to process in the Fourier transform, one can achieve any arbitrary frequency resolution for the display, but this needs to be balanced by the increase in CPU cycles required for finer resolution. In an early version of my modem, I used four hundred forty-one samples with a DFT to achieve a tuning resolution of about fifty hertz.

If the received signal is too high, the modem can attempt to correct the receiver. My software starts a timer, raises the DTR signal on the computer's communication port and then lowers it when the timer has elapsed. The DTR pin is assumed to be connected to the radio's microphone down button, possibly through a simple circuit. I arbitrarily picked the DTR pin because it was easy to control using software, but if the communications port needed to be used for something else, like a GPS receiver or another TNC, the modem software could be easily changed so that it would raise and lower a pin on the parallel port. This method of AFC can result in overcorrection if the digital audio samples taken after the receiver correction are not seen by the modem quickly enough.

The modulator

My modulator program is able to generate a BPSK signal at either 1200 hertz or 1600 hertz, which is the nominal frequency used by other PSK modems. I was able to simplify this task by generating the audio at 9600 samples per second since 9600 is evenly divisible by both 1600 and 1200. The modulator program starts by building a small table in memory containing the digital samples to represent a sine wave at the desired frequency. Then, it takes the actual data to be transmitted, computes the CRC and adds flags before actual data and after the CRC. These raw bytes are fed to a routine which examines them one bit at a time and concatenates copies of the sine wave table to the audio output buffer. If the raw data bit is a one bit, it just copies the sine wave table as is into the buffer. If the raw data bit is a zero bit, it takes samples from the table but adjusts the samples to be 180 degrees out of phase before copying them to the audio buffer. It also performs the necessary zero bit stuffing after five consecutive one bits. After the last flag byte is processed, the audio buffer is fed to the sound card which generates the audio signal to be fed to the transmitter. The modulator could also raise a pin on a communications or parallel port to signal the PTT line on the transmitter.

Testing the modem

Testing was done with a standard TAPR PSK modem, an MFJ-1274 TNC, and a digital recording of a satellite pass. The modulator was tested by taking audio from the sound card jack and feeding it to audio input of the TAPR TNC with a regular 3.5 mm audio cable. The same computer was used to generate the PSK signals while simultaneously running a terminal program to communicate with the TNC. When the sound card generated a signal, the TNC demodulated it to digital data and passed it to the terminal program over the serial port. The demodulator was tested using a digital recording of an actual satellite pass as well as data generated by the modulator program. In addition, a separate program was used for testing which displayed the digital signal samples graphically with superimposed representations of the compared bit samples and demodulated data bits.

A software modem and WiSP

One use for this modem is the current fleet of digital microsats. Since many amateurs use WiSP (Jackson, 1997) to communicate with the satellites through a hardware PSK modem, it seemed natural to try and get this modem to work together with WiSP. At the time of this writing, I have nearly completed a complete set of software routines to allow the PSK modem to exchange information with WiSP. I hope to be able to demonstrate this in Toronto.

Some thoughts about APRS

Bob Bruninga, WB4APR, has proposed that mobile satellite stations could use the PACSATs to digipeat position reports (Bruninga, 1997). A simple sound card modem could generate the Manchester signal and feed it to the radio's microphone jack. Even though the parts used to modify a TNC for Manchester modulation are inexpensive, most of the amateurs I know are reluctant to take a soldering iron to the circuit board of their TNC. A sound card based modem doesn't require any hardware modifications. Using a laptop computer with an internal

sound card and a transmitter, an amateur could send his position through the satellite and be placed onto everyone's APRS map. He could easily add a GPS receiver to the computer's communications port and operate as a mobile APRS station. Since the sound card modem could use the parallel port for external signaling, this is an alternate solution for computers with only one communication port. Also, this modem could be used by APRS stations to receive the signals digipeated by the satellites instead of relying on a local satellite ground station with a PSK modem to relay the information onto the local network. Finally, since this modem does not perform digipeating but does forward all received signals to the application program, it provides a level of flexibility to an application level program which is not found in some TNCs.

A proposal for a Beginner's Day on amateur satellites

This modem is also an effort to encourage newcomers into the amateur radio satellite community. I believe that you need to spark the interest of the beginners with some kind of a gimmick: a strong downlink with voices from far away, or something that they can experience firsthand without a high technical or financial barrier. Many amateurs have become interested in satellites only after they have tried it for themselves. In the past, AMSAT used to reserve one day per week for experimenters. Why don't we pick a day and designate it as Beginner's Day to encourage the beginners? The common belief among many amateurs is that this satellite "stuff" is just too hard and too expensive. This modem is part of my attempt to provide a simple, inexpensive path for beginners to get started with amateur radio satellites.

That's not all folks!

With a few timing changes, a 1200 baud PSK modem could become a 400 baud PSK modem for monitoring a telemetry downlink. With a rewrite of the code to use FSK instead of PSK, a sound card modem could be used to receive UO-11 1200 baud FSK transmissions. A 4800 baud sound card modem, and enough users, might provide the incentive to activate some unused 4800 baud modems that already in orbit on amateur satellites.

I would like to thank Phil Karn and Thomas Sailer for their work with PC sound cards as DSP modems, and I would really like to thank my wife for her support and encouragement during this project.

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Developing Portable Satellite Software Using Java TM

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Introduction

Do you have a spare Sun Sparc Station sitting at home that you would like to use for your satellite ground station, but just can't seem to get WiSP to work on it?

This paper outlines the ongoing development of the software for a satellite ground station written in Java that will run on any platform that supports the Java Virtual Machine and the Java Native Method Interface.

Java - not just for the Internet

Most people have heard of Java because of its use on the Internet, where it is used to write applets that run in a Web Browser. In many cases, it is used to develop applets that perform some sort of animation to make Web pages look more interesting.

But, Java can also be used as a normal programming language just like C and C++. In fact, the Java language is based on C++ with a lot of the nasties removed and some nice features added.

Because Java programs are compiled into a standard byte-code that is interpreted, rather than being compiled to the native machine instruction set. There is no need to recompile a Java application to run on a different platform that has had the Java Virtual Machine ported to it.

if you have developed software using C and/or C++ the move to Java is fairly easy.

Java Origins

Java has been developed by Sun Microsystems Inc. who make freely available development kits, including compiler, debugger, and the runtime interpreter for the development of both applications and applets on the Solaris operating system (both Sparc and Intel) and for Windows '95/NT.

These can be downloaded from their Web site at <http://java.sun.com>.

Several other companies are making ports of the development kit to run on their platforms. Links to these can also be found on Sun's Web site.

There is even a port to Linux available.

Classes, classes and more classes

No, this is not going to be a tutorial in Object Oriented Programming, but a simple introduction may help!

Object Oriented Programming is an approach to designing and implementing software systems by identifying real world objects and defining a set of operations that can be performed on them.

A class is the definition of the state information (data) and the operations (methods) that can be performed to transform the state information.

Programs are made up of several classes.

An object is an **instance** of a class that has had the memory allocated for the state information

and a special method known as the **constructor** has been performed to do any initialisation.

As we progress you will see how this is used in the design of the software.

Native Methods

The current version of the Java Development Kit (1.1.3 as of writing this) does not provide support for communicating with a serial or parallel port directly.

However, it does provide a platform independent way for a Java application to make a call on some native compiled C/C++ code.

On a UNIX system this code is compiled into a shared library and on a Windows '95/NT system it is compiled into a Dynamic Link Library.

To provide support for communicating with a TNC, radios and tracking controllers, two native modules have been developed. One provides the interface to Open, Close, Configure, Read and Write to a serial port, and the other provides similar functions on a parallel port.

In Java the code that interfaces to these native code modules are implemented as the classes Serial and Parallel. As an example, the Serial class source code is shown in Figure 1.

Implementing the TNC interface

The Pacsat satellite protocols uses both connected and unconnected AX.25 protocols to communicate with the satellite. The connected protocol is only used for uploading messages to the satellite. All other communication is performed using unconnected protocols.

To support concurrent uploads and downloads, the TNC must be run in the Kiss mode, with the computer software implementing the connected and unconnected protocols.

In this mode, the TNC is simply acting as a way to receive and transmit packets, but does no processing of the packets.

```
package n6lyt.serial;

public class Serial {

    private int filedes;

    public Serial(int port) throws SerialException {
        filedes = libOpen(port);
    }

    public synchronized void init(int speed,int parity,int width,int stopBits)
        throws SerialException {
        libini(filedes,speed,parity,width,stopBits);
    }

    public void send(byte b) throws SerialException {
        libSend(filedes,b);
    }

    public synchronized byte receive() throws SerialException {
        return libReceive(filedes);
    }

    public void close() throws SerialException {
        libClose(filedes);
    }

    static {
        System.loadLibrary("SerialImp");
    }

    private native int libOpen(int port) throws SerialException;
    private native void libClose(int filedes) throws SerialException;
    private native void libini(int filedes,int speed,int parity,int width,int stopBits)
        throws SerialException;
    private native void libSend(int filedes,byte b) throws SerialException;
    private native byte libReceive(int filedes) throws SerialException;
}

```

Figure 1

KISS

The Kiss protocol defines a simple way of framing packets to be transferred across a serial interface between a TNC and a computer.

The protocol defines special characters to mark the start and end of a frame, and also defines how to handle those special characters when they are found as data within the frame.

A Kiss class has been developed that interfaces to a serial port using the Serial class and provides a method for sending a packet of data which encodes the packet according to the Kiss protocol and send it to the serial port (Figure 2).

Receiving frames is managed in a different way as the application software does not know when a frame will be received, but would rather be

told that a frame is available so that they can look at it to decide if they need to process it.

When a Kiss object is created, a background thread is started that loops getting characters from the serial port and decoding the Kiss protocol. There is a fairly simple state machine that handles detecting the start and end of frames and handling any embedded framing characters.

```
public synchronized void send(byte buffer[]) {
    try {
        s.send(END);
        s.send(DATA_FRAME);
        for(int i=0; i<buffer.length; i++) {
            switch(buffer[i]) {
                case END:
                    s.send(ESC);
                    s.send(ESC_END);
                    break;
                case ESC:
                    s.send(ESC);
                    s.send(ESC_ESC);
                    break;
                default:
                    s.send(buffer[i]);
                    break;
            }
        }
        s.send(END);
    } catch (SerialException e) {
        System.out.println(e.getMessage());
    }
}
```

Figure 2

A method (**addKissListener**) is provided for any interested party to register its interest in being notified when a frame has been received.

When a frame is received they are notified by invoking a method called **kissBufferReceived** with a **KissEvent** object passed as a parameter that contains a reference to the frame as an array of bytes (figure 3).

```
package n6lyt.kiss;
import java.util.EventListener;
public interface KissListener extends EventListener {
    void kissBufferReceived(KissEvent e);
}
```

Figure 3

AX.25

The AX.25 protocols define the structure of a packet as a byte stream and the interaction between two stations for connected sessions.

To manage the encoding and decoding of an AX.25 packet a class called **AX25Packet** has been developed that is used to construct an AX.25 packet from its constituent components for transmitting, or to decode an AX.25 packet into its constituent components from an encoded byte array. There are also a number of methods to get and set the component values.

When sending an AX.25 frame, the packet is created by supplying the source address, destination address, packet type, protocol id and possibly some data. There is also a method supplied that will return the encoded packet as a byte array ready for transmitting (using the Kiss.send method).

Another class, **AX25**, manages the sending and receiving of AX25Packet objects. A send method is provided for transmitting a packet which simply calls the AX25Packet method to return an encode byte array which is then used as a parameter to the Kiss send method (Figure 4).

```
public synchronized void send(AX25Packet packet) throws AX25Exception {
    k.send(packet.getKissData());
}
```

Figure 4

In a similar manner to the Kiss class, a method is provided that allows interested parties to be notified when a valid AX.25 frame has been received.

When an instance of AX25 is instantiated, it registers its interest in being notified that a Kiss packet has been received. When it is notified, it constructs an AX25Packet object from the Kiss byte array and if it is valid will notify any interested parties by calling their **ax25PacketReceived** method passing along an **AX25Event** object that will contain a reference to the **AX25Packet** object.

For connected sessions, a class **AX25Session** manages the setup, sending and receiving of frames and acknowledging their receipt and the

possible resending if the frame is not acknowledged within a timeout period.

For debugging, the **AX25packet** class contains a method that will return a String representation of the packet header information.

An AX.25 Packet Monitor

At this point there is sufficient code implemented to write a simple packet monitor (figure 5).

```
package n6lyt.util;

import n6lyt.ax25.*;

public class Monitor implements AX25Listener {

    public Monitor() {
        try {
            AX25 ax25 = new AX25(0);
            ax25.addAX25Listener(new Listener());
        } catch (AX25Exception e) {
            System.out.println(e.getMessage());
        }
    }

    public static void main(String args[]) {
        Monitor monitor = new Monitor();
    }

    public void ax25PacketReceived(AX25Event event) {
        AX25Packet p=event.getPacket();
        System.out.println(p.toString());
        if((p.getType()==AX25Packet.IFRAME)||((p.getType()==AX25Packet.UIFRAME)){
            String data=new String(p.getData());
            System.out.println(data);
        }
    }
}
```

Figure 5

An example of the output generated to the console by this application can be seen in figure 6.

```
To: BBSTAT From JSAT-12 UI PID=F0
Open: A
To: PBLIST From JSAT-11 UI PID=F0
PB: Empty
To: Time-1 From JSAT-1 UI PID=F0
PHT: uptime is 0/01:20:30 Time is Wed Aug 20 14:39:26 GMT 1997
To: BBSTAT From JSAT-12 UI PID=F0
Open: A
To: PBLIST From JSAT-11 UI PID=F0
PB: Empty
```

Figure 6

Pacsat Broadcast Protocols

The Pacsat Broadcast protocol sends file and directory data as Unnumbered Information (UI)

Frames with a destination address of QST-1. The protocol id is used to determine between file and directory data.

A **Broadcast** class has been developed that is similar to the **Monitor** class, but analyses the AX.25 packets to see if they are a file or directory broadcast packet (figure 7).

Two additional classes have been developed that handle the processing of a file packet (**BroadcastFilePacket**) and a directory packet (**BroadcastDirectoryPacket**).

```
public void ax25PacketReceived(AX25Event event) {
    AX25Packet p=event.getPacket();
    if((p.getType()==AX25Packet.UIFRAME)&&(p.getDestination().equals("QST-1"))){
        try {
            if(p.getProtocolId()==Message.PID) {
                BroadcastFilePacket f=new BroadcastFilePacket(p.getData());
                Message message=new Message(f.id);
                System.out.println("File: "+Integer.toHexString((int)f.id)+
                    " Offset:"+f.offset);
                if(!message.isDownloaded()) {
                    if(message.fillHole(f.offset,f.data)) {
                        if(message.isDownloaded()) {
                            System.out.println("File: "+Integer.toHexString((int)f.id)+" Downloaded.");
                        }
                    }
                }
            } else if(p.getProtocolId()==Directory.PID) {
                BroadcastDirectoryPacket d=new BroadcastDirectoryPacket(p.getData());
                PacsatFileHeader pfh=d.getPacsatFileHeader();
                System.out.println("Directory: "+Integer.toHexString((int)pfh.fileId)+
                    " From:"+pfh.source==null?"":pfh.source)+
                    " To:"+pfh.destination==null?"":pfh.destination)+
                    " Title:"+pfh.title==null?pfh.fileName:pfh.title);
            }
        } catch (BroadcastException e) {
            System.out.println(e.getMessage());
        }
    }
}
```

Figure 7

When a broadcast file packet is received, the packet is decoded to determine what message it is for and at what offset into the message the data is for. The message is checked to see if it has been downloaded already, and if it has not, to load the hole list for the file to see if the data is needed to fill a hole. If it is needed, the data is written to the file, and the hole list is updated.

In a similar manner, a broadcast directory packet is decoded and the directory hole list is checked to see if the directory entry fills a hole. If it does, the directory entry is written to the directory file and the hole list is updated.

Ground Station

So far, we have only seen simple TTY style output to the console.

Java provides a rich set of class libraries to implement a Graphical User Interface (GUI) called the Abstract Window Toolkit (AWT). This provides a platform independent way of implementing a GUI without having to be aware of the systems underlying windowing system.

A simple GUI GroundStation has been developed (figure 8) that provides the a useful graphical interface for receiving Pacsat broadcast data and status information, and for requesting directory and file data to be sent.

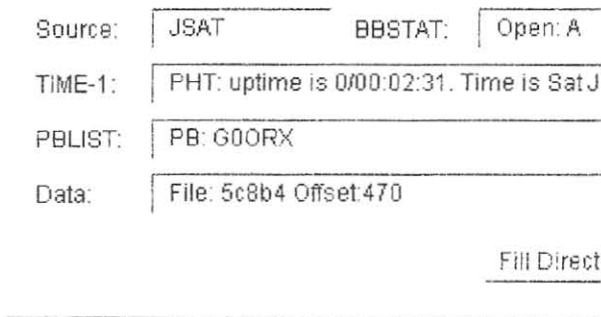


Figure 8

The Pacsats send periodic status information such as the current broadcast queue and the satellite time.

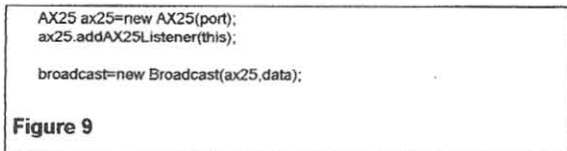


Figure 9



Figure 10

When a GroundStation object is invoked (figure 9), it creates an AX25 object (which will create a Kiss object, which will create a Serial object) and then registers that it wants to be notified when an AX25 packet has been received.

In addition, a Broadcast object is created passing in the AX25 object as a parameter. The Broadcast object will also request that it is notified when an AX25 packet has been received.

When the AX25 object is notified that a Kiss frame has been received, it will create an AX25Packet object and if there are no errors will invoke the ax25PacketReceived methods of both the GroundStation object and the Broadcast object.

Note that the packet will only be decoded once, and that a reference to it is passed to both the GroundStation object and the Broadcast object.

The Broadcast object will ignore it unless it is a Broadcast file or directory packet, and the GroundStation object will ignore it unless it is one of the status packets it is interested in.

Note that the call to construct the Broadcast object also passes in a variable called data. This is a TextField object on the GUI that the Broadcast object can set to show what file and offset was last received or the last directory entry that was received.

Also on the GUI are two simulations of Leds that flash when an AX25 packet is received or transmitted. Yes, there is a class called Led that implements this interface (figure 10).

The source field is set each time an AX25 packet is received to show the callsign of the source. This also is used to determine the path where the files, hole lists and directory entries are stored.

The **Fill Directory** button will cause a packet to be transmitted to request the filling of holes in the current directory. The **Fill File** button will cause a dialog box to be displayed where a file id can be entered and a packet will be transmitted to request the filling of hole in the specified file.

What no satellite!

One of the problems with developing satellite ground station software is that the satellites are never there when you want to do some testing, and when they are there it all a big rush to test, debug, fix and retest before the satellite goes over the horizon.

It just happens that I do have a spare Sun Sparc Station sitting at home, so as I already had the classes built to talk through a serial port, process Kiss frames and process AX.25

packets, I decided it was time to write the code to simulate a satellite.

Currently the simulator sends periodic status packets, accepts and processes directory and file fill requests.

I am currently working on both the ground station and the satellite simulator to support uploading messages (the existing messages are manually loaded into the directory).

Directory and File Viewing

A prototype Directory Viewer and File Viewer have been implemented along with an Image Viewer for viewing the images taken by the Earth Imaging System on board several of the satellites.

Satellite Predictions

A prototype set of classes have been developed that implement the SGP4 prediction algorithms.

This is used to drive the Antenna tracking software and the Radio Control software, and is used to schedule what satellites will be received.

Antenna Tracking

Some prototype tracking software has been implemented that defines a rotor controller interface.

This interface has been implemented to control a SASI tracking controller through the parallel port.

Other interfaces can be implemented by writing an implementation class for the interface that implements the required commands to control the specific rotor controller.

Radio Control

A radio control interface has been defined that allows a class to be implemented to control a radios transmit and receive frequencies and modes.

Currently a prototype implementation exists for an Icom 821.

Conclusion

There is still a fair way to go, but the current signs are that it is a viable way to develop the software.

The existing software has been run without modification (other than the Native Methods to support serial and parallel ports) on a Sun Sparc Station running the Solaris Operating System, an Intel Pentium system running Linux, an Intel Pentium System running Windows '95 and an intel Pentium System running Windows NT Server 4.0.

All systems are using the JDK 1.1.3 development kit from Sun.

Getting a copy of the Software

The complete source of the current version of the software is available from my Web Site <http://images.demon.co.uk>. Just follow the links to the satellite software.

References

The Kiss TNC: A Simple Host-To-TNC communications Protocol
by Mike Chepponis, K3MC and Phil Karn, KA9Q.

AX.25 Amateur Packet-Radio Link-Layer Protocols
by Terry L. Fox, WB4JFI

Pacsat Broadcast Protocols
by Harold E. Price, NK6K and Jeff Ward, K8KA

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There will be regular updates as the software get enhanced.

Java in space

A lot of people are talking about what to do after Phase 3D is finished.

Mainly it is about the size, orbit, digital and/or analogue transponders, up/down frequencies and modes that the satellite(s) should support.

Whatever it is, how about pushing the Onboard Computer (OBC) technology and running a Java VM on the satellite so that we can write the software in Java?

I would even think that Sun MicroSystemes would be interested in helping with this project for the publicity it would generate for them.

If anyone is interested either talk to me here, or contact me via e-mail.

How the Internet and Free Software Help AMSAT

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Introduction:

At the 1995 meeting in Orlando, Lyle Johnson WA7GXD made a very interesting presentation about the changes in hardware development technology during the Phase-3 satellite era. He focussed on the changes in the way schematics are captured and converted into artwork and then into physical printed circuit boards, and then talked a bit about the use of programmable logic devices on this spacecraft. I was impressed by the contrasts Lyle presented in the short time between the AO-10/13 development and Phase-3D.

There is an equivalently interesting story to tell for the software side of satellite building and operation!

This paper is my attempt to chronicle some of the technology and processes we used to develop the software for the original P3D GPS receiver, and RUDAK. Two key elements are the recent explosive growth of the Internet, and the parallel but less-well-known growth of the "free software" movement.

I hope this paper will serve both as a technology introduction to some, and as something we can look back on when we're building the next satellite and need a good chuckle about how primitive the things we're doing today will seem by then! If nothing else, I hope I can provide some food for thought about the way the Internet and the Free Software movement have "changed the rules".

The Internet:

It would be difficult not to be aware of the explosive growth of the Internet as a communications medium in the 1990's.. It is easy, however, for us to use the Internet on a routine basis without ever realizing its full potential for supporting distributed development.

Electronic mail is key to working on projects with others who spread out over vast geographic distances. Sometimes, being 8 or more hours of time zone away from someone you're working with can actually be an advantage... There have been numerous occasions on which I've sent out an email status report detailing some open issues as my last act before going to bed at night, and arisen in the morning to discover a round of replies from team members overseas who saw my message in the morning or at mid-day in their time zone. It's not quite as effective as sitting in the same room with someone, but in many cases it's far more productive communications interface than the telephone, and less expensive, too!

A particular useful feature of Internet electronic mail is the ability to build ad-hoc mailing lists. A "list exploder" can allow a sender to send one copy of a message and know that everyone

involved in a project will receive it in short order. This aids communication by ensuring that everyone who needs to know is kept in the loop without each sender having to remember everyone who should be included. It is also possible to arrange for the list exploder to archive a copy of each message on the list, which can provide a useful history, or "audit trail", of the discussions and the decisions they generated.

Having a file server available on the Internet full-time to use as a drop-box for exchanging files is another amazingly useful invention. The ability to publish software snapshots in a semi-private way, making them available for others on a development team to retrieve at will without having them be visible to the world at large saves us a lot of postage and FedEx fees!

We have experimented with Web technology as a way to capture project documentation, but frankly, it hasn't been very successful. I think the problem is that maintaining a Web demands a non-trivial time commitment from at least one member of a development team...and we just haven't had the time to spare. We have, however, used a few Spartan pages as indices to files that are available to everyone on the development team, including Postscript images of schematic pages, and the like.

Free Software:

What is "free software?" Permit me to quote from a document published by the Free Software Foundation:

"Free software" is a matter of liberty, not price. To understand the concept, you should think of " free speech", not "free beer."

"Free software" refers to the users' freedom to run, copy, distribute, study, change and improve the software. More precisely, it refers to three levels of freedom:

The Freedom to study how the program works and adapt it to your needs

The freedom to redistribute copies so you can share with your neighbor.

The freedom to improve the program, and release your improvements to the public, so that the whole community benefits.

there are many other things that could be said about free software, and if you're interested, chasing some of the links I provide near the end of this paper can provide some thought-provoking insights... but I hope this gets the key points across. Free software scares some people, I can't explain why. I sense that it is sometimes perceived as a threat by those who sell software, particularly with something free works better than the equivalent non-free thing. But, even in a all-free-software world, there's still lots of money to be made providing support!

I suspect that the general public is essentially completely unaware that the Internet is "powered"

mostly by free software. While Microsoft operating systems dominate the desktop, virtually every important service on the Internet, from email to web servers, is provided by free software running on some flavour of Unix, often free itself.

One of the original goals of the Arpanet, which was the predecessor to the Internet, was to foster the free exchange of software written by one research group with other groups. Thus, it shouldn't be surprising that the Internet and free software have grown up together. Part of the success of the Internet is due to the fact the protocols themselves, and the software used to implement those protocols, were developed by small groups who implemented as they went and shared their software with others for review, use, and improvement. Part of the success of free software is that the Internet brings people with similar interests together to form communities that can exist over vast distances... allowing the critical mass needed for interesting software projects to form much more easily than it once could.

The name service that maps symbolic hostnames like "www.amsat.org" into numeric network addresses like "128.54.16.15" is provided almost exclusively by a software system called 'BIND', which was originally written at UC Berkeley for their Unix distribution, and is now maintained by the Internet Software Consortium. The sourcecode is made freely available, and has been ported to all relevant server platforms.

The electronic mail transport system for much of the Internet is a software package called "Sendmail". It again, is freely available in sourcecode form, and has been ported to all relevant server platforms. Recently, several other mail; transport agents implementing the same protocols as Sendmail have started to gain popularity. All of them also make full sourcecode available, since if they didn't, they wouldn't be able to compete with Sendmail at all.

There are lots of other examples, I hope these illustrate the point.

A few years ago, Several different variations of the Unix operating system kernel appeared that the freely distributable in sourceable form, unencumbered by licences restrictions...including Linux and several variants of the UC Berkeley "BSD" distribution. Several organizations have worked to build complete operating system as utility distributions based on these free operating system pieces and the vast number of software packages (compilers, text editors, games, graphic tools, etc, etc) That are also available in freely redistributable form.

It is now quite possible to run an operating system on a variety of computer types, including Intel x86-based computers, for which all of the sourcecode is available, for which good support is available via email distribution lists on the internet, and for which the street price for a couple of CD-ROM's with all the software for a complete system is well under 5\$. Pretty amazing stuff.

Debugging CAN on the 29200:

One of the more interesting episodes in the development of the 29200 processor board for the original P3D GPS receiver came when we were trying to turn on and test the CAN interface. CAN is the primary high-speed data "network" on the satellite, and is the interface RUDAK will

use to communicate with most experiments. The 29200 board bootrom needed to support the CAN interface as a channel for initial bootstrap.

John Conner, WDOFHG, had volunteered to help me figure out how the Intel 82527 CAN chip worked. Unfortunately, we didn't have enough engineering CPU boards to give John one to take home. Since he and I were a local phone call away, and had worked on other projects together before, this did not seem like an insurmountable problem. On the other hand, it's about 45 minute drive between our houses!

We acquired two ISA-bus CAN interface cards, and John wrote a driver and some simple test programs to use these cards under Linux. He kept one card at his house, and we installed the other card in a Linux machine on the test table in my basement. Since we were also using Linux for our software development platform, the ground-support-interface program also ran on this Linux machine.

By putting this Linux machine on my network (which is attached to the Internet full time). John was able to open several terminal windows to it over the network from the Linux machine at his home. With one, he ran the CAN test software that interacted with the DIP card. With another, he could run the ground support program talking to the target over a serial port, to load the test software. With another, he could "push the reset button" by sending a character string to another serial port that was interfaced to a relay.

In other word, John could load software, run tests, and reset the GPS processor board when his software crashed, all without ever leaving his home 45 minutes drive from the hardware he was testing!

The Key technology that made this possible was the use of the Linux on the development platform. Linux is inherently multi-user, and provides network logins and a command-line shell...allowing us to do things that just aren't possible with Microsoft operating systems.

Software Revision Control:

Another really interesting problem that we tackled with free software and the net was managing the many revisions of the software we were developing for the GPS receive's 2900 processor.

The GPS receiver designed for P3D was described in the 1995 proceedings. It was based on integrated circuits from GEC Plessy interfaced to an AMD 29200 processor system. In simple terms, the software task that faced us was to port software from the GEC Plessy GPS Builder package to our processor and I/O configuration, and then tweak it for the different dynamics of a spacecraft in orbit versus a normal terrestrial GPS receiver. This would form the base of the orbit determination software, the attitude deamination software, and the antenna pattern measurement software.

Early in this project, it became clear that with software development definitely processing in two locations in Colorado, and one in Iowa...and other locations possible over time...that we needed

some way to keep up with who had which versions of various software modules. More specifically, it became clear that two or more people aware likely to be working on different source files for a single module essentially at the same time, and we needed to be able to synchronize with each other, and invent some way to manage the software revision process if we were going to retain our sanity.

This was a "new" problem in the AMSAT community, since traditionally software had always been a one-person problem, or a problem easily divisible by a small group of folks who could each take a piece and work in isolation. The goals of the P3D GPS project were too ambitious for such a model to continue to meet our needs.

After some investigation, we selected CVS, the Concurrent Version System, as our software configuration management tool. CVS is free software that implements two really neat ideas. One is that various client computers can all access a central software repository over the Internet, checking out only the pieces needed to perform a given task, and checking in changes as needed.

The second is a concept called "lazy locking". Many revisions control systems enforce rigidly a locking scheme where any time a software engineer checks a file out of the central repository to work on it, all other engineers are unable to work on that file until it is checked back in and unlocked. CVS work differently.

With CVS, each developer acquires from the revision control server a local copy of all the files he needs to work on, and later commits changes that are locally developed and tested. No restrictions are placed on parallel development even within the same source file, since the process of committing a change is only allowed against the most recent revision in the server. In other words, two developers can check out the same module, work on it, and when the second one tries to commit a change after the first one has committed a change, the second is led to update his local copy to include the changes already committed before he is allowed to commit his change. In this way, no developer is ever "locked out" from working on something because someone else is already working on it, and yet all changes proceed incrementally without insurmountable conflict.

The power of this model is that it's ok for someone to check out a set of files with good intentions, and then never get around to checking in any changes. Everyone else in the group carries on in the meantime, without being blocked. Given the all-volunteer, anarchic nature of AMSAT development, this is what my daughter would call "a major big deal".

Like all good networked software, CVS provides a lot of flexibility to control who can read files, and who can post changes to files. It is therefore entirely possible to envision a future where all the operational software on a satellite is checked in on to a CVS server somewhere, which would help to eliminate a lot of the fumbling and confusion that I have observed from time to time...and it would also help to ensure that nothing is ever lost.

During the course of the original P3D GPS project, I found that CVS did a good job of managing files other than software sourcecode...I used it for archiving vendor documentation, schematics

and other hardware documents, and all of our project status reports. As a result, with a simple 'cvs checkout p3dgps', anyone in the project who had been given access to the server could snag a copy of everything relevant to the project...

Summary:

Just how did anyone get anything done before the Internet? It's tempting to ask this question, since our processes have in many cases become very dependent on it. Could we get along without free software? Well, it's certainly possible, but it would cost more money and reduce our capabilities a lot if we tried.

I've enjoyed talking about these topics to various folks over the last few years. I've been a part of the Internet community since long before it was called "the Internet"...and I was helping to write and support free software long before I knew that's what it was called. It's gratifying to see these technologies making a positive difference in the way AMSAT goes about building and operating satellites.

I fear this paper leaves as much unsaid as it manages to say...which I suppose is inevitable with technology that is progressing at such a rapid pace. If you're interested, I encourage you to read more about the topics I have touched on...there are lots of excellent documents floating around on the World Wide Web. Launch a browser, query your favourite search engine, and have at it!

Design of a Space Image Processing System

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Abstract

As part of the SEDSAT-1 project we have designed SEASIS (SEDS Earth Atmospheric and Space Imaging System), an image processing computer system for small satellites. Our design is based on the Transputer chip and features 128 Megabytes of EDAC (Error Detection and Correction) DRAM, redundant video digitizers, and an option for an advanced signal processor. These features are contained on a 13 inch by 12 inch board designed for the thermal and radiation environment of a small satellite. This paper reviews the history and features of the design, including choice of processors, design of an error-correcting mass memory system, signal processor options, power control features, CCD Camera Control Circuitry, and physical structuring for thermal and radiation characteristics. The design has been manufactured in a flight printed circuit board configuration and is undergoing environmental qualification before launch on SEDSAT-1 in July of 1998.

1. SEDSAT Introduction

SEDSAT-1, signifying Students for the Exploration and Development of Space Satellite number one, is being developed at the University of Alabama in Huntsville. The SEDSAT-1 project has grown from two students and their mentors to an international project funded by NASA, DARPA, and major corporations. SEDSAT-1 will have significant impact on space education, amateur radio communications, and space utilization. SEDSAT-1 is scheduled for launch on a Delta II in mid-1998, as a secondary payload on the JPL DS-1 mission. On-orbit, SEDSAT-1 will be a unique resource for education and research.

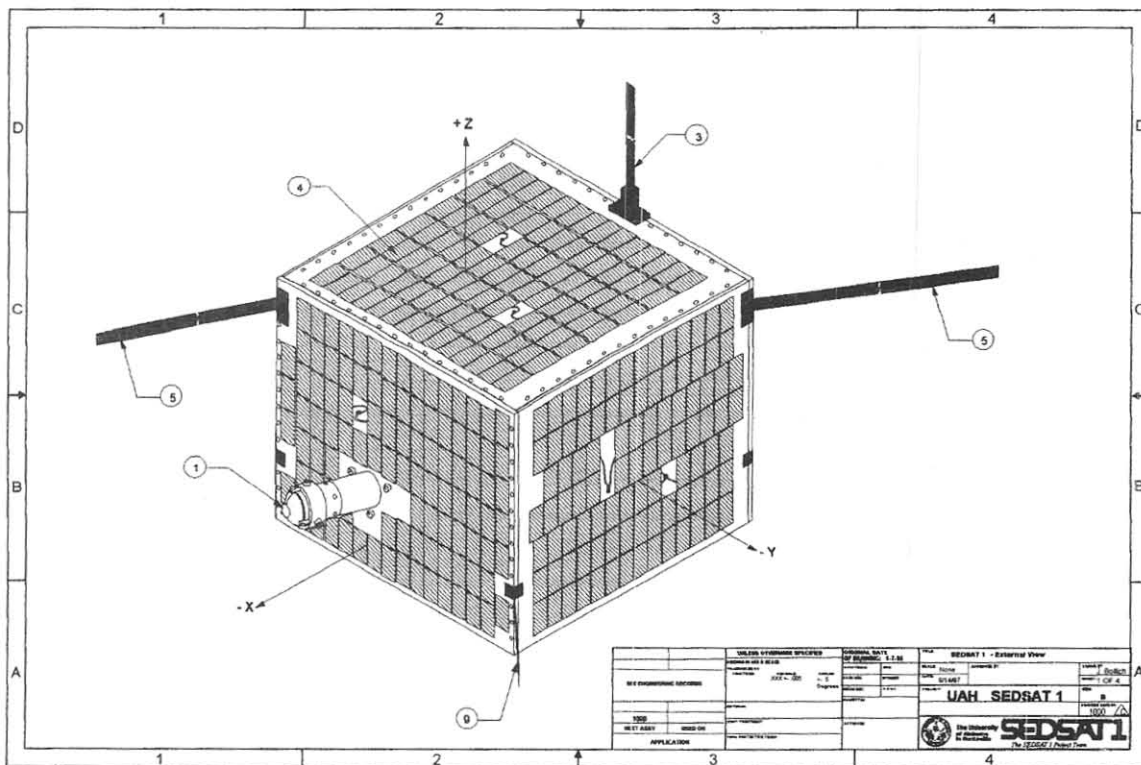


Figure 1. External view of SEDSAT-1 Drawing by John Bollich, UAH

The structural frame of the satellite is approximately 13.5 inch cube, with solar cells on 5 of the six sides, and a marman clamp on the 6th side for interfacing to the delta-II (see figure 1). Also shown are the transponder antenna's and the PAL (Panoramic Annular Lens) - one of the two lens systems used on SEDSAT. In its orbital configuration, the main objectives of the satellite are:

1. To provide multi-spectral remote sensing to the broadest possible community by use of SEASIS (SEDS Earth Atmospheric Imaging System) - the optics system of SEDSAT-1. The two cameras will collect in narrow wave bands (using selected filters) to coordinate with ground based observations across the U.S. Unlike other remote sensing systems, the data will be broadly accessible because it will be

entirely public domain, and because its communication system will be integrated into the World-Wide-Web.

2. Serve as a development platform for advanced microsatellite position determination and control algorithms. The satellite will demonstrate a unique attitude determination system and new technology in active microsatellite control.
3. Provide the amateur radio community with digital packet store-and-forward and analog repeater systems by use of the Mode-L Transponder, which has an uplink of 9600 baud, and downlink of 9,600 or 57,600.
4. Generate new data on the space performance of NiMh batteries, solar cells, and advanced electronic components.

2. SEASIS Specifications

Many design constraints were considered before finalizing on the SEASIS design. Table 1 Shows general information on processor performance and features. The main objective of SEASIS is to digitize from two CCD cameras, one which is fully calibrated. Also, select one of 12 filters from each, and control camera configurations to maximize dynamic range. Real-time video data compression is possible with the addition of the three Analog Devices SHARC ADSP-21062 chips later discussed. Mass RAM is included to store large amounts of images - since the downlink on the SEDSAT is only at 9600 and 57,600 bps. Processor computing capabilities are shown in Table 1.

Processors	Clock	MFLOPS	MIPS	SRAM	DRAM	Total System Power (Watts)
T805-20	20 Mhz	3.3 Peak	20	2 Mbyte SMI	128 Mbyte	0.7 to 5 Watts
3 Analog Devices SHARC DSP	40 Mhz	120 Peak/each 360 Total		512Kbyte on-chip SRAM (1.5Mbyte Total)	N/A	3 Watts Each

Table 1. SEASIS Processor Specifications

3. Processor Selection

Originally, DARPA donated an MCM (the SCC-100) with 3 ZORAN DSP's, a T805 Transputer, and 2 Mbytes of internal SRAM. Unfortunately, the bus design for the ZORAN's would be a great bandwidth constraint (lowering the MFLOP rating of the MCM to a fraction of it's 100Mflops peak), and the system was not designed for our purpose. Also, the SCC-100 consumed over 5 watts of power, and was the only MCM of it's kind - making it almost impossible to have a ground system functionally identical. For this reason, we chose to re-design a lower power, more effective solution.

The heart of the SEASIS board is the 32 bit T805 processor by INMOS running at 20 Mhz. The processor operates under ½ watt under normal operations, has multitasking capabilities built-in, and has a long history of use in space applications. For memory, code and data both reside inside the 128MByte EDAC protected DRAM's linearly addressed memory space without the need for bank switching.

Internal to the T805 are 4 high speed serial links - one running to the CDS board (Command Data System board on the SEDSAT-1 which communicates to the ground station) and the other three to the DSP's (see Figure 2). These links make the communications hardware easier to implement in the system since different sections can be powered off. The three SHARC chips can be powered on separately under the T805 software control, on an external expansion board. Each SHARC has access to one of the T805's 20MBit links for communications and bootup code. Once a SHARC chip is powered on, it immediately accepts code over the link from the T805, and runs the code once the end is reached.

The SEASIS board can be reset from the CDS board under software control. Upon power-up of the SEASIS board, a power-on reset circuit gives maximum reset timings for all circuitry. After reset, the T805 polls the transputer links for bootup code. One of the links is connected to the CDS - allowing the CDS board to send bootup code to SEASIS over the link, placing it in EDAC protected memory and then run once complete.

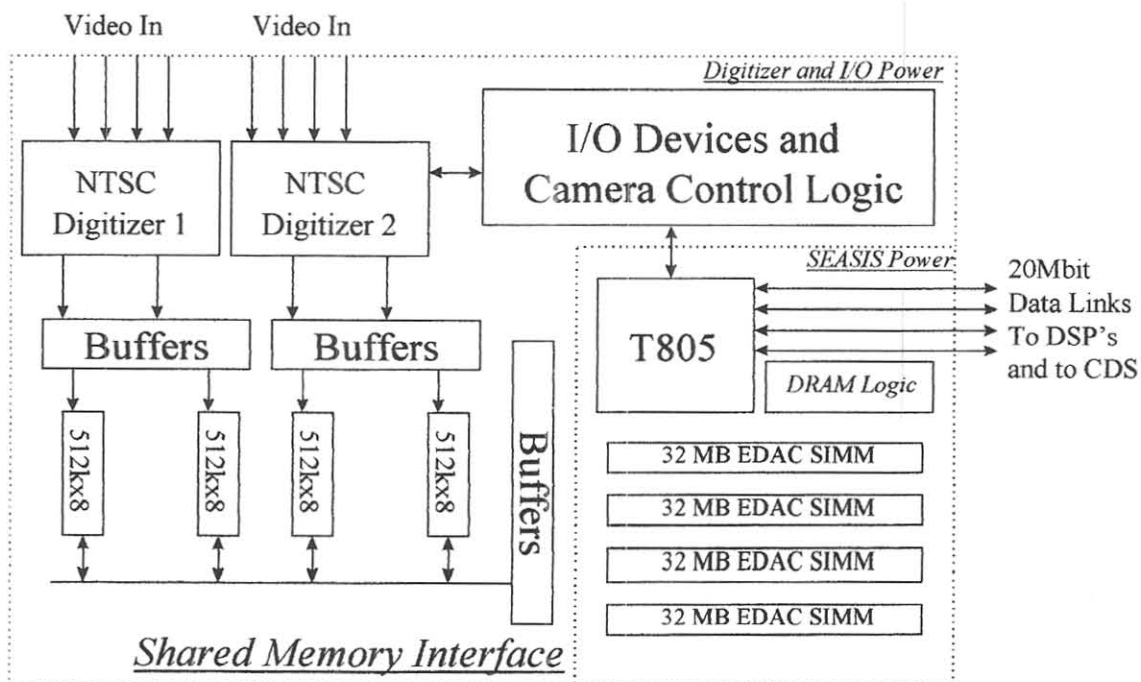


Figure 2. SEASIS Processor Board Block Diagram

4. EDAC Mass Memory Design

Mass memory consists of 128 Mbytes of EDAC (Error Detection and Correction) DRAM (Dynamic RAM) comprising of 4 32 Mbyte SIMM's. DRAM requires refreshing (accesses to every row at intervals no greater than 32 ms) - and this is incorporated into the design external to the Transputer for robustness, even though the T805 does have some limited refreshing capabilities. The refresh design has no memory mapped registers, when the power is applied, the DRAM's are guaranteed refreshed until powered down. Also, by using a CBR refresh (CAS before RAS) cycle, power consumption is minimized and the address bus can remain tri-stated. When refreshing 128 Mbytes, interleaving was chosen to minimize effects on the power bus. Instead of refreshing all 4 SIMM's (both sides) at once, they are refreshed separately and distributed evenly (8 CBR cycles during each refresh interval) throughout the 32 ms.

Each SIMM is 36 Bits wide (4 for parity) and 32 for data bits - along with 4 check bits for each byte. Each byte has a separate EDAC chip - correcting single bit errors in EACH byte (and some double bit errors) - while detecting single and double bit errors. A memory mapped register can be read by the Transputer to determine when single and double bit errors occur - to map error locations and generate SEU statistics.

Using a flow-thru EDAC chip such as the IDT 39C465, the SMI SRAM can be EDAC protected during digitizing, as well as running code. Also, instead of using the IBM EDAC DRAM's for the mass RAM, the 32 Bit IDT EDAC chip has been designed to do read-modify-write cycle on SRAM's and could be modified for standard COTS JEDEC 72 Pin DRAM's. The T805 can vary it's bus cycle write size, making it more difficult to design a 32 bit EDAC memory system that generates code words for the full 32 bits. Because of this, wait states would need to be added, or faster memory would need to be selected. For this reason, SEDSAT chose to use the IBM EDAC byte-wide DRAM's which generate check bits for each byte, rather than for each word - eliminating the need for a read-modify-write cycle during a partial CPU write.

5. Video Digitizer Design

Incorporated in the SEASIS board are two NTSC video digitizers which can sample at speeds up to 20 Mhz. In our case, at 768x484 resolution, we need to sample at the pixel clock rate of the CCD's (14.31818 Mhz) which is far within the specifications. Reference digitizing voltages can be set from software control, as well as the analog multiplexer choosing between one of the four input video channels, allowing for a total of 8 video inputs together, or redundant digitizers.

To digitize, the transputer flips a bit in a memory mapped register, causing the Digitizer to find the beginning of the image. Then, the digitizer starts digitizing into the SMI (Shared Memory Interface) SRAM. Once complete, the digitizer generates an exception (interrupt) for the T805, signaling that the digitizing is complete. Up to four clocks can be software selected (CCD clock, fixed oscillator, software clock, No clock).

Selecting no clock will lower power consumption when the digitizers are powered on but not digitizing.

6. Digital Signal Processing Capabilities

Three SHARC DSP's were chosen for the ability of having redundant computations on each, storing their result in the internal SRAM on-chip (512kbytes each). High speed links connect each DSP together, with speeds up to 240MByte/second using the internal DMA capabilities. Once each DSP has computed the result, each one will transfer their result to the T805, and the T805 will compare their results to see if any SEU (Single Event Upsets) occurred, and in which DSP. Another option is to have all three DSP's operating on different sections of the image, and to have it computed twice for comparison on the T805. If the results are not the same, the T805 will compute what isn't consistent again on the 3 DSP's until it finds a match. Since all software is uploaded to the SHARC chip upon power-on, any scenario can be programmed to ensure data integrity.

7. Power Control Features

SEASIS can be powered on in a base configuration with all mass memory refreshed in under 1 watt. The CDS board on SEDSAT can power off SEASIS, or send a command to power different sections of SEASIS down when it detects a low power state of the batteries on the satellite. Configuration possibilities and power consumption are shown in Table 2.

Configuration	Systems Active	Power (W)
Minimum	Mass RAM, CPU Idle	0.7
Running	Mass RAM, CPU active 100%	3.5
Digitizing	Mass RAM, CPU, all I/O and Digitizers	5.0
Cameras	Stand-alone, each	3.0
Stepper Motor	Single Stepper, single Phase energized	5.6

Table 2. Power Control Configurations

SEASIS always starts up in the base configuration with only the critical memory and logic system enabled. All camera control logic, stepper motor control, and the digitizers can be powered up and down under software control. The cameras, auto-iris lenses, and stepper motors power can also be controlled independently to minimize total power consumption.

8. Image Control Logic

SEASIS has two cameras mounted perpendicular on the experimental mounting plate (see Figure 3). One lens is a PAL (Panoramic Annular Lens), and the other is a telephoto with a field of view of approximately 10 degrees. The unique capability of the PAL allows us to see 360 degrees around the lens, which will overlap the image from the telephoto.

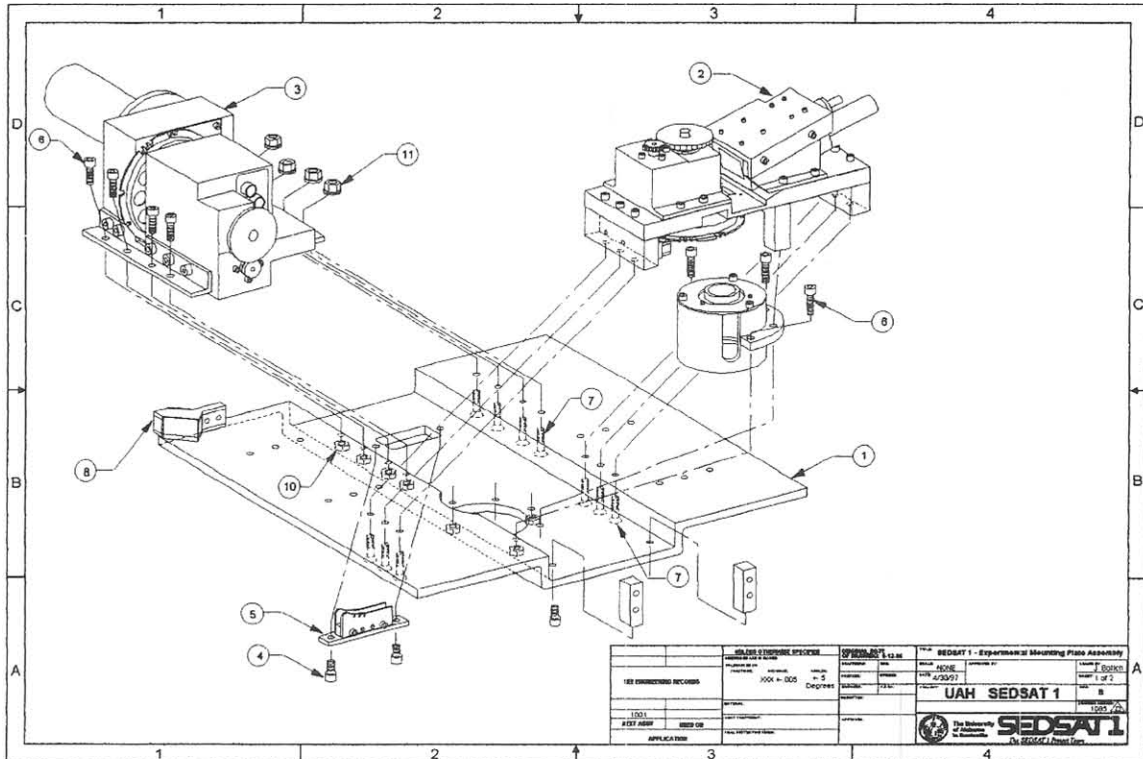


Figure 3. SEDSAT Experimental Mounting Plate Drawing by John Bollich, UAH

The PAL CCD camera is flown in fully automatic mode - allowing the camera to select shutter speed, iris setting, and gain automatically. Only the telephoto camera is required to be calibratable. For this reason, and because we aren't able to read the settings made in automatic mode from the lens and iris, we generate a calibratable system by setting the options on the iris and lens under software control. A list of options and settings is in Table 3.

System	Options	Possible Settings
Lens	Iris Control	14 Bit D/A for 16,384 settings
Camera	Shutter Speed Gain Control	200 PWM Electronic Speeds AGC/Fixed/Manual
Stepper Motor	Phase A,B,C,D	Pulsed to select one of 12 filters
Filter Wheel	12 Filters	Optical encoders on wheel which can be read to determine filter number

Table 3. Image Control Settings on SEASIS

Iris control can be controlled by means of outputting an analog voltage into the auto-iris lens from the D/A converter. This will allow variation in intensity under software control, however, makes the system unable to be calibrated. Because of this, the iris will be flown on SEDSAT fixed completely open on the lens which requires calibration, and only the gain and shutter speed will be configurable (as well as a selection of neutral density filters), which will give us enough dynamic range. Our second CCD camera will be flown completely automatically - CCD camera and auto-iris lens since we have no need to calibrate.

9. Thermal Design

SEASIS is powered by Interpoint DC/DC converters, with maximum output power of 15 to 30 Watts, and efficiencies of around 75%. The DC/DC converters are mounted on the SEDSAT experiment mounting plate, located near the center of the satellite. Our simulations and tests have shown this to be the coldest location in the satellite, and an ideal location for our DC/DC converters. Three DC/DC converters are used, one for cameras (12VDC), one for SEASIS main power (5VDC), and one for stepper motor power (28VDC). All derive their power directly from the main satellite power bus.

PCB's have ground planes located on the top and bottom of all boards in the satellite, secured to the frame with wedge-locks. Our simulations and tests have demonstrated that this is very effective at distributing heat evenly especially when making good thermal contact to the body of the components (using a thermally conductive, electrically non-conductive strip). Soldering was very tedious when soldering pins to ground, so better heat relief was added on the solder side.

10. Radiation Considerations

Almost all of the hardware on SEASIS are commercial parts with radiation information available (see Table 4). One of the main exceptions are the A/D video chips chosen, which have no radiation information (Brooktree BT252). Because of the internal

4 channel mux, and programmable voltage references, we chose to keep the BT252 in the SEASIS design since our orbit will give us a minimal radiation exposure level. However, we have redundant electronics for the video digitizers, and can have components RAD-COAT'ed (© Space Electronics, Inc.) to increase their life expectancy to over 100krad. Also, the HS9008-RH could be used in a future design where long-duration exposure at high doses exist in place of the BT252.

Part Number	Description	Latch up Threshold MeV/ (mg/cm2) **
T805-20	Inmos 20Mhz Transputer	36
HM628512	512Kx8 SMI SRAM	> 90
74 and 54 Series	Discrete Logic	>100
MTR2805S	Interpoint 28-5V DC/DC	>50
MTR2812S	Interpoint 28-12V DC/DC	>50
10.00Mhz	Q-Tech Rad-Hard Oscillator	>100
BT252	Brooktree A/D	No Information Available
HS9008-RH*	Harris Rad-Hard A/D	>300

Table 4. Radiation Specifications

*Feasible replacement part for BT252 on new design.

**Radiation information from <http://www.dasiac.com>, and Interpoint for DC/DC converters.

11. Conclusion

The SEASIS design incorporates low cost, low power, and high performance. In our planned low earth orbit, the life expectancy is 3 years. Alternative chips and packaging methods can increase total dose survival rate on SEASIS to well over 100krad, but was not feasible (due to funding), nor required for our mission.

Future designs will include a more modern microprocessor - the T805 is being phased out. Possible replacements include the 486 or Pentium microprocessors with low power modes, and a VME bus interface. Also, new digital camera technologies could allow for direct digital output instead of NTSC, simplifying the image capture hardware. These options will be more feasible once the technology is more mature, and a longer flight history is developed.

Phase-3D GPS Receiver Progress Report

Overview:

This paper documents progress made on the experimental GPS payload for the Phase-3D satellite since the report given at the 1996 annual meeting.

The goals of this project have been described in previous proceedings, but briefly, we intent to determine the orbital position and three-axis attitude including mapping the (unpublished) antenna patters of the GPS satellites from outside their orbits.

In the last year, the GPS receivers have been prepared for flight, delivered and installed on the spaceframe. The antennas and preamps have been installed and a full "self-survey" process has been performed using a mockup of the satellite's antenna-mounting surfaces, in preparation for attitude deamination with the receivers.

What We Will Fly:

The GPS hardware we will fly includes a pair of Trimble TANS VECTOR receivers donated by NASA. our friends at NASA are just as interested in the viability of GPS for orbit and attitude determination above the GPS constellation as we are! The receivers are commercial attitude determining receivers that each use 4 antennas, consume less than 7 watts of power, and communicate using asynchrinous RS-422 at 9.6 kbaud. The receivers we will fly have software modified by NASA GSFC for our orbital environment.

In order to meet our mission objectives, we need to fly two of theses receiver, one attached to antennas on the +z surface, and one attached to antennas on the -z surface. The antennas on each surface will have different gain characteristics, since the predicated path loss from the GPS satellites we expect to be able to track is substantially different at apogee than at perigee.

One receiver will be attached to 4 patch antennas donated by Ball , and 4 Trimble primps provided by NASA. This receiver will be configured for operation near perigee, inside the GPS constellation.

The other receiver will be attached to 4 higher-gain, air loaded match Aerospace donated by Ball Aerospace, and 4 higher-gain primps designed and built for AMSAT by GUY WEST, NOMMA. This receiver will be configured for operation near apogee, inside the GSP constellation.

The Trimble receivers do not provide either an internal power switch, or an external RESET input. We design and fabricated a power switch using ideas already tested in other module designs, that will allow the IHU to control overall power to the GSP receivers, and will allow Rudak to reset either receiver by power cycling.

Both receivers interface to Rudak using asynchronous serial ports, clocked at 9.6 kbaud. The flight version of the RUDAK processor hardware was updated to include support for the power switch and switching of the serial ports from either GPS receiver to either RUDAK CPU board.

The GSP service task for RUDAK is being written by Harold Price, NK6K. This task will support initialization and command of the receivers, and capture of telemetry for analysis on the ground. Other features, such as providing precise time to RUDAK, are under investigation

Testing

Over the last weekend in June, Ed Davis from NASA GSFC delivered the two TANS VECTOR receivers for an initial fit-check on the satellite in conjunction with the initial fit-check of RUDAK. The testing we accomplished during that visit demonstrated that the RS-422 links between RUDAK and the receivers functioned correctly, but we uncovered a minor wiring problem with the interface between RUDAK and GPS power switch.

After additional flight preparation work at GSFC, the receivers were returned to the integration facility, and an antenna self-survey was performed. This process allows an attitude-determining GPS receiver to calibrate itself, learning antenna positions and cable lengths by measuring signal variances from the GPS constellation while the antennas are in a known orientation. This procedure is carried out using a mockup of the antenna surface of the satellite which precisely matches the GPS antenna positions to those that will exist on the real satellite. The procedure was otherwise carried out using all of the actual flight hardware... antennas, cables, preamps, etc. This should provide sufficient accuracy while eliminating any need to take the actual satellite out of the clean-room.

At the time of this writing, the RUDAK flight hardware has been delivered for integration, and minimal checks have been made of the interface between RUDAK and the GPS receivers. Structural modification to the satellite has delayed further testing. Before the satellite's environmental testing begins, we expect to perform a more thorough check-out of the RUDAK to GPS interfaces.

Conclusion:

The P3D GPS project hardware delivery is complete. Sufficient testing has occurred to confirm RUDAK'S ability to communicate with the TANS receivers, and to control their power. The flight software for RUDAK is under development. This is the last report on the P3D GPS project plan until after the launch of the satellite.

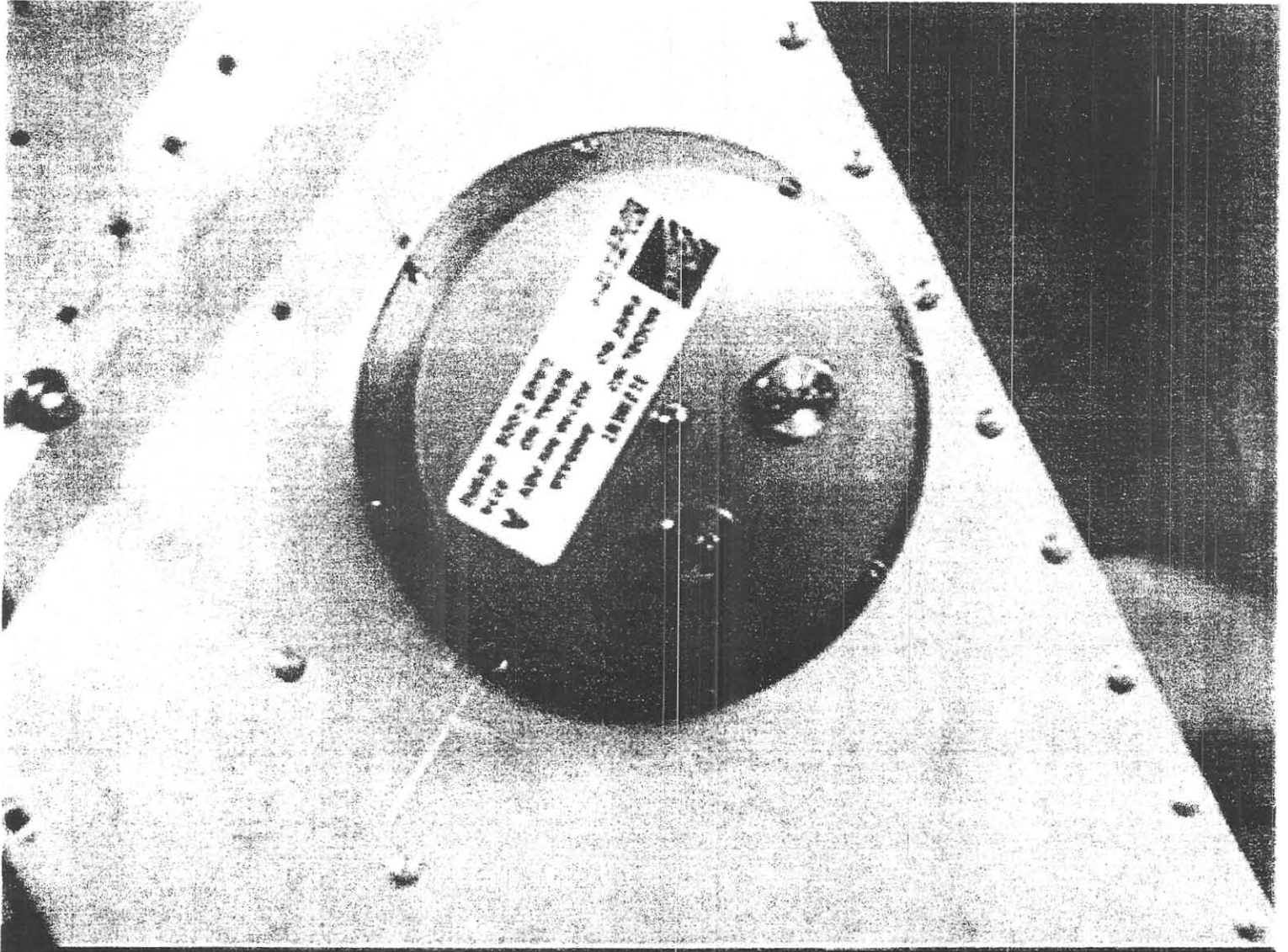
References:

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

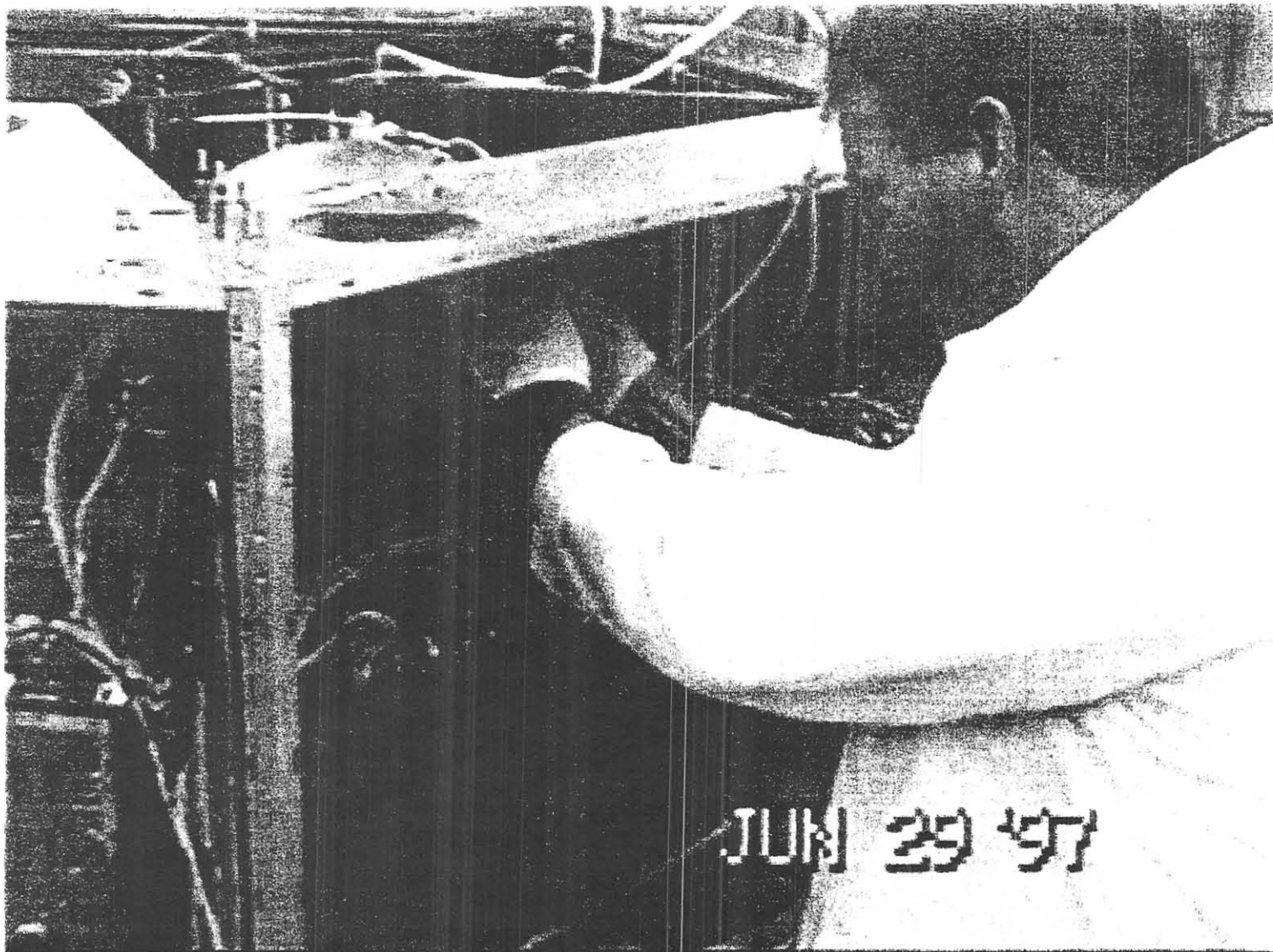
http://www.trimble.com/cgi/products.cgi/pd_m1007.htm

The web page for the P3D GPS project, which is currently somewhat out of date, may be found at

<http://www.amsat.org/amsat/sats/phase3d/gps/>



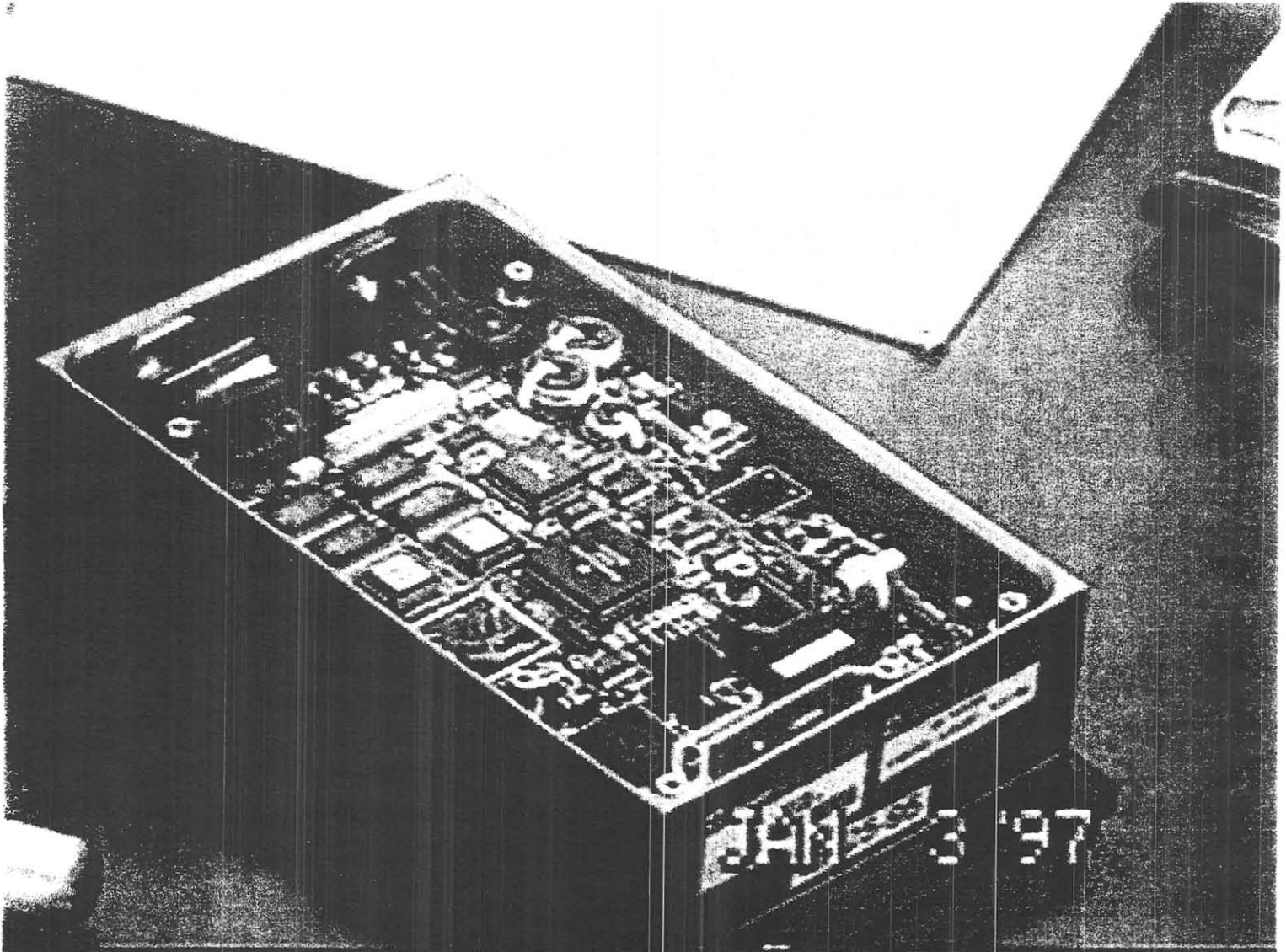
This is one of the air-loaded, high-gain patch GPS antennas provided by Ball Aerospace.



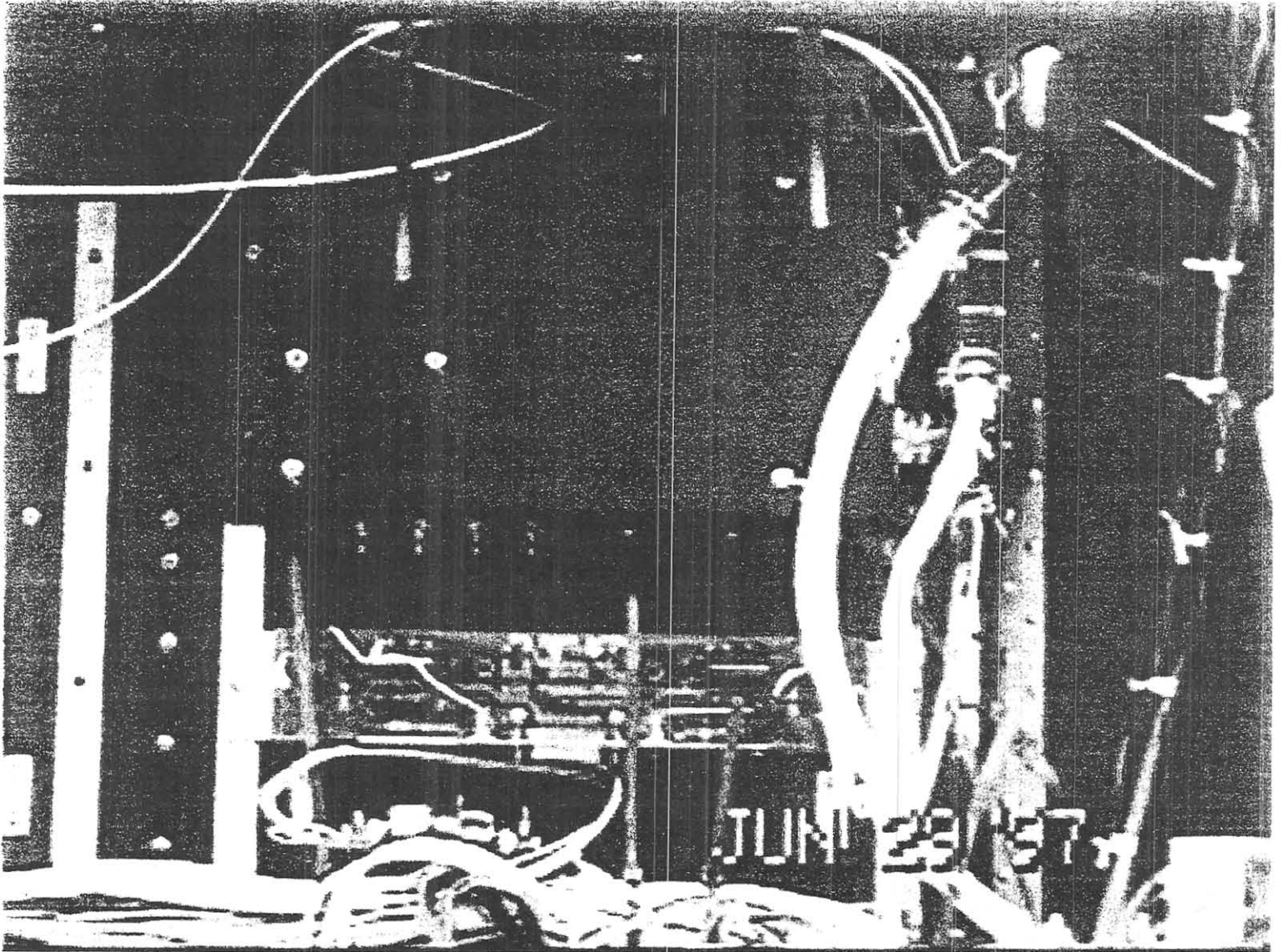
Ed Davis from NASA GSFC, attaching cables to one of the TANS VECTOR receivers. Just above his hands, one of the air-loaded, high-gain Ball GPS antennas is visible.



The first meeting of NASA and AMSAT personnel to discuss the details of the GPS project. Glenn Lightsey from NASA, on the left, is author of the software we will fly in the TANS VECTOR receivers, one of which is seen here with the cover removed. Lou McFaddin W5DID, is to his right.



A closeup of a TANS VECTOR with the cover removed at the January meeting.



One of the TANS VECTOR receivers mounted to the spaceframe, with the GPS power switch circuit board visible below. This was taken on the weekend when we first test-fit the various pieces to the spaceframe.

Introduction to Amateur SETI

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Executive Director, The SETI League, Inc. ¹

The notion of humankind's uniqueness in the universe had been challenged by philosophers since before Copernican times. Nevertheless, it is only within the twentieth century that the existence of other technologically advanced civilizations in space has become a possibility accepted within the scientific establishment. Far more recently still has the feasibility of detecting such other civilizations entered mainstream thinking. Today, the search for evidence of other inhabited worlds is in full swing, thanks in part to the interest and expertise of the world's amateur radio operators, radio astronomers, and microwave experimenters. This Introduction tells you how you can join the search.

The first scientific paper seriously contemplating surveying nearby stars for intelligently directed microwave signals was titled, boldly enough, "Searching for Interstellar Communications." It was written by Cornell physics professors Giuseppe Cocconi and Philip Morrison, and published in the British journal Nature in 1959. Unbeknownst to Morrison and Cocconi, as they were writing their pivotal paper, a young radio astronomer was preparing to perform the very experiment which they were describing. That scientist, Dr. Frank Drake, launched his *Project Ozma* search from the National Radio Astronomy Observatory (NRAO) facility at Green Bank, WV in 1960, ushering in the era of modern SETI.

Why do we suppose other civilizations might be detectable by their microwave radiation, and how will we know where to look for them? For that matter, why don't we simply look with our eyes? One problem is that stars typically outshine their unseen companions by about a billion to one. Seeking a planet orbiting another star is a little like

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trying to see a firefly perched on the rim of a searchlight. This is why the detection of extra-solar planets was not even possible until the current decade, and required the development of rather elaborate instrumentation. But at certain times, on certain frequencies, our Earth outshines the Sun a million to one.

The Earth is currently surrounded by a sphere of microwave radiation roughly fifty light years in radius, which is readily detectable over interstellar distances utilizing technology such as is today available to even *amateur* radio astronomers. This radiation, emanating primarily from our planet's UHF TV transmitters and long range search radars, would mark our planet as inhabited to any similar technological society within fifty light years. Within that range are found hundreds of stars, tens of which are sufficiently sun-like to probably host one or more habitable planets.

The distance over which we are detectable is limited only by the time since we first began transmitting these sufficiently strong signals in the appropriate frequency range. Fifty years from now, we will be detectable out to 100 light years distance. At that point our signals will have engulfed thousands of stars, including hundreds of potential life sites. With every successive doubling of elapsed time (out to 1,000 years or so), the number of civilizations which our radiation signature can potentially reach goes up by a factor of eight. Sooner or later, our signals may well reach distant ears.

SETI hypothesizes that other technological civilizations are similarly surrounded by a detectable sphere of microwave radiation, the radius of which will be limited only by how long such civilizations have possessed sufficiently advanced radio technology. We depend upon our ability to intercept and recognize (though not necessarily decode) such a radiation signature, to provide existence proof of other intelligent civilizations.

The problem with seeking incidental radiation is that the unknown factors exceed the known. We can only guess as to where physically to point our antennas, when to listen, and on what frequency. Interesting signals, after all, could be coming from any direction in the 4π steradians of space surrounding us. Other civilizations might well

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have harnessed any segment of the electromagnetic spectrum, and could be transmitting now, in the distant future, or in the deep past. Or maybe not at all. We just don't know.

The time dimension is resolved by starting to look now, and continuing until we detect something noteworthy. Given a great enough number of coordinated stations, effectively looking in all directions at once, we might resolve the pointing uncertainty. And we can narrow the search space in the frequency dimension by recognizing that particular range of frequencies which is least attenuated by planetary atmospheres and the interstellar medium. This, however, leaves us with most of the microwave spectrum, and much of the optical, as our likely range of frequencies.

Since there are no "wrong" frequencies to search, SETI has attempted to scan them all. One person's guess is as good as another's, so any frequency for which you can assemble a sufficiently sensitive telescope is fair game. Radio astronomers have long explored protected portions of the 406 MHz, 610 MHz, 1.42 GHz and 10.6 GHz bands, and I can think of no good reason why not to pursue the SETI dream in those spectral regions as well. And the world's radio amateurs have the capacity to scan a good many additional VHF, UHF and microwave frequencies, any of which may bear cosmic fruit.

The foregoing, however, applies only to the problem of scanning for incidental radiation from the distant civilization. What if another intelligent race were making a deliberate, concerted attempt to signal its presence to its interstellar neighbors? Is there a particular frequency, or range of frequencies, which would be self-evident to the receiving civilization? Can we narrow the search space?

Cocconi and Morrison thought so when they published their 1959 Nature article. They reasoned that 1420.40575 MHz, a natural emission frequency of neutral hydrogen atoms, was a good place to start looking for intelligently directed interstellar beacons. This frequency, which falls in the quietest part of the radio spectrum, is marked for all to see, by Nature herself. Everywhere you point a radio telescope, from anywhere in the Universe, you can hear this radiation, emanating from the one hydrogen atom which

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occupies each cubic centimeter or so of interstellar space. There is nothing geocentric about hydrogen radiation. Perhaps, it can be reasoned, selecting it for interstellar communication is a mark of intelligence, in and of itself.

Drake had arrived at this same conclusion independently of Morrison and Cocconi, and indeed set out to monitor a narrow band of frequencies encompassing the neutral hydrogen line (also known as H1) during his *Project Ozma* search. Today, nearly four decades later, the hydrogen line region still looks like a good bet to many SETI professionals. But the search need not stop at hydrogen.

Just a little ways higher up the microwave spectrum, around 1660 MHz, is another interesting spectral line, this one being the mark of radiation from interstellar hydroxyl (OH to the chemist). The late Dr. Bernard M. Oliver, who headed the now defunct NASA SETI effort, pointed out in the Cyclops Study (NASA's monumental 1971 research effort documenting the greatest radio telescope never built) that these two clearly discernible signposts occupy a prominent position in the quietest part of the sky. There are no other distinct radiation lines between them. And taken together, hydrogen and hydroxyl represent the disassociation products of water, the one solvent critical to all life processes known to us. This hydrogen-plus-hydroxyl-makes-water line of reasoning led Oliver and others to dub the region between their radiation lines the Water Hole, and to suggest that this may well be the natural interstellar communications band, defined for us all by Nature herself. "Where shall we meet other lifeforms?" asked Barney poetically. "At the water hole, where species have always gathered."

Fortunately for SETI, much classical radio astronomy research already goes on at the hydrogen line, the hydroxyl line, and the spectrum in between. Equipment for this frequency region is abundantly available, and much of it can be readily adapted to SETI use. From radio observatories at Ohio State and Harvard Universities in the US, from the Arecibo Observatory in Puerto Rico, from dishes in Argentina and Russia and Australia and Germany, cosmic anglers continue to cast their radio nets across the Water Hole,

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hoping to snag a big fish. There have been a few nibbles already. And some of those have been detected by radio amateurs.

There are indeed other likely "magic frequencies" which are being scanned for signals of possible intelligent extra-terrestrial origin, and once again, one person's guess is as valid as another's. Nevertheless, since many of the world's radio telescopes are already scanning the hydrogen line and its environs for natural astrophysical phenomena, it's a small step to make their receivers search for artificial signals as well. This is precisely what Drake's *Project Ozma* attempted to do in 1960.

Project Ozma must be considered the very first SETI study. It surveyed two nearby sun-like stars (Tau Ceti and Epsilon Eridani), for just a few weeks, at just one frequency, and detected no extra-terrestrial intelligent signals. Nevertheless, *Ozma* served as a model for dozens of later SETI endeavors, including The SETI League's own *Project Argus* sky survey.

The world's first professional SETI meeting was convened by Frank Drake at Green Bank in 1961. As the agenda for that conference, Drake drafted an equation for estimating the number of possible communicative technologies in the cosmos. He scribbled it on the blackboard, thus:

$$N = R^* \cdot f_p \cdot f_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

I do not intend to analyze the Drake Equation here, or to speculate on assigning values to its various factors. Whole books have already been devoted to that study. Suffice it to say that Drake's Equation is the primary probabilistic tool whereby SETI scientists assess their prospects of success. It is engraved on a plaque which graces the very wall at Green Bank where once hung the blackboard on which it first appeared. Drake himself considers his equation a way of quantifying our ignorance. Its seven factors encompass cosmology, planetology, atmospheric science, evolutionary biology, psychology, technology, and sociology. Thus SETI is possibly the most interdisciplinary of the sciences.

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In the nearly four decades intervening, on the order of fifty different SETI projects have been conducted around the world, with frequency coverage extending throughout the microwave, millimeter-wave, and optical spectra. These searches have been attempted by Government agencies, educational institutions, non-profit scientific organizations, and, more recently, by amateurs.

Although no definitive proof of extra-terrestrial intelligence has yet been received, SETI has achieved scores of tantalizing hints that such signals might indeed exist. Many candidate signals have been attributed to terrestrial, aircraft and satellite interference, others to equipment malfunction and natural astrophysical phenomena, but about one candidate signal per year defies explanation. Since these signals have failed to repeat and have eluded our attempts at verification, we can draw no conclusion save that there is much to be learned about the universe we inhabit.

It's important to remember that SETI was emerging at a time when in the US, nationalism ruled science. Our government had set out in the late 1980's to become the world leader in subatomic particle research, and to do so, Congress had authorized funding for a multi-billion dollar Superconducting Supercollider. Construction was actually begun near Waxahatchee, TX, and some hundreds of millions of dollars expended, before more mundane projects (such as feeding and clothing the populace) began to vie for attention.

At about this time, NASA had a modestly funded but technologically ambitious SETI project under way from headquarters at the Ames Research Center, Mountain View, CA. Budgeted at \$12.6 million annually (about 5 cents per American per year), NASA SETI kicked off on October 12, 1992, the 500th anniversary of Columbus' first voyage of discovery. The plan was to conduct a ten-year search.

Just one year later, in October of 1993, Congress pulled the plug on the Supercollider. Particle physics was deemed wasteful of our limited resources. And if particle physics was wasteful, the reasoning went, SETI was all the more so. We had been

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searching for a full year, argued Senator Richard Bryan (R - Nev.), and not one little green man had yet walked up and said 'Take me to your leader.' Which proved they do not exist.

In a single sweep of the pen, our elected leaders opted to cancel the Superconducting Supercollider, and NASA SETI as well. This makes good economic sense to some, since the cancellation of NASA SETI alone did indeed reduce the federal deficit . . . by all of 0.0006 percent!

Now enter Richard Factor, a New Jersey radio amateur (WA2IKL), science buff, and industrialist of more than modest means. Factor's company, Eventide Inc., was a leader in broadcast and studio electronics, aircraft navigation equipment, and a number of other high-tech products. For years Factor had toyed with the notion of building up his own amateur SETI station, and scanning the stars for signs of life. With the termination of NASA SETI, his resolve intensified.

"I got really mad when Congress killed SETI and the Superconducting Supercollider in the same year," says Factor. The Supercollider, with a price tag of \$10 billion, was beyond his help. But SETI, he decided, could be salvaged. So he founded a non-profit, membership-supported educational and scientific corporation to privatize SETI. And he hired me, then an electronics professor in the Pennsylvania State University system, to run it. The SETI League was not my first taste of non-profit science, but it quickly became apparent that it would be the most challenging. For starters, it fell to me to decide exactly what role a citizen's group could play in resurrecting some component of the late NASA effort.

NASA SETI had been comprised of two distinct but complimentary research elements: a targeted search of nearby sun-like stars, and an all-sky survey for interesting signals of unknown origin. The former, which involves aiming powerful radio telescopes at likely candidate stars for long periods of time, is well suited to large, steerable dishes with their narrow beamwidths and high sensitivities. If we guess right as to which stars

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constitute likely candidates, the thinking goes, the targeted search will provide us with the greatest likelihood of immediate success. But since only a limited number of relatively nearby candidate stars is known to us, concentrating our search in their direction may cause us to miss an equally good star of which we happen to be unaware.

An all-sky survey, on the other hand, makes no *a priori* assumptions as to the most likely direction to explore. The sky survey attempts to sweep out the entire sky which can be seen from a given location. No antenna tracking is required, since it is the entire sky, rather than individual stars, which we seek to scan. While targeted search antennas must be constantly moved, sky survey radio telescopes are operated in meridian transit, or drift-scan mode, in which the experimenter never needs to aim the antennas. Rather, it is the Earth's rotation which turns them.

Shortly after its demise, NASA's late targeted search was resurrected by the non-profit California-based SETI Institute. This scientific organization had been the institutional home of many key players in NASA SETI, and they set about securing private sponsorship. Their aim was to utilize the same receivers and computer analysis tools they had designed for NASA, in a private search of the thousand nearest sun-like stars. They called their search *Project Phoenix*, having risen from the ashes of the late NASA SETI program.

Their success in this endeavor has been an inspiration to all who advocate the privatization of science. If they are as effective at science as they are at fundraising, the SETI Institute cannot miss. *Project Phoenix* employs some of the world's finest radio telescopes, aiming them sequentially at promising targets from a catalog of nearby sun-like stars. But since large antennas have quite narrow beamwidth, they see only a small portion of the sky at a given time. To sweep out the whole sky with such large antennas would consume inordinate amounts of time. A sky survey effort, as opposed to a targeted search, would be best performed with antennas of moderate size.

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Smaller antennas can see more sky within their beam patterns, but have correspondingly less gain, thus more limited range. We achieve reasonable sensitivities through digital signal processing, the application of powerful computers to sift through the cosmic static for patterns which Nature cannot produce. But the antennas need to remain fixed on their targets for a relatively long time period, as the computers average out the background noise. With large antennas, this would require active tracking as the area of interest appears to drift east to west across the sky. Fortunately, when used in meridian transit mode, small antennas, with their relatively wide beamwidths, provide us with far greater signal acquisition time than do the larger antennas typically used for targeted searches.

The SETI League was actively attracting radio amateurs and microwave experimenters around the world, with the promise of some undefined great SETI project. And the sky survey approach seemed ideally suited to the community of amateur radio astronomers desiring to pursue SETI. So that is the aspect of SETI which Factor and his fledgling organization chose to pursue. A grass-roots effort ultimately involving thousands of amateur radio telescopes worldwide, the SETI League's *Project Argus* sky survey was initiated in April of 1996, with only five active stations. Within a year, the network had grown to 28 listening posts, and the League to 500 members in 26 countries. When fully deployed early in the next century, it is expected that *Project Argus* will provide (for the first time ever) real-time full-sky coverage, its thousands of antennas collectively looking in all directions at once, across all four pi steradians of space and time.

How can you join the *Project Argus* team? You might start by checking out The SETI League's extensive documentation on the World Wide Web, more than 700 documents exceeding 21 MBytes! Point your browser to <http://www.setileague.org/>. If you lack Web access, you can email your postal address to join@setileague.org, or phone it in to the SETI League Membership Hotline, 1 (800) TAU-SETI, and introductory material will be sent to you through the mails. The SETI League's Technical

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Manual (ISBN 0-9650707-2-7) and other books will show you how to build your own amateur SETI station, for between a few hundred and a few thousand US Dollars.²

Full sky coverage is not likely to occur overnight, but with a clear goal now articulated, it does stand a reasonable chance of becoming a reality. If signals are out there to be heard, I expect we will be able to detect and verify them, maybe even within my own lifetime. It takes only one verified signal to answer definitively a fundamental question which has haunted humankind since first we realized that the points of light in the night sky are other suns: Are We Alone?

If, on the other hand, after a generation or so of careful searching, we have still detected no evidence of other life, then we may be forced reluctantly to conclude that we are very much alone, the sole communicative species in our corner of the cosmos. Is not that discovery, too, worth the price of admission?

Either possibility, I am continually reminded, boggles the imagination.



² The cost of the required SETI-unique microwave hardware (a suitable feedhorn, preamplifier and downconverter) currently runs around \$500 US. To this you'll need to add a surplus satellite TV dish, ham radio receiver, home computer and analysis software. Thus the exact cost of assembling a station depends largely on your own skill, expertise, and willingness to construct equipment from kits or from scratch.

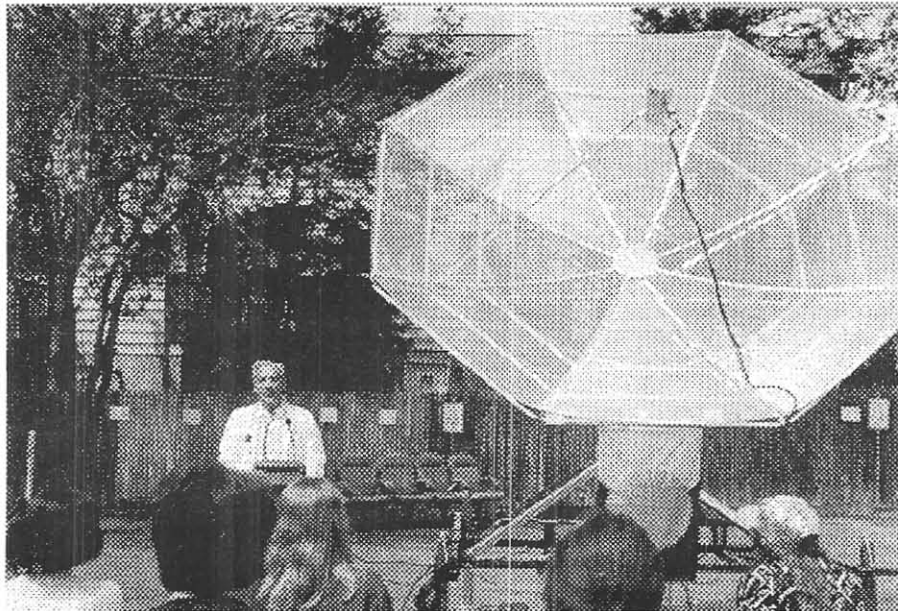


Figure 1

Amid great fanfare the first *Project Argus* station goes on the air, 21 April 1996
 (Downloadable image : <<http://www.setileague.org/photos/argus02.gif>>)

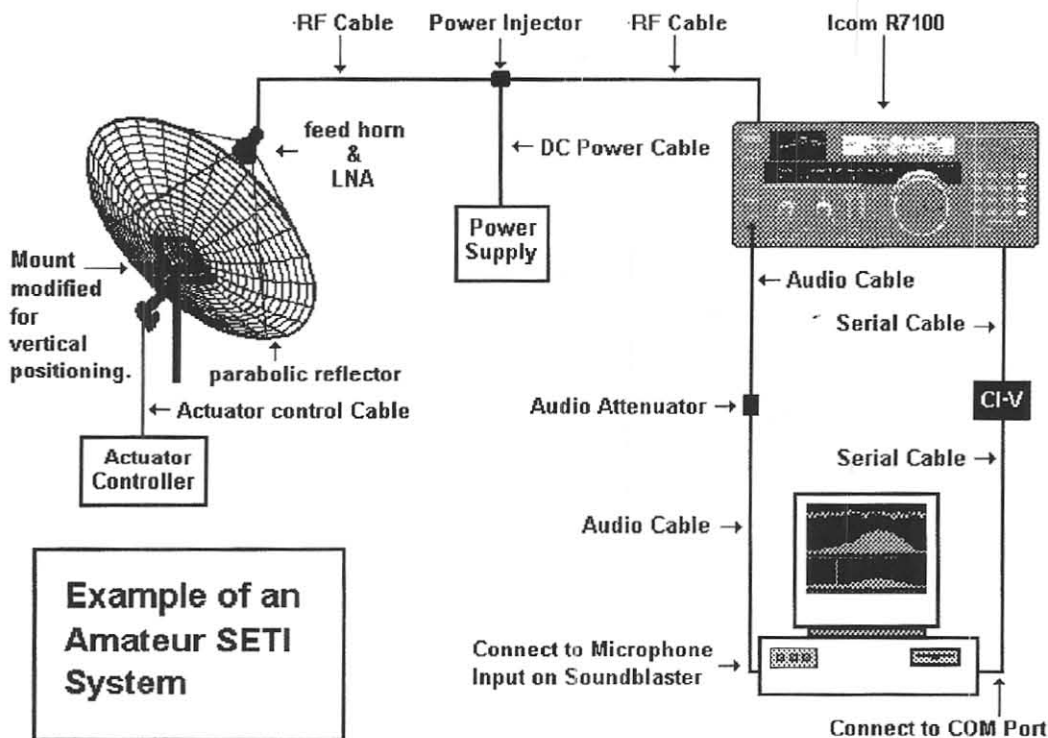


Figure 2

First generation *Project Argus* system by SETI League member Daniel Fox, KF9ET
 (Downloadable image : <<http://www.setileague.org/hardware/layout.gif>>)

ALTERNATIVE START SEQUENCES AND ORBITAL EVOLUTION OF P3D

Viktor W. Kudielka, OE1VKW, AMSAT LM-240

ABSTRACT

The 16 hour, highly elliptic, and highly inclined orbit of P3D is subject to quite substantial luni-solar perturbations. These are influencing the orbital evolution to a great extent. Three problem areas of orbit design and maintenance are discussed in this paper.

The first part deals with the selection of proper initial orbital parameters and/or maintenance operations, so that the orbital evolution guarantees a lifetime of twenty or more years.

In order to avoid long-term space debris, possibilities for a planned reentry after a proper lifetime are investigated in the second part.

In the third part, orbital manoeuvres for arriving at the proposed target orbits from the Ariane 5 GTO, employing the two very different propulsion systems and considering a number of constraints, are presented.

SPACECRAFT CHARACTERISTICS

The P3D S/C has a hexagonal shape, the 400 N bipropellant motor with a specific impulse $I_{sp} \approx 306$ sec is situated at the center of the top panel and the 0.1 N arc-jet with $I_{sp} \approx 484$ sec at the opposite side, slightly off center. The solar panels are initially attached to the six side walls and will remain there during the first flight phases, when the S/C will be spin stabilized. In the operational phase, the S/C will be three-axis stabilized by momentum wheels with magnetic bearings, and four of the six solar panels will be unfolded to provide maximum power.

The power required by the arc-jet is beyond the supply of the solar panels and has to be provided, at least partially, from the battery. Recharging the battery in spin stabilized mode depends on the sun angle with respect to the main axis of the S/C, which will be aligned with the direction of the wanted velocity changes.

Changing attitude in spin stabilized mode as well as unloading the momentum wheels has to be done with magnetic torquers near perigee.

THE NOMINAL TARGET ORBIT

The 16 hour orbital period has been chosen to serve the three main areas, Europe, Far East, and the Americas, during the local morning and evening hours in a two day periodic pattern [3].

Nominal eccentricity is .678, corresponding to 4000 km height of perigee and 47700 km height of apogee.

With the nominal argument of perigee $\omega = 225^\circ$, ground stations at 50° N have an average access time of 15 hours per day, and stations at 40° S have access for 5 hours per day.

While a 24 hour geostationary orbit ($i \approx 0^\circ$) requires for the North-South correction a ΔV of 40 to 50 m/s/year, and a 16 hour Molniya-type orbit ($\omega \approx 270^\circ$) requires between 15 and 35 m/s/year [4], a stabilization of the perigee of a 16 hour orbit at 225° together with the maintenance of eccentricity and orbital period will cost around 90 m/s/year on the average [5]. Figure 1 shows the Kepler elements for such a stabilization. The vertical jumps in inclination and eccentricity are the necessary corrections, assumed to be done once a year, for maintaining the argument of perigee at 225° . Figure 2 shows a similar case for $\omega = 315^\circ$. The corrections of inclination and eccentricity are just in the opposite direction.

A straightforward correction with the arc-jet motor seems not to be feasible for several reasons. The total arc-jet propellant would last for about 6 to 8 years only. The correction manoeuvres will need also a substantial amount of electric power. Considering all required manoeuvres, the communication facilities would be heavily restricted for about two months per year. Total lifetime at 225° would not be much longer than ten years.

Alternative strategies for the orbital evolution are therefore discussed in the following.

CHOICE OF ARGUMENT OF PERIGEE

Besides the second zonal harmonic of the earth's gravitational field, gravitational perturbations

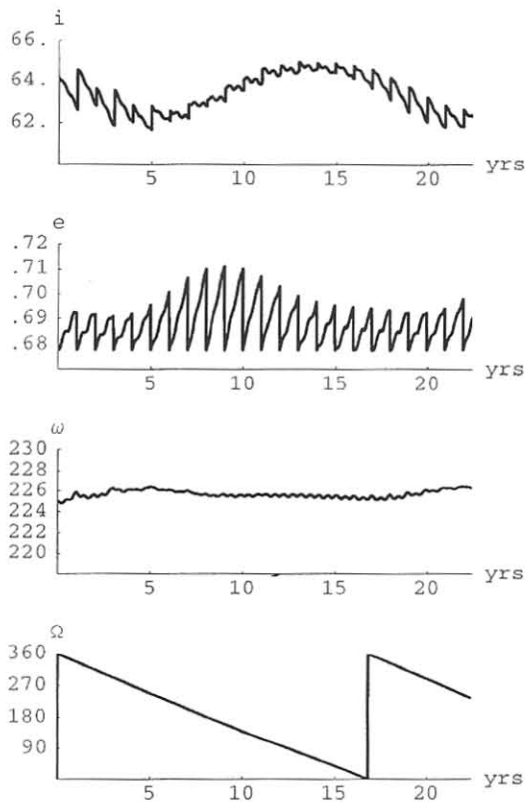


Figure 1: 16^h , highly elliptic orbit at $\Omega = 0^\circ$ with yearly correction manoeuvres in inclination and eccentricity for maintaining $\omega = 225^\circ$.

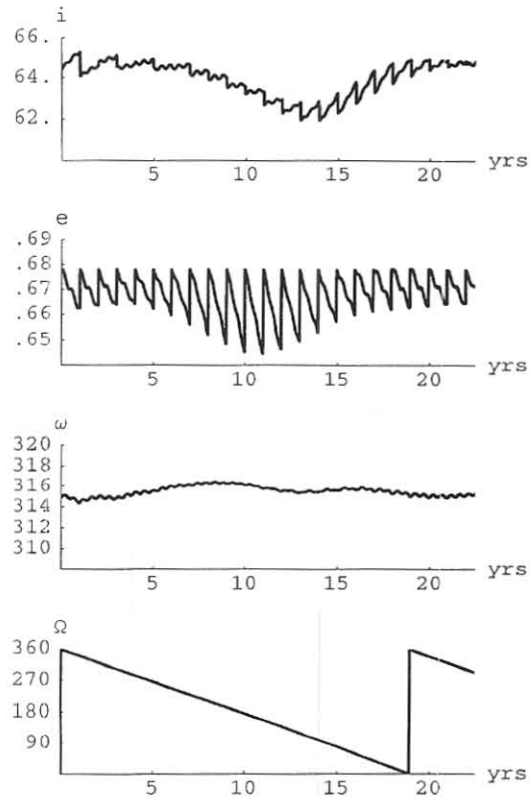


Figure 2: 16^h , highly elliptic orbit at $\Omega = 0^\circ$ with yearly correction manoeuvres in inclination and eccentricity for maintaining $\omega = 315^\circ$.

by the moon and the sun are the decisive factors for the evolution of orbits with periods greater than about ten hours, as long as the height of perigee is above 500 km and the size of the S/C is small, thus reducing solar radiation pressure and other influences to effects of secondary order.

Analysing third body perturbations of the eccentricity [1][7], we see a secular term with $\sin^2 i \sin 2\omega$. For highly inclined orbits, this term is the dominant one. It changes sign at $\omega = 270^\circ$, positive for $180^\circ < \omega < 270^\circ$ and negative for $270^\circ < \omega < 360^\circ$. Figures 1 and 2 demonstrate this for the case of corrections of inclination and eccentricity, while Figures 3 and 4 show practical examples for this behaviour for the case of a freely drifting satellite [6]. The initial inclinations in these latter cases are chosen such that the argument of perigee stays as long as possible within $\pm 15^\circ$ of the initial value of 225° and 315° , respectively. For $\omega = 225^\circ$, we get a lifetime of

around 5 years, since the eccentricity increases pretty fast to the critical value of .802. For $\omega = 315^\circ$, on the other hand, we experience a fairly constant argument of perigee, with the disadvantage of a continuously decreasing eccentricity. Height of perigee is increasing from around 3300 km to around 15000 km within 20 years. For communications at apogee, this evolution is even useful, since the decreasing height of apogee yields a reduction of the path attenuation and might compensate for the decreasing efficiency of the solar panels and the therefore reduced transmit power. But problems might occur with the reduced efficiency of the magnetic torquers, used for unloading the momentum wheels.

Since for communications, both values of the argument of perigee, $\omega = 225^\circ$ and $\omega = 315^\circ$, are completely equivalent, the value $\omega = 315^\circ$ will be preferable, considering the risks of a malfunction of the motor for correction manoeuvres, caused for example by loosing propellant pres-

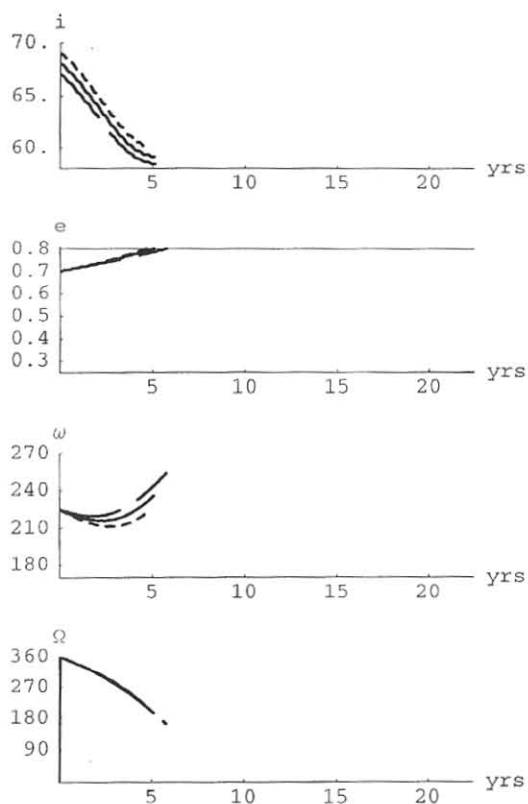


Figure 3: Evolution of 16^h , highly elliptic orbits at $\Omega = 0^\circ$, $\omega = 225^\circ$ for different inclinations ($68^\circ \pm 1^\circ$)

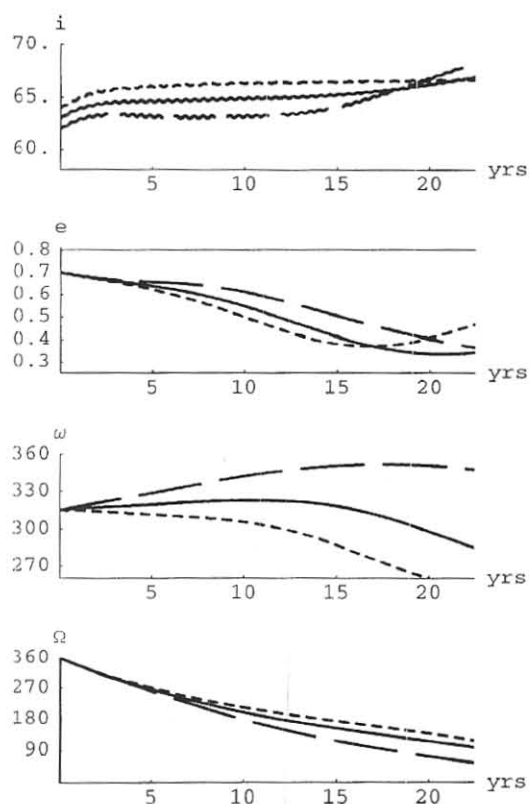


Figure 4: Evolution of 16^h , highly elliptic orbits at $\Omega = 0^\circ$, $\omega = 315^\circ$ for different inclinations ($63^\circ \pm 1^\circ$)

sure with time or even exhausting the propellant altogether.

INFLUENCE OF THE ASCENDING NODE

Figures 3 and 4 have shown the situation only for one value of the ascending node ($\Omega = 0^\circ$). Figures 5 and 6 together with Figure 4 illustrate the variations due to different ascending nodes.

While at $\Omega = 0^\circ$ (Figure 4), the argument of perigee can be held close to 315° for about 15 years and at $\Omega = 60^\circ$ (Figure 5) for nearly 20 years, the situation is much worse at $\Omega = 150^\circ$ (Figure 6), where the argument of perigee cannot be kept within $315^\circ \pm 15^\circ$ for more than ten years.

More calculations show that, for keeping the argument of perigee near $315^\circ (\pm \approx 15^\circ)$ for the longest possible time, the initial values for the inclination ($60^\circ \pm 3^\circ$) are varying in a sinus-like form with the ascending node.

AVOIDING SPACE DEBRIS

Due to third body gravitational perturbations of the eccentricity, there are several possibilities to plan for a reentry of satellites in highly inclined orbits.

For circulating ascending node and circulating argument of perigee, resonance effects are one possibility. AO-13 experienced a 2:1 resonance of apsidal to nodal motion at an inclination around 56° . For an approximately stable argument of perigee, the obvious solution for reentry would be $\omega \approx 225^\circ$, as shown in Figure 3, but this implies a fairly short lifetime.

To extend lifetime, a librating argument of perigee can be considered, starting with an argument of perigee around 315° , passing through 270° , and finally ending around 225° . The major issue with this approach is, that the argument of perigee must really librate, that is, reverse before reaching 180° , and spend enough time between 270° and 180° for a proper reentry.

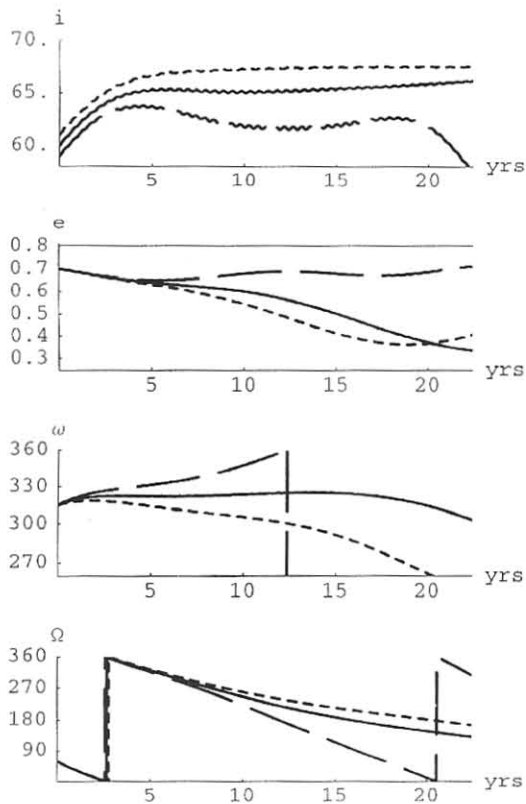


Figure 5: Evolution of 16^h, highly elliptic orbits at $\Omega = 60^\circ$, $\omega = 315^\circ$ for different inclinations ($60^\circ \pm 1^\circ$)

try. But this can be achieved only for a small range of values of the ascending node. Figure 7 shows examples of such cases. Two of them are firmly committed to reentry, while the third one shows a border case, where the argument of perigee might pass a second time through 270° . Of course, in this case atmospheric drag might come into play also.

SAMPLE LAUNCH SEQUENCES

Although the recent developments are requiring more compromises, as will be explained further down, we will show first a few examples of theoretical start sequences with their requirements in terms of ΔV .

Target orbit with $\omega \approx 225^\circ$

The GTO's initial argument of perigee of 178° offers a great chance to change inclination with minimum effort at $\omega \approx 180^\circ$ just a few or-

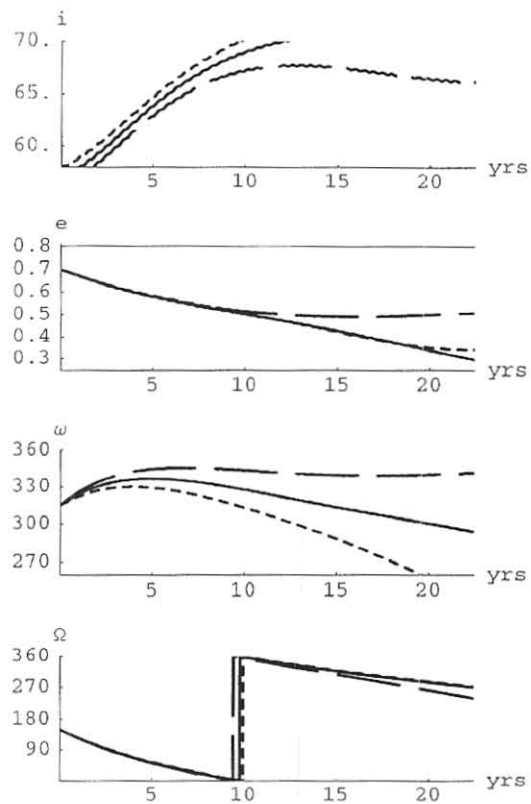


Figure 6: Evolution of 16^h, highly elliptic orbits at $\Omega = 150^\circ$, $\omega = 315^\circ$ for different inclinations ($57^\circ \pm 1^\circ$)

bits after separation. Two manoeuvres with the bipropellant motor are necessary, one increasing orbital period and the other raising perigee from 500 km to 4000 km and increasing inclination from 7° to 60° [8]. Total ΔV would be 1453 m/s, slightly above the nominal value. Balancing properly the propellant masses and planning for some contingency would make this approach achievable. Following these two burns, a drift phase is necessary to obtain $\omega = 225^\circ$. This drift phase will last four to five years, until a final correction of inclination with the arc-jet could be tried. No detailed simulation of this correction has been made, but as a rough guess we can assume a ΔV of 200 to 300 m/s.

One drawback of this approach is the short time between S/C separation and optimal argument of perigee, leaving just a few orbits for orbit and attitude determination, adjustment of attitude and spin rate, and other tests. The same opportunity will occur only after another

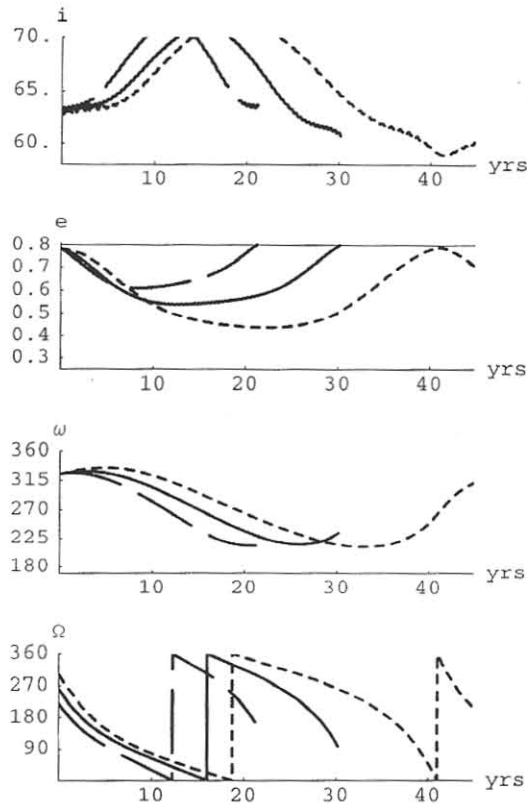


Figure 7: Evolution of 16^h, highly elliptic orbits at $\omega = 325^\circ$ for different longitudes of the ascending node ($\Omega = 260^\circ \pm 40^\circ$)

15 months, when the argument of perigee of the GTO is again at 180° .

Another disadvantage is, that after four or five years an activation of the arc-jet is necessary. The risk of leakage of the highly pressurized propellant tanks after such a long time will not be negligible.

Target orbit with $\omega \approx 315^\circ$

For achieving an argument of perigee of 315° , a start sequence with impulsive maneuvers only is presented here. The sequence could be as follows:

- (1) Increasing the orbital period to 16 hours at one of the first perigee passes. $\Delta V = 191m/s$.
- (2) At $\omega = 180^\circ$, increasing inclination by 32° to 39.8° . $\Delta V = 676m/s$.
- (3) After a drift of the argument of perigee to $\omega = 270^\circ$, which will take about a year,

rotating the orbital plane around the line of apsides by 52° . The new orbit will have $\omega = 315^\circ$ and $i = 61.25^\circ$. $\Delta V = 1073m/s$.

Total $\Delta V = 1939m/s$.

Although we are assuming drift phases in both sample cases, we would need ΔV s in the range of 1700 to 1900 m/s. The different lengths of the drift phases are caused by the different inclinations. A drift of the argument of perigee by 45° at 63° inclination takes much longer than a drift of the argument of perigee by 90° at 8° inclination.

REDUCING ΔV REQUIREMENTS

With the initially planned S/C and propellant masses, the 400 N bipropellant motor would have provided a ΔV of about 1500 m/s in less than 20 minutes, while the 0.1 N arc-jet motor would have provided a ΔV of about 800 m/s in 550 hours of operation.

During the last months of S/C integration it became apparent, that the initial assumptions were far too optimistic. The actual start mass of the S/C will now be around 600 kg, with maximum propellant masses of 192 kg for the bipropellant motor and 52 kg for the arc-jet motor. That means we can expect ΔV s of 1200 m/s from the bipropellant motor and around 500 m/s from the arc-jet motor. Planning for at least a few percent contingency reserve, the new target for the orbital maneuvers will be around 1100 m/s for impulsive maneuvers plus 460 m/s with the arc-jet. All these figures are obviously dependent upon the sequence of operation of the two motors, that is, which propellant is used first.

These changes require new strategies and compromises for the target orbit. First, we have to drop the intention to reach an argument of perigee of 315° immediately. We have just to make shure, that we achieve a value in the range $270^\circ < \omega < 360^\circ$, where we can expect a negative trend of eccentricity. It turns out that, using the initial inclination of the GTO of about 8° and a proper drift period, we can achieve something like $\omega = 352^\circ$.

The second strategy is subject of the next section.

BALANCING PROPELLANT MASSES

The design of the launch sequences for P3D is dependent upon the very different characteris-

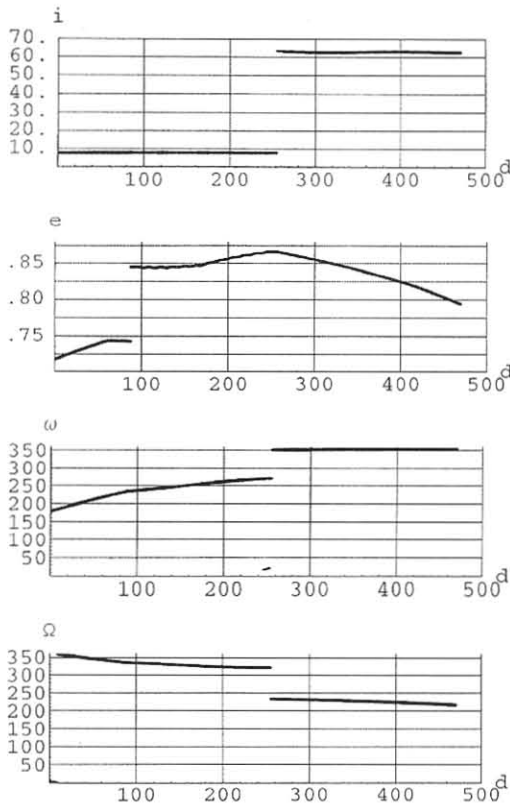


Figure 8: Kepler elements during the first (partially powered) flight phases for a daylight start on 97-09-30

tics of the two motors available. When considering arc-jet operation of one hour per orbit, which might just fit the power budget, we get a ΔV in the order of 1 m/s per orbit. For a 16 hour orbit with eccentricity $e = .678$, this would yield an inclination change at apogee of $0.04^\circ/\text{orbit}$. At low inclinations and orbital periods of 12 or 16 hours, the argument of perigee is changing much faster, and therefore we could not achieve a larger inclination change. Arc-jet operation is more useful for along-track velocity changes, increasing and decreasing orbital period and height of perigee. Larger inclination changes can be done efficiently by the bipropellant motor only.

The cost of an inclination change at apogee depends on the orbital period and on the eccentricity, which is restricted by the minimum height of perigee. There is another constraint on the orbital period, the height of apogee. Reliable communication links for command and telemetry must be maintained throughout. For

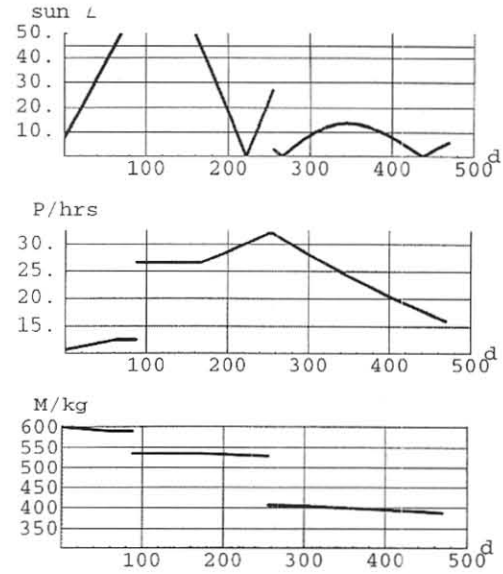


Figure 9: Sun angle, orbital period, and S/C mass during the first (partially powered) flight phases for a daylight start on 97-09-30

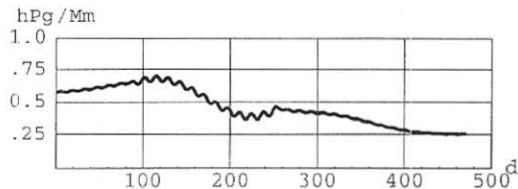


Figure 10: Height of perigee during the first (partially powered) flight phases for a daylight start on 97-09-30

P3D, a 32 hour intermediate orbit with a height of apogee of about 90000 km is thought acceptable.

Although the total ΔV for increasing the orbital period, changing inclination at apogee, and reducing orbital period again pays off only when the inclination change is above 60° , this strategy is perfect for our problem. It offers just the right balance of using the arc-jet primarily for increasing and decreasing the orbital period and the bipropellant motor for the inclination change.

MODIFIED LAUNCH SEQUENCE

Following the strategies outlined in the previous sections, we present here a proposal for a launch sequence fulfilling most of our constraints. Fig-

ures 8, 9, and 10 present a description of this launch sequence.

The steps are as follows:

- (1) As soon as the first tests and the orbit and attitude determination are successful, attitude has to be adjusted for along-track operation of the arc-jet near perigee. Arc-jet operation (in the order of one hour) should go on around each perigee pass as long as the sun angle is favourable (smaller than 45°). In this example, a $\Delta V = 87m/s$ is obtained.
- (2) For increasing the orbital period from the 10.7 hours of the GTO to 32 hours, the arc-jet would need three or four periods of proper sun angles. In order to reduce this time, the bipropellant motor is used. The increase of orbital period has to be adjusted such that the arc-jet can achieve the 32 hour orbital period in the next period of proper sun angles. Before the operation of the bipropellant motor the attitude has to be changed by 180° and the spin increased to proper values. $\Delta V = 285m/s$.
- (3) As soon as the sun angle is becoming favourable again, the attitude has to be changed once more by 180° , and the arc-jet operation will continue until a 32 hour orbital period is reached. $\Delta V = 52m/s$.
- (4) The previous phases should be finished before an argument of perigee $\omega = 270^\circ$ is reached. Now the attitude has to be adjusted for the major inclination change at apogee effectuated by the bipropellant motor. About 255 days after start an inclination change of 64° with a $\Delta V = 790m/s$ will be made. By this inclination change also the argument of perigee and the ascending node will be changed by around 80° .
- (5) Now the satellite could be despun, and the three-axis stabilized mode could be started. Since in the highly inclined orbit the sun angle remains favourable, decreasing the orbital period by the arc-jet can go on at each perigee pass. $\Delta V = 233m/s$.
- (6) About 570 days after start a 16 hour orbit with $\omega = 352^\circ$ and $i = 63.6^\circ$ will be reached.

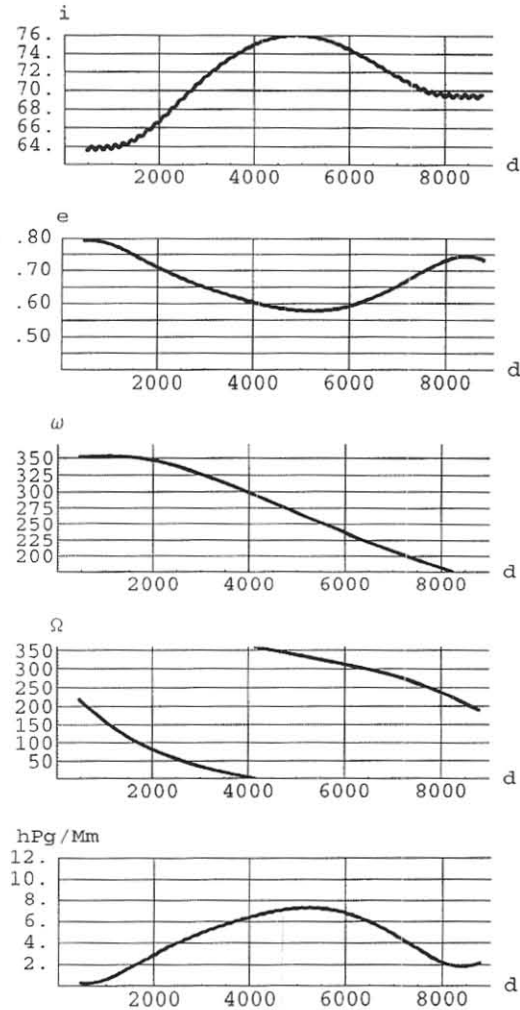


Figure 11: Orbital evolution for 24 years after start without any further correction

Total ΔV s add up for the bipropellant motor to 1075 m/s and to 372 m/s for the arc-jet motor. There are some margins, which should allow to make further refinements and also to cope with a delayed start.

Figure 11 shows the orbital evolution for 24 years in case of no further correction. The argument of perigee will be nearly constant for several years and then will continuously decrease. 270° will be reached after about 15 years. The height of perigee will then be at its maximum of about 7000 km. The apogee will be over the northern hemisphere for 22 years. No reentry will happen during the span shown.

FURTHER REFINEMENTS

When looking at Figure 10, we see a significant variation of the height of perigee and especially a significant decrease during the reduction of the orbital period from 32 to 16 hours. This will not be acceptable, and further corrections have to be included in the plan.

In the simulations made so far only one hour arc-jet burns have been assumed. But as soon as the satellite is in a high inclination orbit, and the orbital period is also in the order of a full day, the power budget will be very much improved, and longer burns of the arc-jet will be possible. This will slightly improve the overall schedule.

START TIME AND DATE

So far we have assumed a daylight start with the line of apsides of the GTO in the direction to the sun. This gives an optimal sun angle for the spin stabilized S/C with its solar panels around the hexagonal structure and with an attitude for orbit corrections at perigee or apogee, in case of any irregularities during the start phase. The second active payload on Ariane flight 502 has somewhat different requirements for a special tether experiment. At the time of writing this paper the launch window is still an open issue, and we must be prepared for some more changes of our launch sequence.

As more simulations show, a delay of the start by one or two months will cause a temporary, but significant decrease in the height of perigee at the beginning of the final drift phase. Since we are approaching a period of increasing solar activity, this drop might not be acceptable, and additional manoeuvres for increasing the height of perigee will be necessary, consuming a little bit more propellant and time. Some margins have to be reserved for such cases.

SUMMARY

Due to the ratio of satellite dry mass and propellant mass, the initially planned nominal orbit can neither be achieved nor maintained for a longer period of time. Compromises have to be found for the orbit and its evolution as well as for the transfer from GTO to the final orbit. Time is one item which can be traded in.

Orbital manoeuvres will be necessary until about 14 to 17 months after start. Several

burns of the bipropellant motor as well as several hundred burns of the arc-jet will pose an extreme workload on the command stations in terms of orbit and attitude determination and motor and magnetic torquer control, not comparable at all to AO-10 or AO-13. During this period general communications via the satellite will be restricted, since much of the available electric power will be used for the arc-jet, and the spacecraft's directional antennas will not be pointing to earth. Patience is called for.

ACKNOWLEDGEMENTS

Thanks are due to the OeVSV, the Austrian radio amateur association, for supporting the P3D mission analysis project for more than three years.

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A PRACTICAL GUIDE TO P3D OPERATION ON MODE L AND ABOVE

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Phase 3D (although not yet launched at the time of writing) is a marvel of technology. Its matrix-coupled transponders, wide range of experiments and powerful computers offer, literally, something for every ham. And even for SWL's and non-hams. But to those who would like to work through the satellite, the large variety of modes is almost bewildering. And each mode and band looks strangely like money. While ham gear is getting more versatile, it sure isn't getting any cheaper. And all these modes; once one finds a mode of interest, how does one do it? This paper will offer a few of the basics involved with operating the higher frequency modes, and doing it without breaking the bank.

Which band?

Although the official stance is that the frequency pairs and modes of operation will be determined by a committee of the largest contributors, it is most likely that, at least for the first years, the most used band pairs will be those for which equipment and experience already is in place. The most popular will probably include modes U/V (436 up and 146 down; formerly mode B), V/U (146 up and 436 down; formerly mode J) and followed by L/U (1269 up, 436 down; formerly mode L), then mode U/S (436 up, 2401 down; formerly mode S). Many European and Japanese hams from large metropolitan areas have great difficulty with any scheme that includes a V band (146 MHz) downlink due to narrow band allocations and large repeater populations, not to mention encroaching commercial usage, so these modes will probably decline in popularity. It is not known at this time whether P3D will include 29 MHz downlinks, but the original concepts used 10 meters only as a broadcast band.

Station requirements: Downlink (All antennas RHCP)

V (146 MHz)	7x7 element Cross Yagi	23 dB S/N
	Crossed dipoles over reflector	16 dB S/N
U (436 MHz)	10x10 el Cross Yagi	24 dB S/N
	Crossed dipoles over reflector	13 dB S/N
S (2401 MHz)	60 cm Parabolic Dish	26 dB S/N
	14 Turn Helix	18 dB S/N
X (10450 MHz)	60 cm Parabolic Dish	24 dB S/N
K (24050 MHz)	60 cm Parabolic Dish	13 dB S/N

Station Requirements: Uplink (All antennas RHCP)

V (146 MHz)	7x7 element Cross Yagi	10 Watts
	Crossed dipoles over reflector	50 Watts

meter band on his HF radio. All modes will be received exactly as they appear on 2 meters. The converter can also be remotely mounted, a real advantage as frequencies increase and cable losses increase. Both of these features point to the use of converters as the only practical method of operating on the S, X and K band downlinks on P3D. On X and K, it is mandatory that the converter be mounted right at the antenna feedpoint to minimize noise figure by reducing feed line loss (which becomes noise figure). Variations in actual LO frequency will show up as variations from actual in the HF radio frequency readout (this is generally of little concern to the satellite operator, but of large concern to moonbounce and certain other weak-signal operations). A receive-only converter is not a stopgap measure but a real, practical method of expanding the frequency range of existing radios. This is especially true for satellite operations, since many of our bands are downlink only.

A real advantage in the use of converters is in performance, where really good HF radios, available at reasonable prices, can be adapted to the microwave bands. Older Drake and Collins radios (yes, with vacuum tubes!) can provide exceptional performance on SSB and CW. In my own satellite and moonbounce station, I have never owned a radio that would tune above 30 MHz, yet I operate up through 10 GHz. My old Drake R4B and T4XB, with a variety of converters and transverters, work just fine.

Frequencies: Satellite versus Terrestrial

Note that a converter or transverter made for terrestrial use is not directly suitable for satellite operation because the frequencies are different. It is frequently possible to take a converter designed for, say, the weak signal portion of a band, and convert it to use in the satellite sub-band by changing the crystal in the LO, then tweaking the LO to get the crystal to oscillate. On 23 cm, which extends from 1215 MHz to 1300 MHz, the most common transverters are for the weak-signal portion of the band at 1296 MHz. These typically use an 1152 MHz LO (usually a 96 MHz crystal and 12x multiplier) to give a 144 MHz IF. For use on the satellite sub-band, 1268 MHz should equal 144 MHz, requiring a 1124 MHz LO obtained by changing to a 93.667 MHz crystal. While the filters in the common "no-tune" transverters usually work fine with minor LO tweaking, some weak-signal converters may also require realignment of their RF sections to move them to the satellite sub-band. Be sure you ask the manufacturer before you buy! This is true in all the satellite sub-bands. On 13 cm, weak signal work occurs on 2304 MHz, while satellite operation is on 2400 MHz and 2448 MHz (proposed). "No-Tune" transverters for 2304 MHz generally work fine on 2400 MHz, but their sharp-edged printed filters tend to fall off by 3-6 dB at 2448 MHz, diminishing performance there. On 6 cm, weak signal is on 5760 MHz, satellites on 5668 MHz. On 3 cm, weak signal is on 10385 MHz and satellites are on 10450 MHz.

Practical Transverters

There are few transmit-only converters, but they work with exactly the same principles as the receive converters. One will occasionally run across an "LMW" L band (1269 MHz) transmit converter, designed specifically for satellite mode L uplink only. Transverters are more common. Where only an up or downlink is required in a certain band, simply use the appropriate section of the transverter and ignore the other. 2 meters,

U (436 MHz)	10x10 el Cross Yagi	10 Watts
	Crossed dipoles over reflector	40 Watts
L (1269 MHz)	12 Turn Helix	10 Watts
S (2401 MHz)	60 cm Parabolic Dish	5 Watts
C (5670 MHz)	60 cm Parabolic Dish	10 Watts

Equipment: Separate Radios

Since satellite communications is cross-band, full duplex, use of separate radios for each band is the most straightforward. The ham world is well populated with 2 meter and 70 cm multi-mode radios and powerful, inexpensive amplifiers. This approach is durable and versatile.

Equipment: Integrated Radios

Another approach is to buy a rig such as the extremely popular Yeasu FT-736R (and similar radios) that incorporate a variety of user-selectable bands in one box. Buy a 736R with plug-ins for 2 meters and 70 cm, add a couple of antennas and you have a ready-made satellite station. Decide you want to move up to mode L (1269 MHz)? Add another plug-in and the appropriate antenna and off you go. The advantage of the multi-band rig is that it is compact, all the various plug-in modules and bands are designed to work together, and it may be less expensive than separate rigs. The disadvantage is that you are limited to 23 cm (1269 MHz) as the highest frequency band available and the modules are pricy.

If you looked inside the FT736R, you would see a full-duplex (capable of transmitting and receiving simultaneously) 10 MHz all-mode HF radio. To this 10 MHz radio are added modules that convert the frequencies of the bands of interest to this 10 MHz IF. In this manner, a single HF radio with a lot of capability can be used on a variety of bands, while avoiding the cost of duplicating the low frequency sections for every band.

Equipment: Converters

There is yet another approach to satellite operation with significant advantages, not the least of which are price and versatility. This is through the use of external converters attached to existing VHF or even HF radios. Converters come in 2 basic forms; the "receive only" converter, and the "transverter", which converts both receive and transmit functions from the band of the existing radio to the band of interest. A "transverter" coupled to an HF radio is exactly the operating principle of the FT736R.

A receive-only converter consists of a broadband frequency selective network feeding RF to a mixer. A crystal controlled Local Oscillator supplies the second (LO) input to the mixer. The mixer mixes the RF and LO signals and produces an Intermediate Frequency which may be either the sum or the difference of the LO and RF frequencies. There is usually some broadband network following the mixer that both selects the desired mixing product and properly terminates the mixer. To use a common example, if a converter with a 116 MHz LO is feeding a 10 meter HF receiver, 144 MHz RF will be seen as 28 MHz on the HF receiver. Since the mixer is "subtracting" the 116 MHz LO from the 144 MHz RF input signal, it will appear to the operator that he is tuning the 2

70 cm and 13 cm have both up and downlink usage, so transverters are especially useful on those bands. A significant limitation to the use of transverters for satellite operation is that satellites never have up and downlinks in the same band, therefore, even with a transverter, another receiver or transmitter (with converter, if necessary) is still required for full duplex operation. Transverters are sometimes available with different IF's. In order to operate as many bands as possible with as few separate radios as possible, it is advantageous to set up a matrix that graphically equates bands and IF's.

Try this example. Assume you have separate 2 meter and 70 cm transceivers. You need to transmit with one and receive with the other for full duplex operation. These go on the X-axis. Then, list desired frequency combinations on the Y-axis. Now, add converters/transverters with various IF's in such a manner that you do not use the same IF for both transmitting and receiving. Try this with different IF's until you get an arrangement that suits your gear.

Old frequency designations are in parenthesis. I have left out S up and K down.

Freq.	146 Tr	146 Rec	436 Tr	436 Rec
V/U (J)	Tr			Rec
V/S	Tr			(S conv w/436 IF)
V/X	Tr			(X conv w/436 IF)
U/V (B)		Rec	Tr	
U/S (S)		(S conv w/146 IF)	Tr	
U/X		(S conv w/146 IF)	Tr	
L/V		Rec	(L xvrtr w/436 IF)	
L/U (L)	(L xvrtr w/146 IF)			Rec
L/S	(L xvrtr w/146 IF)			(S conv w/436 IF)
L/X	(L xvrtr w/146 IF)			(X conv w/436 IF)

Now change the IF's of the converters and refigure the matrix; see what happens!

Transverter interfacing

The most difficult part of interfacing the transmit section of a transverter (or transmit converter) to an HF radio is throttling the HF transmitter down to a low enough output power level to keep from frying the transverter. Transverters seldom require more than +10 dBm (10 mW the decibel-impaired) and generally require less. 0 dBm (1 mW) is a typical input level for a double balanced mixer. How do you get this low a power from a 100 watt transmitter? Sometimes, it's not easy! If you are lucky, your HF or VHF transceiver may have a transverter port. These have low level RF outputs and receiver inputs and switching lines in a single multi-pin plug. Older Yeasu and Kenwood HF transceivers frequently had them. My Kenwood TS-430S has a transverter port that automatically disables the transmitter and provides 5 mW of RF. Very convenient.

While it is sometimes possible to adjust the output power down to a sub-watt level with the RF gain control, this is usually not a good idea, as a moment of forgetfulness will result in a cooked transverter. Some radios have a low-power output setting for the QRP crowd, or some internal modification to get there. Contact the radio's

manufacturer. One way or the other, it is necessary to know what the output level is and then reduce it to a useable level. The ARRL Handbook (and other sources) have excellent primers and construction information on attenuators. Always start with too much attenuation, as that way you are less likely to blow something up. It is good idea not to use more than about 10 dB attenuation per stage; use attenuators in series. Also, since converters are linear to very low input levels, you can always amplify a weak output signal up to something useable.

A rule of thumb is to design the attenuation scheme to allow the transmitter's controls to be set at normal range during operation. This prevents expensive blunders.

Tube-type transmitters with pentodes in the output can be modified for low output power by disabling the output stage and tapping RF out of the driver stage plate circuit with a low value capacitor. The output stage can be disabled by removing the screen voltage (doesn't work with triodes!). If you aren't sure what you are doing, refer this to someone competent to perform this. Tube-type transmitters have lethal internal voltages and are extremely dangerous!

Interfacing packaged transceivers to stand-alone transverters (those that have separate receive and transmit IF ports) can be troublesome if the transceiver has only a single antenna connector that is used for both transmit and receive. Frequently, the transceiver will have a separate receiver antenna port, but it may be buried in an accessory connector. Generally, for satellite use, the transceiver/transverter combination will only be used for one function at a time, so switching between transmit and receive is not necessary.

One additional note on interfacing transverters to transceivers. Some transceivers have been known to transmit a strong pulse when turned on, which can be very hard on any receiving gear or preamp in the line. Many mode S operators picked up the habit of not connecting their mode S converter to the antenna port of their transceiver until after the transceiver was powered up.

The bands

Obtaining suitable equipment, amplifiers and antennas to provide sufficient uplink power and downlink performance is easy on 2 meters and 70 cm. In fact, P3D has such powerful transmitters on these bands, short beams or even omni-directional antennas may be satisfactory. Following is an equipment summary by band.

L band (23 cm) uplinks

The 23 cm band should be very popular on P3D. Transceivers and transverters are available from DEM, SSB, Parabolic and others. Amplifiers are both commercially available and home-buildable. Most commercial and home-brew amps, as well as commercial transceivers, use the same output amplifier! The M57762, commonly referred to as a "brick", is a readily available linear amplifier module for the 23 cm band. The device only requires DC power, input and output connections and a heat sink to turn less than 1 watt RF input into 10-15 watts RF out on 23 cm. Also, the M67715 module requires less than 10 mW in to produce over 1 watt out and provides the ideal driver for the M57762. See the 1994 ARRL Handbook. Amplifiers based on these modules are easy to build, require no tuning at all and work quite well.

Most transverters for 1269 MHz use an 1124 MHz LO, so 145 MHz equates to 1269 MHz.

S (13 cm) band

The next band, 13 cm, is unusual in that both up and downlinks are permitted. Of course, they will never be used together. AO-13 sported an S band downlink transmitter and was fairly easy to receive with a 2 foot diameter dish, preamp and converter. Mode S was quite popular on AO-13. "Barbecue grill" dish antennas are readily available and quite inexpensive (Myers Communications). Downlink converters are available from Down East Microwave (kits and built; must be adapted for outdoor mounting, preamps sometimes required), SSB Electronic (ready made, suitable for mounting outdoors at the antenna feed, no preamp required), Parabolic AG (ready made, suitable for outdoor mounting) and Myers Communications (ready made, suitable for outdoor mounting).

Uplink on 13 cm is another story. While 13 cm transverters are easily available from Down East Microwave (kits or built) and SSB Electronic (built), getting from 10 mW to 5 watts RF out is not. SSB Electronic has 10 watt amplifiers available, based on discrete components. DEM presently has a 2 watt amplifier available and may have higher power modules available in the near future. All are quite expensive. The problem is that there are no mass-produced commercial amplifier modules for this band. This may change with the coming popularity of "wireless" LAN's, which operate on 2 to 2.4 GHz. I have seen 2 watt "bricks" advertised, but they do not seem to be available. Several could be paralleled for higher power.

I have found no easy, inexpensive way to get 5-10 watts RF output on 13 cm. For the builder, designs exist for use of AT8140 power GaAsFET's to the 2 watt level and various transistors to even higher power in class C operation, but these are not for the faint of heart... or pocketbook! DEM handles such amplifiers and devices. Promising designs have been published in DUBUS, the German technical magazine, which use the MGF0905 power GaAsFET. These devices offer 6-7 dB gain and are useable up to 5 watts, but have a \$60 list price tag. This gain level dictates several stages to get from MMIC power level (10 to 50 mW, depending on device) up to 5 watts out. Circuit boards and parts are available from Eisch Electronic.

For the serious and skilled builder, VE4MA has published designs for coaxial cavity amplifiers that use the 7289 planar triode tube. The tubes are cheap as surplus and only cost \$60 new, and can be pushed to over 50 watts output and as much as 15 dB gain. I speak from the experience of having built several; they are quirky, difficult to build and tune, require high voltage power and water cooling and are definitely only for the most rabid experimenters!

S band transceivers generally use 2 meter IF's, with 2256 MHz LO's, so 145 MHz equates to 2401 MHz. A converter that could be build for various IF's was featured in the AMSAT Journal, Jan/Feb. 1997.

C (6 cm) band

This will be P3D's highest uplink band. No downlink is available. C band transverters are available both as kits (DEM and Eisch Electronic) and built up (DEM and SSB Electronic). Numerous designs for LO multipliers and mixers have been

published over the past few years in QEX by Zack Lau W1VT, Paul Wade N1BWT and others. Note that the weak-signal frequency is 5760 MHz, whereas the satellite uplink frequency is 5668 MHz. Be sure to specify. DEM is developing a 5668 MHz transmit converter, designed specifically for P3D, with a 1269 MHz IF. This would be well suited for tower mounting, where the L band uplink signal could be switched to either an L band amplifier and antenna or the C band converter, amplifier and antenna. Most other designs use a 2 meter IF.

Power on 6 cm is even trickier. The only practical (and reasonably priced) method of generating a strong signal on this band is through the use of surplus solid state telephone link amplifiers. These offer high gain (40 dB) and 10 watts RF output, ideal for P3D. However, availability is sporadic; it took me 1 1/2 years to find one, and that had to be shipped from 1000 miles away! However, these amplifiers may be more readily available and less expensive than high power on 2400 MHz, so C uplink may be more popular than S uplink. Go figure.

X (3 cm) band

X band may be the big-hitter microwave downlink. 10 GHz is popular and well used on terrestrial paths. The ARRL even sponsors an annual 10 GHz contest. Moonbounce on 10 GHz is a reality. The technology is known and parts are available.

With a 60 cm (2 foot) diameter dish, a preamp and converter should be mounted right at the antenna feed. Converters are available from the usual sources (DEM and SSB), as well as in kit form from the RSGB (Radio Society of Great Britain) and Eisch Electronic. IF's of 144, 432 and 1296 MHz are available. Note that the satellite frequency is 10450 MHz, while terrestrial is 10385.

K (1.5 GHz) band

Truly an experimenter's band, transverter parts are available from Eisch Electronic and HB9MIN in Switzerland. A low-noise preamp/converter mounted directly at the feed of a 60 cm dish will be required.

Equipment Suppliers

Down East Microwave
Steve Kostro N2CEI
954 Rt. 519
Frenchtown, NJ 08825

SSB Electronic
Parabolic AG
Gerry Rodski K3MKZ (rep)
124 Cherrywood Dr.
Mountaintop, PA 18707

Myers Communications
Bob Myers W1XT

P.O. Box 17108
Fountain Hills, AZ 85269-7108

RSGB Microwave Committee Components Service
P. Suckling
314A Newton Road
Rushden, Northants, NN10 0SY
UK

Eisch Electronic
Abt-Ulrich-Str. 16
89079 Ulm - Goggingen
Germany

Amateur Radio Satellite Imaging - The Past, Present and Future

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ABSTRACT

A brief overview of Amateur Radio Satellite imaging hardware that has already flown in the past, is currently operational and those currently under construction and awaiting launch.

A step-by-step description of what hardware and software is required to decode and display these Amateur Radio Satellite images - especially aimed at those who have never attempted it before. In particular, I will demonstrate how to use WiSP by Chris Jackson G7UPN to collect the raw images from the 9600 baud satellites and CCD Display by Colin Hurst VK5HI to display the images and some post-processing software such as PaintShop Pro.

OVERVIEW

UoSAT-OSCAR-9

As far as my research indicates the first Amateur Radio Satellite to have an imaging capability was *UoSAT-OSCAR-9* (UoSAT-1 or UO-9) which was built at the University of Surrey, Guilford, England and launched on the 6th October 1981. UO-9 carried a Charge-Coupled-Device (CCD) camera to send back pictures of the earth formatted to be viewed on a regular TV after minimal processing. I was never fortunate enough to decode a picture from UO-9's CCD camera experiment but like Bob Diersing, N5AHD I did successfully decode many hours of 1200 baud ASCII telemetry. With the exception of a brief period between the 4th April and the 20th September 1982 when a software glitch caused both UO-9's 2M and 70cm beacons to switch on together which de-sensed the command receivers, UO-9 performed flawlessly until it re-entered the earth's atmosphere and burned up in late 1989.

UoSAT-OSCAR-11

The next Amateur Radio Satellite to have an imaging capability was the next satellite in the UoSAT series *UoSAT-OSCAR-11* (UoSAT-2 or UO-11) which was launched on 1st March 1984. UO-11's CCD camera was an improved version of the unit flown on UO-9 and had an active area of 384x256 pixels, with each pixel having 128 grey levels. The image was stored in 96K of RAM in the Digital Store and Readout (DSR) experiment. Once again, even though I captured many hours of UO-11's 1200 baud ASCII telemetry I was never fortunate enough to decode a picture from UO-11's CCD camera.

However, I remember reading with great envy the UO-11 Bulletin #008 on the 29th May 1987 which stated that 'at least one UoSAT receiving station in Europe (HB9RKR) has been listening in on the CCD and magnetorquing experiments which use the 4800 bits/sec DSR output on 70cm. HB9RKR is using a home-made high speed demodulator and wide-

band receiver which he described in OSCAR News.' I never did establish if he actually succeeded in displaying a UO-11 CCD image.

UoSAT-OSCAR-15 and WEBERSAT-OSCAR-18

Next came *UoSAT-OSCAR-15* (UoSAT-4 or UO-15) another in the UoSAT series and *WEBERSAT-OSCAR-18* (WO-18) one of first batch of AMSAT-North America's Microsats. WO-18 was built at the Weber State University and was launched on the 22nd February 1990 alongside three other Microsats - AMSAT-OSCAR-16 (PACSAT or AO-16), DOVE-OSCAR-17 (DOVE or DO-17) and LUSAT-OSCAR-19 (LO-19) and UoSAT-OSCAR-14. Unfortunately, UO-15 suffered a catastrophic failure shortly after its third orbit, so no pictures were ever received from UO-15's CCD camera experiment. WO-18's full-colour CCD camera did digitise Earth images and downlink them as a AX.25 serial data stream using 1200 baud PSK using the Pacsat Broadcast Protocol. WO-18's CCD camera has a resolution of 700 pixels by 400 lines, and could be viewed with Weberware software running on a personal computer having adequate graphics display capability. Digitised NTSC video from the camera is assembled into packets that are sent as unnumbered information UI frames. Ground stations must receive this data over several passes to capture a complete image. Each image contains about 200 kilobytes of data. WO-18 can also transmit CCD images on 70-cm using an analog "turbo" mode that is much faster than using the AX.25 packet downlink. This was the first Amateur Radio Satellite from which I received an image from space. I would have to be honest and say that I was rather disappointed with the quality of the pictures but in the process I had upgraded my station to the point that I had an excellent receive capability on 70cm.

UoSAT-OSCAR-22

Next came another in the UoSAT series called *UoSAT-OSCAR-22* (UoSAT-5 or UO-22) which was launched on 17th July 1991. The primary purpose of UO-22, however, was to provide non-amateur radio related store-and-forward digital communications for VITA and SatelLife, a non-profit, humanitarian organisation. One of the most unique aspects of UO-22 is its Earth Imaging System (EIS), designed by University of Surrey doctoral student Marc Fouquet. The EIS was designed to capture earth images from low-earth orbit using a CCD camera, and broadcast those images to ground stations using Amateur Radio frequencies and the AX.25 Amateur Radio Packet Radio "Pacsat Broadcast Protocol" when the spacecraft was not providing service to SatelLife. The monochrome CCD imager produces a CCIR video image having a resolution of 578x576 pixels with an aspect ratio of 4:3. Images taken by the CCD camera are first digitised using an 8-bit half-flash analog to digital converter, and then stored in RAM for later processing and transmission over the downlink transmitter using 9600 baud FSK. Received images can be captured and displayed using a personal computer with suitable graphics capability. The images can also be converted to popular GIF and JPEG formats and viewed in those forms if so desired. The first widely available software for displaying these images came from Harold Price, NK6K and the images were 'stunning'. Although in those early days it was rather difficult to download the raw image files which were over 300K bytes in length.

A particularly interesting aspect of UO-22 was that while it was serving the needs of SatelLife, UoSAT-OSCAR-14 (UO-14) was providing the Amateur Radio Service with its only 9600 baud packet radio store-and-forward communications satellite. In late December 1991, UoSAT spacecraft controllers introduced an enhanced broadcast server on UO-14 which did a lot to reduce congestion on the satellite's single uplink frequency. However, since UO-14 had only 256 kilobytes of memory, the spacecraft used a RAMDISK system which could only store 400 packet messages at a time. With uplink contention reduced, packet gateways on line, and more than 150 stations regularly active on OSCAR-14, the 400 message limit was often exceeded. When the satellite message space became full, new messages could not be uploaded and older messages had short lifetimes before being deleted automatically to make way for new messages.

After some initial use, it became clear that OSCAR-22's CCD imager success and the less than optimum conditions on UO-14 required that some operating changes to both UO-14 and UO-22 be made. Amateur Radio stations around the world were downloading CCD Earth images several times per week, with each image containing more than 300 kilobytes of data. Furthermore, it was discovered that UO-22's high power amplifier which produced excellent output on amateur frequencies, did not work reliably on the non-amateur frequencies used by SatelLife operations. Taking into account the resources available and the obligations to SatelLife, HealthNet and VITA, UoSAT controllers decided to swap the roles of UO-14 and UO-22 in an attempt to optimise the capabilities and resources of each spacecraft. On the 5th February 1992, all non-Amateur Radio traffic, both SatelLife and VITA, moved from UO-22 to UO-14 which no longer transmits on its amateur downlink frequency. All amateur traffic moved from UO-14 to UO-22, and UO-22 now operates as a dedicated Amateur Radio satellite transmitting constantly on its amateur downlink frequency.

Now that UO-22 is operating exclusively in the Amateur Radio Satellite Service, the spacecraft can dedicate its 512 kilobytes of memory for storing as many as 800 packet messages. Two 9600 baud uplink receivers are available on frequencies of 145.900 and 145.975 MHz, and the single downlink transmitter on 435.120 MHz is available on a non-interrupted basis.

While researching this paper I found it quite amusing to read the following statement: 'The only minor inconvenience occurs when some users access the satellite to download CCD images while others connect just to check their mail. Solutions to these problems are being investigated by UoSAT controllers, while more efficient spacecraft operating software is developed to maximise the efficiency of UO-22 operations.' I find it quite ironic that (in my humble opinion) the single most significant event to 'maximise the efficiency of UO-22 operations was the development of the ground station software called WiSP written by Chris Jackson ZL2TPO and now has the callsign G7UPN and is working at the University of Surrey continuing to maximise the efficiency of the UoSAT operations by continually enhancing the ground station and onboard software.

In the early days of the digital satellites it was quite a daunting task decoding the signals as you had to come to terms with a suite of DOS-based Pacsat terminal software such as PB, PG, PHS, and PFHADD. A UoSAT ground station was also required to have a 9600 baud

packet radio modem and meant they had to get into their radios to connect directly to the RX discriminator and TX varactor circuitry (fortunately for some of the newcomers the new radios are starting to come '9600 baud ready').

KITSAT-OSCAR-23

Next came ***KITSAT-OSCAR-23*** (KITSAT-A or KO-23) which was launched on 10th August 1992 and was an enhanced version of the UO-22 spacecraft. It was built by engineers of the Korean Advanced Institute of Science and Technology (KAIST) after participating in a Masters degree course in Satellites and Telecommunications held at the University of Surrey in England. KO-23 carries several payloads, including a high resolution Earth Imaging Camera System, a Digital Signal Processing Experiment, a Cosmic Ray Experiment, and a 9600 bps AX.25 protocol store-and-forward PACSAT Communications System.

The satellite is in a non sun-synchronous circular orbit with an inclination of 66 degrees and a mean altitude of 1300 km. The 66 degree inclination tends to favour service to the mid-latitude areas of the world. KITSAT's orbital precession does not track with the Earth's terminator, so passes do not occur around the same time of day after local sunrise or after sunset as is the case with the MicroSat satellites and other satellites in sun-synchronous orbits.

KO-23's Earth Imaging System (EIS) camera has two monochrome charge coupled device (CCD) imagers. One acts as a "spotting camera" with a wide-angle lens having a resolution of 3500 meters, while the second uses a telephoto lens for a resolution down to 400 meters. Ground-stations equipped for reception of UO-22 CCD images can receive KITSAT images without modification. JPEG image compression is also possible with the imaging hardware and software capabilities of the satellite. Some of the images captured from KO-23 have been quite spectacular.

KO-23 operates in "Mode J" with a primary uplink on 145.850 MHz and a secondary uplink on 145.900 MHz. A single downlink transmits on a frequency of 435.175 MHz. 9600 bps FSK modulation.

KITSAT-OSCAR-25

Next came: ***KITSAT-OSCAR 25*** (KITSAT-B or KO-25) which was launched on the 26th September 1993 along with ITAMSAT-OSCAR-26 (IO-26) and AMRAD-OSCAR-27 (AO-27). KO-25 is a South Korean experimental microsatellite based on the SSTL UoSAT bus built by the Korean Advanced Institute of Science and Technology (KAIST). KO-25 is operated from The Satellite Technology Research Center (SaTReC) in South Korea.

KO-25's mission is to take CCD pictures, process numerical information, measure radiation, and receive and forward messages. The Infra-red Sensor Experiment (IREX) is designed to acquire I/V characteristics of IR sensors. A passive cooling structure was devised for this experiment and currently the ground controllers are monitoring the temperature of this experiment. KO-25 is presently operating as a packet store-and-

forward satellite, very similar to UO-22 and KO-23. In fact ground-station requirements are basically the same for all three spacecraft.

PoSAT-OSCAR-28

Next came *PoSAT-OSCAR-28* (PO-28) which was launched on 25th September 1993. PO-28 was another UoSAT built satellite which was meant to operate on both Amateur Radio and commercial frequencies in a similar fashion to UO-22, KO-23 and KO-25 and had the best quality CCD camera ever to be launched where the images were to be transmitted down on Amateur Radio frequencies.

Unfortunately, the Portuguese consortium that paid for PO-28 to be built and launched were unwilling to allow Amateur Radio operators to download PO-28 images as they claimed copyright on the images. As this was in contravention of the agreement to use Amateur Radio Satellite frequencies, it was decided to discontinue any transmissions from PO-28 on Amateur Radio Satellite frequencies. However, before this decision was taken a number of spectacular images were in fact taken by the CCD camera and can be seen if you visit the SSTL at the University of Surrey. This also meant that Amateur Radio Satellite operators also lost the use of another 9600 baud digital store-and-forward packet radio system.

Phase 3D with JAMSAT's SCOPE Experiment

SCOPE stands for **S**pacecraft **C**amera experiment for **O**bservation of **P**lanets and the **E**arth. SCOPE has two high resolution 3-CCD (Charge Coupled Device) head image sensors and provides wide-angle and zoom lenses for snapping views of the earth. Since 1990, when JAMSAT decided to participate in the Phase 3D project, many volunteer members have been involved in the project.

SCOPE is a microprocessor based digital camera which connects with P3D through its CAN-Bus LAN system. Moreover, SCOPE has an interface with RUDAK-U as a backup system. CPU control makes the system more flexible and allows independent operation. The SCOPE project team expects to change and improve its command software after P3D launch. Some commands may be released for general Amateur Radio use, a distant remote controlled camera in space. Amateur Radio operators will control SCOPE and get images via packet radio at will.

The SCOPE project has the following three objectives. 1) Taking full colour pictures of the earth from high altitude orbit (Apogee = 47000 km, Perigee = 4000 km). Although there are several Amateur Radio Satellites that have CCD cameras on board, most of them are monochrome and in low earth orbit. SCOPE is intended to show us the image of earth floating in space in real colour just like astronauts saw from Apollo on their way to the moon. 2) Supporting satellite's attitude control as an Earth sensor. Phase-3D satellite has capability of controlling its attitude with its 3 axis attitude control system that makes it possible for the satellite to look down at the earth at any desired angle. This axis control system consists of three momentum wheels, an earth sensor and a sun sensor. The SCOPE camera can serve as an alignment tool for this attitude determination system or may serve

as a backup system. 3) Evaluate SCOPE as a sensor for the flight guidance system. JAMSAT has a plan for an Amateur Radio Satellite that will fly from the earth to another planet. Travelling from planet to planet requires a flight guidance sensor called a star tracker. The SCOPE camera is capable of seeing relatively bright stars and this capability may make it useful as a star tracker. SCOPE is also able of capturing the image of a destination planet. This capability of the SCOPE camera will be evaluated with the Phase-3D project.

Camera-A with a narrow angle lens and Camera-B with a wide angle lens are housed in a single module case. They use a 3 CCD head from a PAL standard camera used in the industrial image processing field. This CCD head consists of a dichroic mirror to separate the colours and 3 inter-line transfer CCDs for red, green and blue. The dichroic mirror is a kind of prism and is stable in a space environment since it does not use any organic material. Specification of the CCD is as follows: Image Circle = 1/2 inch, Pixels=752(H) x 582(V), Pixel Size=8.6(H) x 8.3(V) micron.

Commercial off the shelf zoom lenses which were designed for the CCD head were employed. The zoom is not adjusted in space but is set before launch to a specific focal length determined by a study for obscuration from a nearby object (V band antenna) on the spacecraft and the viewing angle from the final orbit. The zoom will be fixed when the final orbit characteristics are determined. The two cameras have the same zoom lens with different zoom ratio settings to provide narrow and wide view angles.

An Amateur Radio operator can not "task" directly the SCOPE system from his/her own ground station. As in-orbit operation mode of RUDAK system, which transmits images captured by SCOPE cameras, has not been finalised as yet, it is not clear whether Amateur Radio operators can "receive" directly the images or not. Generally speaking, it will be possible for Amateur Radio operators to download the images via RUDAK if the downlink is not crowded

The SCOPE cameras can capture images independent of the spacecraft's operation mode. It is possible to capture images even when all the transponders are switched off. The SCOPE cameras will be switched on as long as the spacecraft has sufficient power budget, but the cameras will not capture images all the time. It is anticipated that images will be captured once per an hour because bird's view at perigee will change very slowly.

You do not need any special radios nor modems for the SCOPE system but you will need to be able to copy the transmissions from RUDAK. A broadcast protocol for transmitting the SCOPE images is being considered by the SCOPE team but they are planning to study carefully traffic efficiency of the downlink channel for broadcasting such large files. In general operation, a user of the RUDAK system can request a image file to be downloaded.

To view SCOPE images you will not need any "special" software package. Any of the popular image viewing software that can view BMP, GIF or JPEG images is all that is required after you have downloaded the image files via the RUDAK system. SCOPE cameras compress the captured images using these compression method. If you can access

the SCOPE home page (<http://www.jamsat.or.jp/>) and view the images on the pages, you are ready for the SCOPE system already. The raw image data without compression is 1.4MB(!) in size. The compressed image files should be about 100-200kB in size.

SEDSAT-1

SEDSAT is an acronym for Students for the Exploration and Development of Space Satellite and is being developed at the University of Alabama in Huntsville. The SEDSAT-1 project has grown from two students and their mentors to an international project funded by NASA, DARPA, and major corporations. SEDSAT-1 will have significant impact on space education, Amateur Radio communications, and space utilisation. SEDSAT-1 is scheduled for launch on a Delta II in mid-1998, as a secondary payload on the JPL DS-1 mission. On-orbit, SEDSAT-1 will be a unique resource for education and research. In its orbital configuration the satellite will: Provide multi-spectral remote sensing to the broadest possible community. The cameras will collect in narrow wave bands chosen to coordinate with ground based observations across the U.S. Unlike other remote sensing systems, the data will be broadly accessible because will be entirely public domain, and because its communication system will be integrated into the World-Wide-Web. Serve as a development platform for advanced microsatellite position determination and control algorithms. The satellite will demonstrate a unique attitude determination system and new technology in active microsatellite control. Provide the amateur radio community with digital packet store-and-forward and analog repeater systems. Generate new data on the space performance of NiMh batteries and advanced electronic components. Provide additional opportunities for space studies because of its extensive reprogrammability, on board GPS, and other flexible instruments. As an example, we are developing an experiment to demonstrate mobile IP on SEDSAT allowing SEDSAT to appear as an active node on the Internet.

Of particular interest in the context of satellite imaging is the fact that SEDSAT is designed to collect and distribute, as a public resource on the Internet, multi-spectral remote sensing data, including data specifically targeted at lightning. SEDSAT will contain a video-based imaging system designed to produce a resolution of 200 meters in an 800 km orbit. The imaging system will operate with a filter wheel containing at least ten narrow-band filters chosen to match the edges of major atmospheric absorption bands, and coordinate with ground based radiometric calibration systems. Onboard computing resources will archive all data, and provide an advanced image browsing system based on progressive loss-less compression. All data downlinked through cooperating ground stations will be forwarded to an archive center, and accessible through web protocols using standard browsers and provided plug-ins. SEDSAT will also provide packet store-and-forward and analog relay capabilities to the amateur radio community

Two Future Satellites from the University of Surrey with Satellite Imaging on Amateur Radio Frequencies

TMSAT is the first Thai Microsatellite, and stands for Thai-Microsatellite. It will be launched on a Russian Zenit rocket later this year and will operate in a Low Earth Orbit

(LEO), and is being constructed by Thai engineers with engineers at Surrey Satellite Technology Ltd. at the University of Surrey.

TMSAT is a microsatellite includes a number of applications including remote sensing, allowing the satellite to take a picture on the earth from space, space experimental payloads (Digital Signal Processing for enhancing communications, Solar cell experiments for testing out new technologies, etc.), earth environmental monitoring, technology demonstration, or military intelligence gathering. The cameras will consist of a wide-angle camera, 3 narrow-angle cameras (Infrared, red, green) and 1 CMOS camera (CCD camera).

MYSAT (or *TIUNGSAT*) is another microsatellite being constructed at the University of Surrey for Malaysia that will have satellite imaging capability with downlinks on Amateur Radio Satellite frequencies. *MYSAT* will also be launched on a Russian Zenit rocket probably in the first quarter of 1998.

Both these satellites should have a similar imaging capability to PoSAT and will use compression algorithms to reduce the size of the image files that need to be downloaded.

HOW TO COLLECT AND PROCESS IMAGES FROM THE CURRENTLY ACTIVE AMATEUR RADIO SATELLITES

The Amateur Radio satellites that are currently transmitting images are UO-22, KO-23 and KO-25 (possibly PO-28) here are some 'hints' that I hope will make displaying the images from these satellites a relatively easy process.

Automation and Unattended Operation

The image files on UO-22, KO-23 and KO-25 are quite large, approximately 256 or 352 Kb (Kilobyte) in length and therefore take a significant amount of time to download under even ideal conditions. Typically at 9600 baud if you had the satellite entirely to yourself and had 100% receive capability it would take at least a third of a typical pass to download a 352Kb image file.

It is certainly possible to download UoSAT and KITSAT images (and any other files for that matter) with minimal ground-station hardware and software but if you want to make the process easier - then automation that enables unattended operation is definitely a step in the right direction. However, I should mention that when I first started downloading files from the AMSAT-NA Microsats and UoSAT digital satellites I used both manual tracking and Doppler correction. I must admit that I have never personally experimented with low-gain omni-directional antennas but have read many articles from digital satellite users that have successfully used such antennas the Lindenblad or Quadrafilar Helix.

To automate your station for unattended operation there are three basic requirements, first you must be able to automatically track each satellite of interest and the second to be able

to automatically tune your radio(s) to compensate for Doppler shift and finally you must have ground-station software that will run unattended.

My Ground Station

My ground station consists of the Windows95 version of Chris Jackson G7UPN's WiSP software controlling the stand-alone SatTrak4 Automatic Satellite Tracking and Doppler Correction hardware 'talking' to an ICOM IC820H and the Kenpro KR400 (azimuth) and KR500 (elevation) rotators with the MASPRO WHS32 'Oscar Hunter' antenna system consisting of a 40 element circularly polarised crossed yagi on 70cm and a 24 element circularly polarised crossed yagi on 2M. I also use a mast-mounted Landwehr 70cm preamplifier on receive.

Automatic Antenna and Doppler Frequency Tracking Hardware

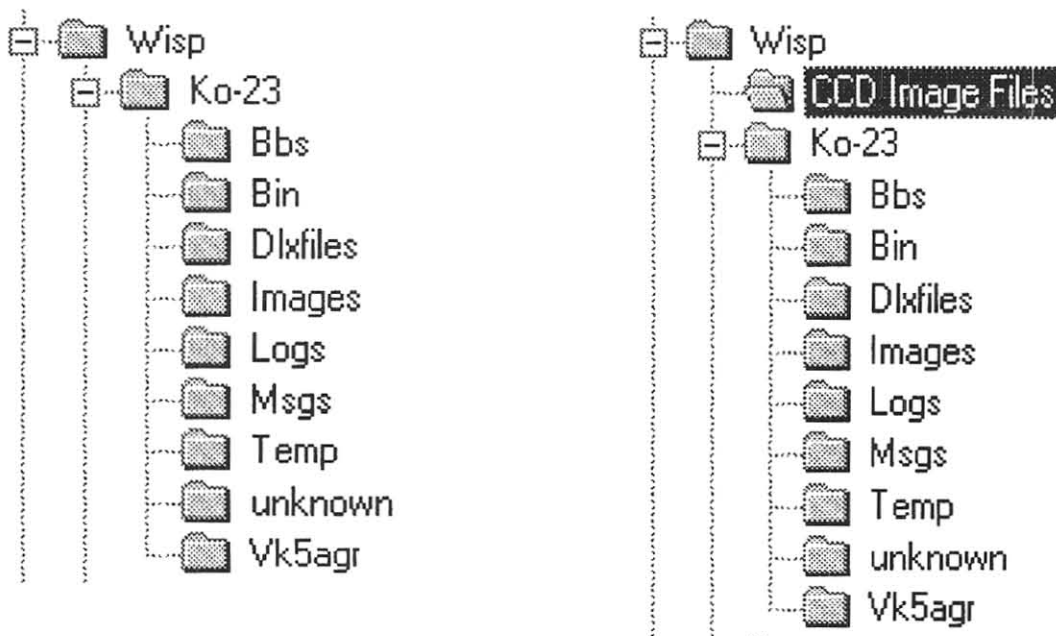
Unfortunately, at the time of writing, the stand-alone SatTrak4 and JAMSAT/TAPR TrakBox hardware are no longer available but the Antenna and Doppler Frequency Tracking Engine (ADFTE) by Dave Lamont, ZL2AMD, the Kansas City Tracker (KCT) with the Tuner option from L.L.Grace or the FODTRAK system by Manfred XQ2FOD are still readily available. There are also a number of other systems available from distributors such as AEA (ST-1) and Myers Communications (SASI Tracker).

PACSAT Software

With respect to software there are a number of different software options depending on what computer hardware and operating system you are currently running. As I have already mentioned, I use the 32-bit version of Chris Jackson G7UPN's WiSP program running under Windows 95. However, there is also a version of WiSP that runs under Windows 3.x or if you prefer the Linux or Unix operating systems then there is an excellent suite of software consisting of SatTrack 3.1 (for antenna tracking), Microsat (for file uploading/downloading/telemetry), xv (popular Unix image viewer, patched to handle the CCD image file format just like any other format) and ImageMagick (popular Unix image processing software). If you need any more information on the Linux or Unix software then I suggest you contact Klaus Kudielka OE1KIB, Peter Jordanstr. 165, A-1180 Wien, AUSTRIA or oe1kib@oe1xtu.ampr.org

How WiSP works with the PACSAT Broadcast Protocol

The recommended directory structure for WiSP is shown below on the left-hand side. However, I recommended creating an extra sub-directory of WiSP called CCD Image Files as shown below on the right-hand side. This is a convenient location into which you can instruct WiSP to automatically save any CCD image files that it successfully downloads and extracts that can later be displayed using Colin Hurst, VK5HI's CCD Display 97 software.



To instruct WiSP to save all image files to the sub-directory C:\WiSP\CCD Image Files you need to enter that pathname in the image directory entry for each satellite. In *GSC*, select *Setup*, then select *Satellite Setup*, then select *Select Satellite*, then select the '*Directories*' tab, then change the '*Image Directory*' entry to C:\WiSP\CCD Image Files.

Unfortunately, WiSP only allows you to define only one image directory per satellite and puts all image files (e.g. GIF, PCX and JPG) not only the CCD image files into that directory.

Without going into too much detail I think it is important that you understand how WiSP organises all the files it uses and/or creates and how you can put this knowledge to your advantage.

The 'program' files used by WiSP are stored in the main WiSP sub-directory:

GSC.EXE	Ground Station Control - the main control program of WiSP.
DISPHOLE.EXE	Display Holes - displays the missing holes in downloaded files.
LHA.PIF	PIF to compress or decompress files using LHARC.EXE.
MSGMAKER.EXE	Message Maker - for creating new messages.
MSGVIEW.EXE	Message Viewer - for viewing downloaded messages.
MSPE.EXE	<u>M</u> icro <u>S</u> at <u>P</u> rotocol <u>E</u> ngine - this is the program that is called by GSC.EXE to 'control' the downloading of the directory and files from each satellite.
PKUNPAK.PIF	PIF to decompress files using PKUNPAK.EXE.
PKUNZIP.PIF	PIF to decompress files using PKUNZIP.EXE.
PKZIP.PIF	PIF to compress files using PKZIP.EXE.
PROCMail.EXE	Process Mail - the program that processes all files that are downloaded.

UPDKEPS.EXE	Update Keplerian Elements - the program that downloads files containing Keplerian elements and updates the file WiSP.KEP.
VIEW-DIR.EXE	View Directory - the program that views the directory for each satellite.
WISP.HLP	Help file for WiSP.
WISP.OBS	WiSP Observers file contains the latitude and longitude information for many locations on the earth's surface.
WISP-TLM.EXE	WiSP Telemetry program for decoding satellite telemetry

The most important file in this directory for 'processing' the CCD image files is MSPE Equations.TXT which defines which files MSPE downloads from all satellites and in what order of priority.

I have added the following lines to my MSPE Equations.TXT file to ensure that the CCD image files from UO-22, KO-23 and KO-25 are all automatically downloaded as an 'AUTO1' priority. The first files to be automatically downloaded are those defined by the [Priority] label, next are those defined by the [Auto1] label in the MSPE Equations.TXT file:

```
[Auto1]
{
filetype = 211 |
filetype = 215 |
filetype = 221
}
```

To change your MSPE Equations.TXT files - in *GSC*, select *Setup*, then select *Edit MSPE Equations* which should automatically load MSPE Equations.TXT into your favourite editor e.g. Notepad.exe

Here is a 'brief' explanation of what WiSP does when you start copying signals from a digital satellite:

1. Every packet that is successfully received by your hardware is then processed by WiSP as per the various settings you defined when you setup WiSP and if this packet is therefore required it is then saved to your hard disk drive.
2. If the packet is part of a message file it is saved as part of an *.ACT file with the appropriate message number e.g. 123456.ACT and if it was the first packet received for that message it would also create a *.HOL file which as the extension HOL implies contains the number of holes for that file which are filled and unfilled. Subsequent message file packets are saved to the appropriate *.ACT file and update the associated *.HOL file.
3. If the packet is part of the Pacsat File Header then it is saved at the beginning of the *.ACT file. Once the Pacsat File Header has been successfully received then MSPE can

tell you exactly what percentage of a file you have downloaded and how many holes you currently have unfilled.

4. When all the packets for a particular message file are successfully received the *.ACT file is renamed to *.DL file and the associated *.HOL file is deleted.
5. Depending on your WiSP settings at some stage Procmail.EXE will process the completed *.DL files creating a *.DLX file and extract the messages or files into their appropriate subdirectories by stripping off the Pacsat File Header. For example if file 123456.DL contained a UO-22 CCD image file U5IW1052 then Procmail.EXE would extract the file U5IW1052. and place it in the CCD Image Files subdirectory of WiSP

Processing CCD Image Files

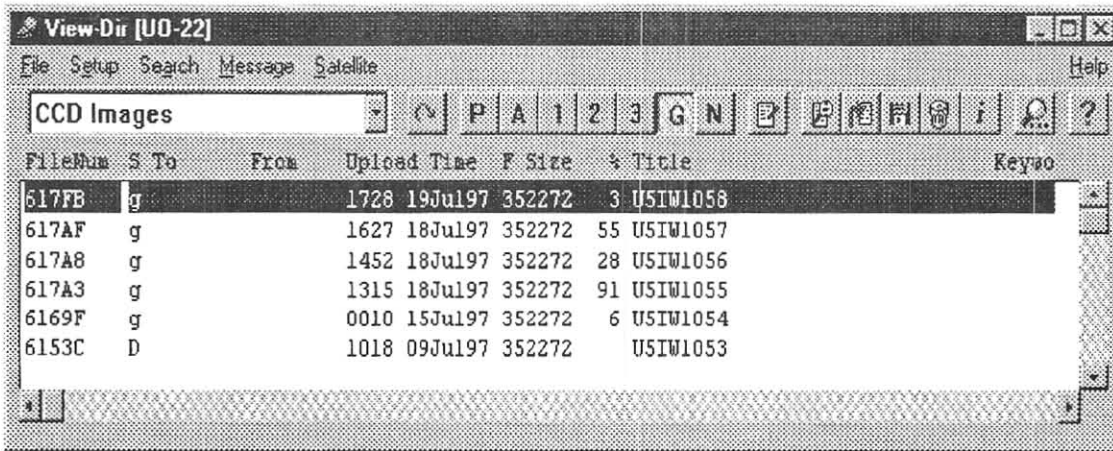
The reason for giving the above explanation is that CCD image files take quite a long time to download and if for some reason the image is not all that 'good' because of incorrect settings, poor location or bad weather, etc then you really do not want to waste your time completing the download. Well, Colin Hurst, VK5HI has kindly written a little DOS-based program called *DISP_ACT.EXE* which attempts to display CCD image files contained in the partially downloaded *.ACT files. The success of this program is very dependent on what percentage of the file has been downloaded and typically if you have around the 50% mark you can usually get a reasonable idea of the 'quality' of the CCD image. However, many CCD images files are corrupted usually due to the occurrence of duplicate packets and *DISP_ACT.EXE* cannot handle these duplicate packets and therefore the images it displays are somewhat misleading although with experience you can often still predict whether or not an image is worth downloading.

To find out which *.ACT files contain partially downloaded CCD image files I suggest that you first edit the VIEW-DIR Equations.TXT file to include the following lines:

```
[CCD Images]
{
filetype = 211 |
filetype = 215 |
filetype = 221
}
```

To change your VIEW-DIR Equations.TXT files - in *GSC*, select *Setup*, then select *Edit VIEW-DIR Equations* which should automatically load VIEW-DIR Equations.TXT into your favourite editor e.g. Notepad.exe

Now run *VIEW-DIR* and *Select Satellite*, then in the drop-down selection box select *CCD Images* and all the CCD image files for the currently selected satellite should be displayed with the percentage that has been successfully downloaded.



In the above example file 617AF which contains the CCD image file U5W1057 is 55% downloaded so I would expect that if I ran *DISP_ACT C:\WISPUO-22\617AF.ACT* then I would get a reasonable indication of what the final 'quality' of the U5W1057 CCD image would be.

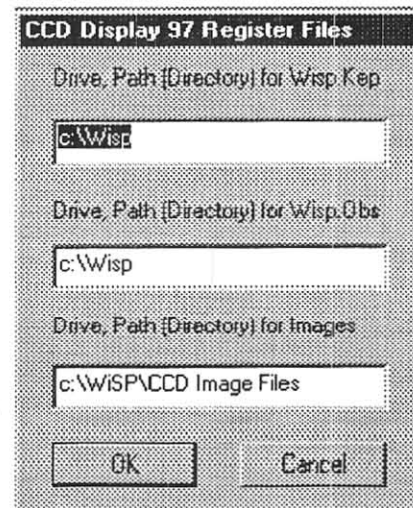
Assuming that WiSP has successfully downloaded and extracted the CCD image files and has saved them into the CCD Image Files subdirectory of WiSP then I can recommend Colin Hurst, VK5HI's Windows 95 program called *CCD Display 97*. *CCD Display 97* is a very simple program to use from the users point of view and has only a 3 options that need to be setup the first time it is run. When the program is run select *Help*, then select *Settings*.



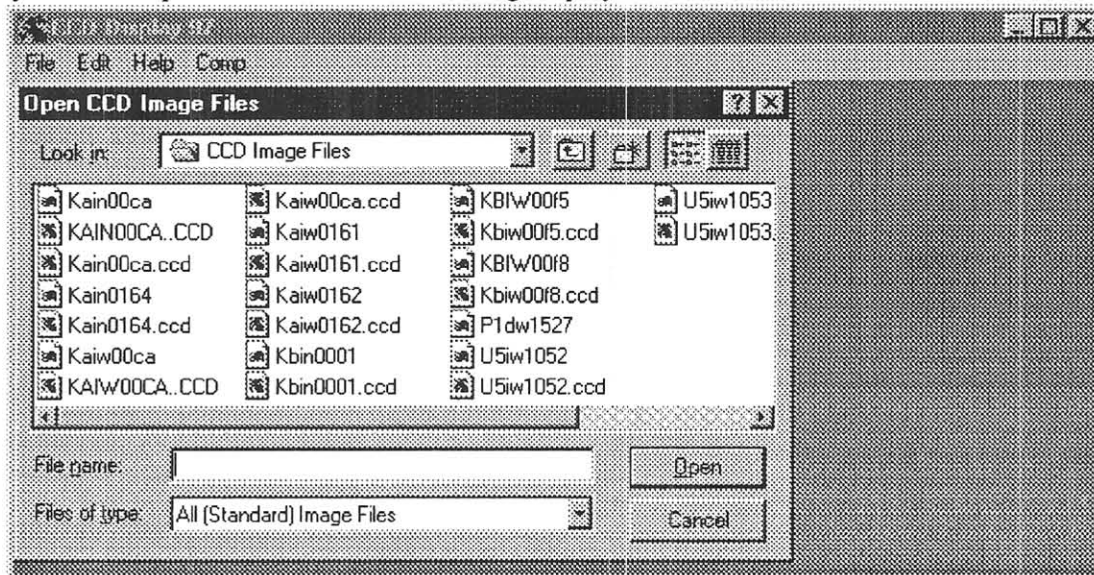
The first is where to find the file *WISP.KEP* which the Keplerian element data used by WiSP and is usually located in the main WiSP directory.

The second is where to find the file *WISP.OBS* which contains latitude and longitude data for many locations on the earth's surface and is usually located in the main WiSP directory.

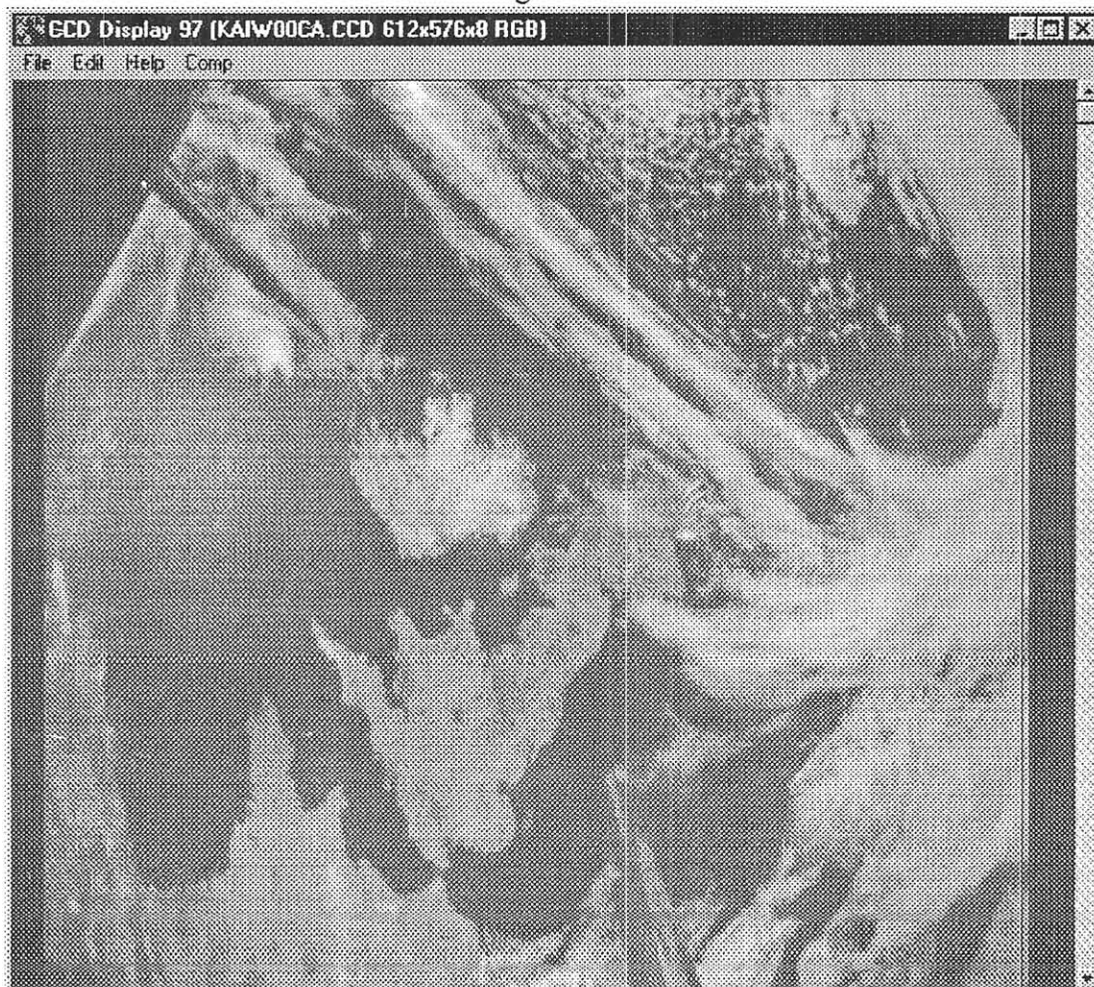
The third is where *CCD Display 97* will automatically look for any image files to process and as I have already indicated I use a subdirectory of WiSP called *CCD Image Files*.



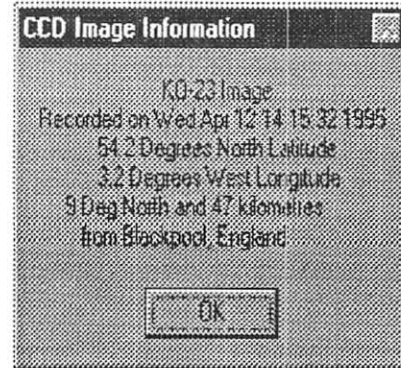
To display a raw image file using CCD Display 97 select *File*, then select *Open CCD* and you will be presented with the following display:



Select the file you want to display e.g. Kaiw00ca and click on open and the following image should be displayed with a dialogue box (as shown on the next page) providing the information on when and where the image was taken.



As mentioned previously CCD Display 97 uses the Keplerian element data file WISP.KEP and the Observer data files WISP.OBS to calculate the CCD Image Information displayed in the opposite dialogue box. To clear the dialogue box when it appears just click on the 'OK'. I should also mention that if the raw image file that you are trying to display is an old one then the 'CCD Image Information' dialogue box will contain a warning message and will not display the location information but will still display the date and time that the image was taken. To get the correct location information you would have to load Keplerian elements for that satellite at the time the CCD image was taken. You can do this in two ways - first, in *GSC*, select *Database*, then select *Edit Satellite Data*, then *Find* the appropriate satellite then either edit the data manually or alternatively change the epoch year for the satellite to prior to the desired year and then use the automatic update function to update the Keplerian elements from a NASA Keplerian element data file from around the time the image was taken.



I must admit that in the 'old days' one of the challenges of decoding the CCD images was trying to work out when and where the image was taken by calculating when the CCD image was taken from the header information then running InstantTrack to see where the satellites was located at that time and from that identify the what was in the image. Well, Colin VK5HI's CCD Display 97 software now does that all 'automagically'.

Other CCD Display 97 Features

There are also a number of other features of CCD Display 97 that I should mention. If you refer back to the *Open CCD Image Files* dialogue box you will note that it contained a number of different file types which can be divided into 2 groups - those with no extension and those with an extension of CCD.

Those with no extensions are the raw CCD image files that have the format:

- U5W1052 - where the first 2 characters indicated the satellite e.g. U5 means UoSAT-5 or UoSAT-OSCAR-22 (UO-22) as we know it. The 3rd character refers to whether the image is a Wide or Narrow angle image and the next 4 characters are the image number.
- KAIN00CA - where the first 2 characters indicated the satellite e.g. KA means KITSAT-A or KITSAT-OSCAR-23 (KO-23) as we know it. The 3rd character is an I for image and the 4th character refers to whether the image is a Wide or Narrow angle image and the next 4 characters are the image number.
- KBIW00F5 - where the first 2 characters indicated the satellite e.g. KB means KITSAT-B or KITSAT-OSCAR-25 (KO-25) as we know it. The 3rd character is an I for image and the 4th character refers to whether the image is a Wide or Narrow angle image and the next 4 characters are the image number.
- PIDW1527 - where the first 2 characters indicated the satellite e.g. P1 means PoSAT-1 or PoSAT-OSCAR-28 (PO-28) as we know it. The 3rd character is a

D for Decompressed image and the 4th character refers to whether the image is a Wide or Narrow angle image and the next 4 characters are the image number.

Those with the extensions CCD have the same format but have already been processed by CCD Display 97.

The only difference between the two groups is that the raw image files have been 'processed' by CCD Display 97 and the CCD image file headers of 256 bytes have been replaced by the information contained in the CCD Display Information dialogue box. Optimally you should process a raw CCD image file as soon as possible after capture while the Keplerian elements for that satellite are up-to-date in WiSP. If you do that I would recommend that you delete the matching raw image file to save disk space. This can be quickly achieved while in the Open CCD Image Files dialogue box by holding down the Control key and selecting the raw image files you want to delete with the left mouse button, then hit the Delete key and those files will be deleted to the Recycle Bin'.

Therefore, selecting a file that has a CCD extension that was processed at the time of capture means that the location data is already included and the image can be displayed faster. Also one can setup an 'association' with the extension CCD so that clicking on a file with an extension of CCD automatically loads and displays it using CCD Display 97.

To do this, load Windows 95 Explorer select a file with the extension of CCD and click the right mouse button. Then select '*Open With*', then select the application CCD Display 97 from the Open With selection menu.

Image Compression

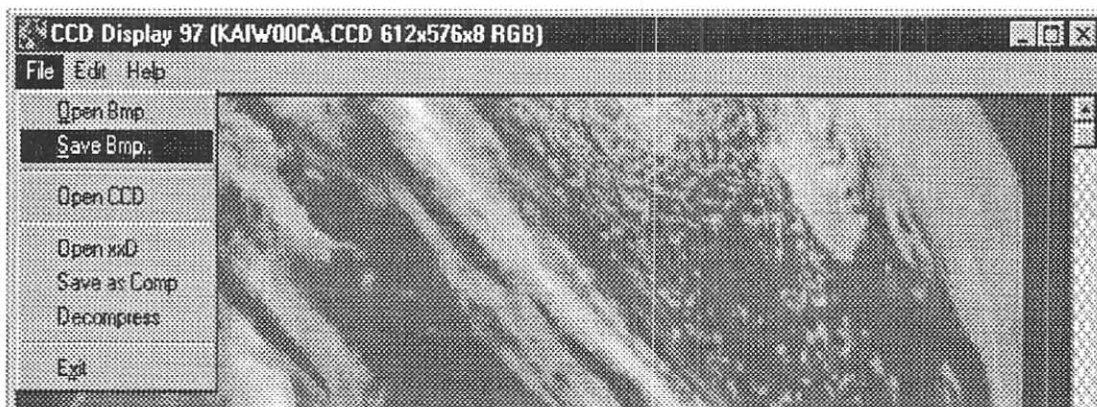
With the advent of PO-28 another feature was added to the onboard satellite software that would process the captured CCD image file and produce 2 separate files, a 'thumbnail' and a 'compressed' file that are then available for downloading as PITWxxxx and PICWxxxx files. CCD Display 97 processes these 2 files to create a PIDWxxxx.CCD file. To display a PIDWxxxx.CCD file select *File*, then select the *Open xxD* option.

Similarly, CCD Display 97 can take a *.CCD file such as KAIW00CA.CCD (352,192 bytes) and produce a Compressed image file called KACW00CA. (80,941 bytes) and a Thumbnail image file called KATW00CA.CCD (22,144 bytes). The thumbnail image can be displayed directly using CCD Display 97 and looks like the adjacent image. If you want to save CCD images for posterity and you carry out the process *Save as Comp* under the selection *File*. This will save you about 250 Kbytes of your hard disk drive capacity per image!



Converting CCD Images to Other Formats

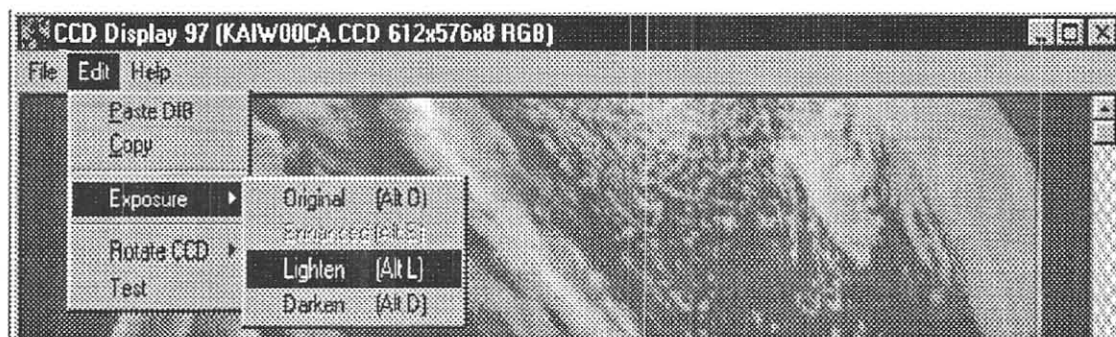
CCD Display only allows you one 'standard' graphical format to save processed images and that is as a *.BMP (bit-mapped) file. Having processed a CCD image so that it is currently displayed by CCD Display 97, select *File*, then select *Save as BMP* to save the image as a *.BMP image file which can then be processed later using your favourite image viewing or graphics program.



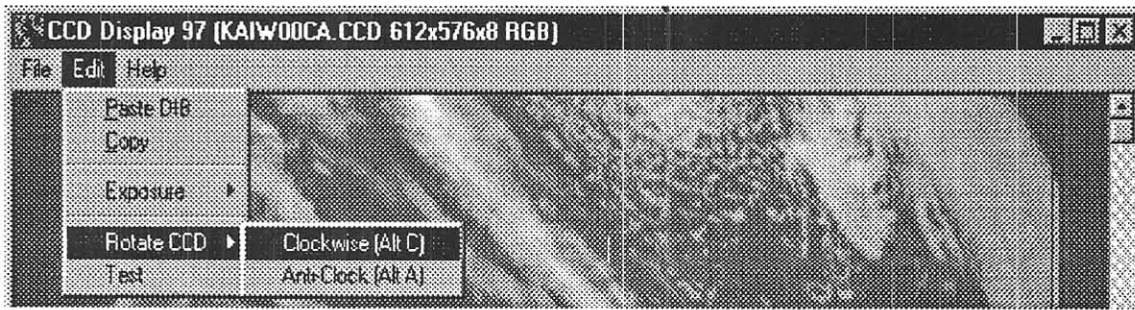
As you can see in the above File options you can also use CCD Display 97 to view *.BMP files by selecting the *Open BMP* option..

Image Manipulation

CCD Display 97 also provides the ability to manipulate a CCD image file. You can change the *exposure* to lighten or darken the image. Manipulating the exposure can often reveal geographical features not easily visible in the image as displayed using the 'default' settings derived by CCD Display 97. If after manipulating the exposure by hitting <Alt>+<L> or >Alt>+<D> you want to automatically return to the 'default' exposure you can hit <Alt>+<O> for original.



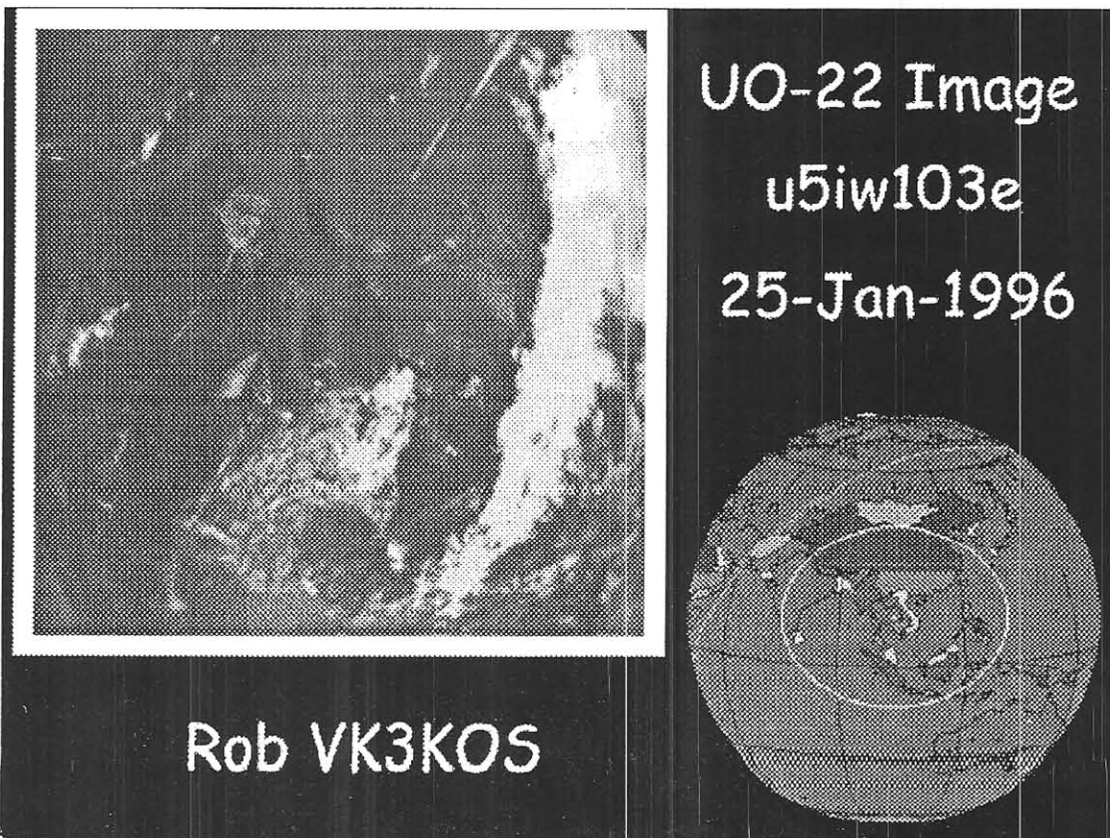
You can also rotate the CCD image - either clockwise by hitting <Alt>+C which will rotate the image 90 degrees clockwise or <Alt>+A which rotates the image 90 degrees anti-clockwise. This is very helpful for those of us who have trouble visualising images unless they are in the 'correct' orientation!



The other functions in the selection *Edit* are for copying information to and from the 'clipboard' and can be useful at times when preparing material for a lecture or handouts. Personally, I tend to use the *Save as BMP* option and then use my favourite graphics manipulation program which at the moment is PaintShopPro but I have used Graphics Workshop.

Impressing Your Friends and Neighbours

Many people, my self included get some satisfaction out of enhancing the images produced by CCD Display 97 by adding place names or in the case of Rob VK3KOS he likes to add the 2P or Orthographic view in InstantTrack V1.0 tracking software (written by Franklin Antonio, N6NKF and is available from AMSAT) to his image so that people can more easily visualise where the satellite image was taken. The InstantTrack image is in fact in colour and in my humble opinion enhances the CCD image but unfortunately in this paper is only shown in black and white.



To capture the 2P orthographic view from InstantTrack under Windows95 I run InstantTrack in a Windows95 DOS window. At the top of this there is a button bar, the first button is the *Mark* button, click on that button then press the left mouse button and drag the mouse over the area you want to 'capture', then release the mouse button, then click on the *Copy* button and then exit InstantTrack and close the DOS window. Now load PaintShopPro and select *Edit*, then select *Paste*, then select *As New Image* and the InstantTrack you marked will be loaded into PaintShopPro and create a *.BMP image file. Within PaintShopPro this image can be cropped and sized for later use in creating a combined image of the CCD and InstantTrack images as per Rob VK3KOS's image shown on above.

ACKNOWLEDGEMENTS

- AMSAT-NA (AMSAT North America) web pages - <http://www.amsat.org/> from which I sourced much of the information included in this paper.
- SCOPE information - Yoshiyuki Takeyasu / JA6XKQ e-mail:(Home) ELA58925@biglobe.ne.jp (Work) takeyasu@sdv.msc.yh.nec.co.jp
- SEDSAT-1 information - Dr. Mark W. Maier maier@ece.uah.edu and web page <http://146.229.5.181/>
- Linux Software information was provided by Klaus Kudielka OE1KIB, Peter Jordanstr. 165, A-1180 Wien, AUSTRIA - email: or oe1kib@oe1xtu.ampr.org
- CCD Display 97 software - Colin Hurst, VK5HI, email: hurst_cj@msn.com
- WiSP software and PoSAT image data format - Chris Jackson, G7UPN, email: C.Jackson@ee.surrey.ac.uk
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APPENDICES

Satellite IDs and Frequencies

UoSAT-OSCAR-22 (UO-22)

Broadcast Callsign UOSAT5-11
BBS Callsign UOSAT5-12

Downlink Frequency 435.120 MHz
Uplink Frequency 145.900 or 145.975 MHz

KITSAT-OSCAR-23 (KO-23)

Broadcast Callsign HL01-11
BBS Callsign HL01-12

Downlink Frequency 435.175 MHz
Uplink Frequency 145.850 or 145.900 MHz

KITSAT-OSCAR-25 (KO-25)

Broadcast Callsign HL02-11
BBS Callsign HL02-12

Downlink Frequency 436.500 or 435.175 MHz
Uplink Frequency 145.980 or 145.870 MHz

A Phase 4 Lite Proposal

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Abstract:

As the Phase 3-D project winds down the inevitable question comes up - what should we do next? Is AMSAT in a situation where it can support a project to build a next-generation spacecraft? Should it be a single large spacecraft, or a series of smaller spacecraft? Can we afford to do another large project like Phase 3-D?

A goal which amateurs have never successfully achieved is a geosynchronous amateur satellite. Previous projects, OSCAR 4 and Arsene (FO-24) have not been successful for different reasons. This proposal for a geosynchronous amateur satellite addresses shortcomings of previous proposals, lessons learned from the Phase 3-D project, and one well thought out approach to a geosynchronous project. The paper will address frequencies, spacecraft design, spacecraft sub-systems, orbital locations, ground station requirements, potential launch opportunities, and potential sources for external funding.

Introduction

One of the ultimate goals for OSCAR enthusiasts is a ham radio satellite in geosynchronous orbit. It was attempted on OSCAR 4 and Arsene (FO-24) unsuccessfully for various reasons. But it remains one of our most desirable goals. A geosynchronous altitude satellite will permit hams to talk to other hams over a third of the Earth, and a pair of satellites can cover almost every populated portion of the Earth. This proposal is a 'broad stroke' outline of what would be desirable for a geosynchronous amateur satellite, and some cost-effective approaches which we should examine in detail. It is not a detailed design study, which should be performed by qualified aerospace experts if this proposal is deemed desirable. Many of the concepts in this paper may be suitable for use in other amateur communications applications.

Fine print -

It's rare for any individual to come up with a perfectly original idea. Arthur C. Clarke has acknowledged that he was just the lucky person to publish the concept of geostationary satellites, and it took many engineers at Hughes Aircraft to actually take the concept to reality¹. This proposal for Phase 4 Lite builds on the previous work done by government and commercial geostationary satellites, previous amateur radio satellites, and previous proposals for amateur geosynchronous satellites. Nevertheless this particular concept is by Philip Chien KC4YER who takes responsibility for all of the statements and comments made within.

Lessons learned from the Phase 4 and Phase 3-D projects.

Phase 4 was an AMSAT-NA project to determine the feasibility of building a geosynchronous amateur radio satellite². While it was certainly technically feasible, the cost was well beyond what could be considered reasonable for amateurs to build. In addition there was no suitable launch opportunity identified, so AMSAT-NA decided instead to join forces with AMSAT-DL on the Phase 3-D project.

Phase 4 had three significant limitations -

At first only one satellite was to be built, positioned at 46 West. A single satellite can only serve one third of the planet, so it's doubtful that hams in Asia would be interested in supporting the project. A second satellite was to follow, positioned at 145 West. But hams who could only be served by the second satellite would certainly be skeptical about the status of their satellite.

The project design called for a three-axis stabilized satellite, similar to the Phase 3-D design. This paper will discuss in detail the tradeoffs of different methods of stabilizing spacecraft.

Since Phase 4 was supposed to support existing Mode B users it was designed with extendible 2 meter Yagi antennas. It would have been an extremely difficult engineering challenge to design a reliable deployable antenna system which would be a critical spacecraft system.

While Phase 3-D promises to be an incredibly versatile and powerful platform, that capability comes with a very large price tag. When the launch vehicle's engines ignite we will be putting a vast investment at risk - both in terms of time and money. With 20/20 hindsight I think most of us realize that Phase 3-D was a wonderful concept, but we've bit off a very large chunk - possibly too much. We've overextended ourselves in terms of human resources, budget, and every other way. Some times I wonder if AMSAT will have enough resources to even build another satellite (much less what type of satellite) after all of the bills and favors for Phase 3-D are paid off.

One of the key issues which must be addressed for Phase 4, or any other future AMSAT project is better management and control. We can't take the risk of hoping that the launch vehicle will delay to ensure enough time for us to finish our project. Could we have completed Phase 3-D in time for the original 1995 launch date? It's highly doubtful. We need better organization for most of our activities. As an example, there have been dozens of photographers at the Integration Laboratory in Florida. But no consistent system for cataloging all of the photographs and ensuring that they're available for future reference or any other requirements.

I do not feel it's possible for us to build any large spacecraft projects primarily with volunteer labor. If we had experienced project managers working full time earlier in the Phase 3-D project things would have gone more smoothly. Just as important is the delegation of responsibilities. The overall project managers must make assignments for sub-tasks (e.g. modules, integration, antennas, etc.) to appropriate groups - and give those groups the freedom and flexibility to complete their tasks. The era of three hams building a spacecraft in their garage as a weekend hobby is over. We must adapt if we want amateur radio on future spacecraft. On the other side of the coin parties who commit to building modules and subassemblies must complete their tasks on schedule - the excuse "we can delay because the launch vehicle isn't going to be ready in time to meet the schedule" isn't justifiable.

On the technical side I would hope that Phase 3-D will be the last spacecraft we build with a wiring harness. While contractors Mike Garity and Jennifer Lemeke have done an outstanding job of assembling and testing the harness it's a very labor and resource intensive task. Certainly some types of wiring will always be required (e.g. power bus, antenna coax cables) but all of the data between the modules should use either a ribbon cable or serial bus.

In simple we should always remember our original design philosophy - Keep it Simple Stupid! Mechanical systems, complicated subsystems, and other potential sources for failures should be minimized.

The entire spacecraft should be designed with a 'fail soft' approach - much more so than Phase 3-D or any previous amateur spacecraft. The number of critical one systems (e.g. place where if there's a plausible failure the spacecraft is lost) must be minimized. In every case where it's feasible a system should be designed so if it fails the spacecraft can still work, even if it's in a less efficient configuration.

Phase 4-L considerations -

Phase 4 Lite (as in less filling, less expensive) must take all of the above in to consideration. It must be a feasible project, within a budget which we can afford. I would prefer that no more than two thirds of AMSAT's technical resources be spent on any given project. There's always a possibility of another project coming along in a couple of years which we otherwise wouldn't be able to support. In addition not using all of our resources will prevent folks from getting 'burned out' and will permit a smooth overlap between one project finishing up while the next project starts.

It's very doubtful that we will ever get a free, or heavily discounted launch vehicle opportunity in the future. There are many universities, aerospace companies, and government agencies who want to launch payloads in to space and they're willing to take the same risks which we've always accepted. With launch services becoming more and more a commercial business it's doubtful commercial companies would be willing to give us free rides when there are paying customers available.

Given the increasing costs of building and launching spacecraft we must consider all outside sources of funding and cooperative activities. I realize many AMSAT members would prefer to stay completely independent without being ' beholden ' to a government agency or commercial company. But we may have to cooperate in order to survive.

Whatever is chosen as the follow-up project to Phase 3-D should start as soon as possible, to keep the 'knowledge base' in place from the existing Phase 3-D team members who are interested in continuing.

All of the tradeoffs in this paper are based on the axiom that the number of hams served by the satellite - over time - is the greatest consideration. There are 'people, radios and money' on every continent, and all of their needs and desires must be taken in to account. This concept tries to serve as much of the populated world as possible. Lower populated regions like Alaska, Hawaii, New Zealand, and Australia will be taken in to consideration only where feasible. Nevertheless there will be an attempt to reach those regions. Anything which increases satellite lifetime is considered extremely important.

Introduction to geosynchronous orbits

As Arthur C. Clarke noted 52 years ago you only need three satellites in geosynchronous orbit to cover the entire Earth, other than the extreme polar regions¹. But three isn't an absolute minimum. The Earth is primarily ocean, and we can easily make the choice to ignore an extremely low populated ocean region when taking in to consideration our constellation requirements. Two satellites are adequate to cover over 85% of the Earth's surface, as illustrated using the locations of two existing commercial comsats. (Figure 1).

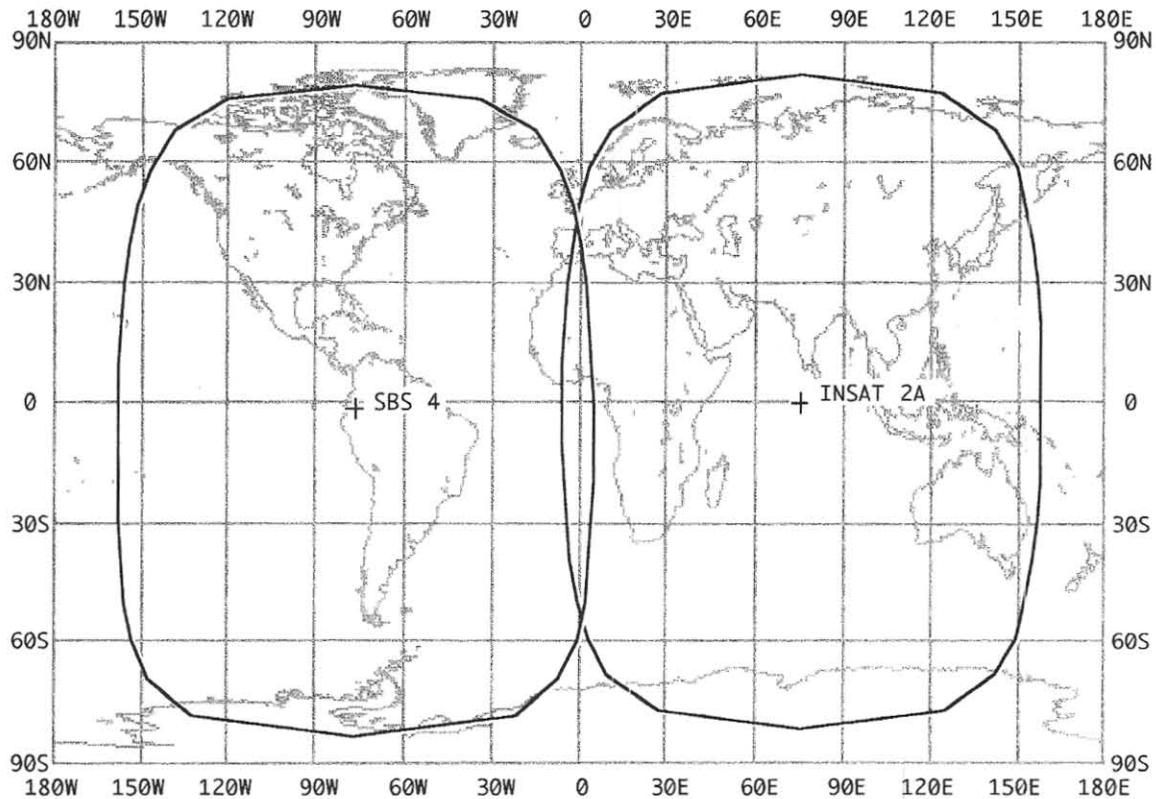


Figure 1 How two geosynchronous satellites can cover most of the Earth

It would certainly be desirable to build a third 'lesser brother' satellite while we're building the two primary spacecraft. The third spacecraft would have less priority, and if the schedule slips would get less consideration. However in the long run it would be quite useful as a backup, as well as a replacement spacecraft whenever the need arises.

What isn't realized by many people - even within the aerospace industry - is the difference between a geoSYNCHRONOUS orbit and a geoSTATIONARY orbit.

A true geostationary satellite has a inclination of zero degrees (or very close to zero degrees) with a mean motion of one and eccentricity of zero. Actually like any orbit in a multi-body physics problem it's a theoretical orbit, since there are always minor perturbations due to the moon, equatorial bulge of the Earth, Sun, other planets, etc. In practice any satellite which actively keeps its inclination and longitude drift under control is considered geostationary. 90% of a geosat's propellant budget is for North-South stationkeeping (inclination control), 10% for East-West (longitude). From the point-of-view of a user on the ground the geostationary satellite remains in a fixed place in the sky, which is fairly easy to calculate (heck, with most DBS receivers you just enter your zip code and the receiver tells you the Az/EI -- you don't even have to know your latitude and longitude! Who knows, there may eventually come out with a version where you input your grid square coordinates!)

A geosynchronous satellite is any satellite with a mean motion of one (e.g. an orbital period of 24 hours)³. You can have a satellite in an elliptical orbit (e.g. IUE) or a circular one where the inclination isn't zero (e.g. the Marisat series or ATS-3)^{4, 5}. From the point-of-view of a viewer in space the satellite's orbit (assuming a circular orbit) is a figure-8, centered on the satellite's longitude, with the two loops reaching the latitude of the satellite's inclination (e.g. a geosync satellite with an inclination of 28.5 degrees and longitude of 80 degrees would cross over my house at an altitude of 35,888 km. Figure 2 shows the orbit of ATS-3, which has an inclination of 19.2 degrees.

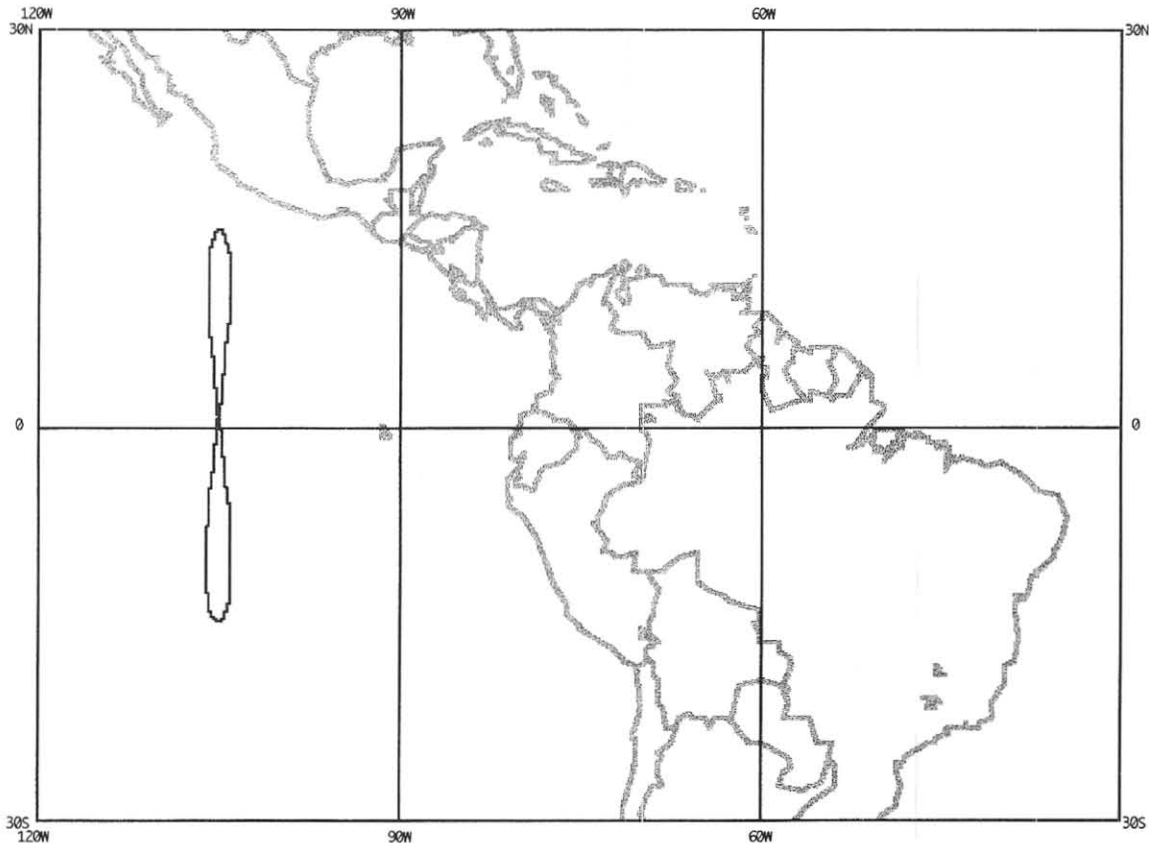


Figure 2 - One day's orbit for ATS-3

Since a geosynchronous satellite doesn't keep its inclination under control it only requires one tenth of the stationkeeping propellants as a geostationary satellite. The additional benefit of a geosynchronous satellite vs. a geostationary satellite is that while it's at high latitudes it can communicate with users in polar regions (if this isn't immediately obvious, imagine the Earth wobbling under a satellite's fixed orbit, or do a thought exercise with a geosynchronous altitude satellite at extremely high inclinations).

If North-South stationkeeping is not maintained a geosynchronous satellite will gradually increase its inclination over many years, reaching a maximum of 23.5 degrees (I think). At that point the process reverses and the inclination gradually decreases.

For most broadcast applications a geostationary satellite is extremely desirable, since it requires the minimum hardware for the end user - just a simple parabolic dish which makes your neighbors stare and wonder. With my C-Band 3 meter (10 foot) TVRO (beamwidth 1.75 degrees) I can watch anything with an inclination of about 2 degrees or less. Older satellites where North-South stationkeeping is no longer maintained (e.g. Telstar 302) stay within my satellite dish's field of view for about half a day. Higher inclination satellites (e.g. SBS 4) are only visible for a couple of hours each day when they happen to cross over the equator.

However, many government satellites have less stringent inclination requirements, which reduces stationkeeping requirements. This can translate in to a smaller satellite (e.g. less expensive satellite and launch vehicle) or longer useful lifetime. When NASA's TDRS constellation was originally approved somebody made the very bonehead mistake of forgetting that the proposed commercial users would want a true geostationary satellite. So TDRS grew in size (and cost) and had to be delayed from the planned Atlas-Centaur class launch vehicles to shuttle-class payloads. (a rather embarrassing -- and costly mistake!)

There are three key advantages of a geosynchronous satellite for ham radio operators -

- a) Smaller launch vehicle requirements (translation - lower launch costs). The 'dog leg' maneuver to cancel out a satellite's inclination for any geostationary satellite launched from Florida requires almost half of a spacecraft's propellant supply.
- b) Better coverage for extremely high latitude users (just what is the ice loading situation for a pair of OSCAR antennas in Anchorage?)
- c) Longer anticipated spacecraft lifetime since we don't have to allocate any of our precious propellant resources to North-South stationkeeping. It's important to note that most geostationary comsats are retired because they're out of fuel - not because of component failures.

The key disadvantage of a geosynchronous satellite vs. a geostationary one is the requirement for tracking antennas (e.g. your existing az/el OSCAR setup) to follow the satellite in its figure-8 across the sky. The geosynchronous orbit still has the advantage of always remaining in the same (sort of) place in the sky and continuous availability. Geosynchronous satellites also encounter more eclipses than true geostationary satellites, which does affect the power budget.

There is a tradeoff for hams in medium to high latitudes for inclined geosynchronous satellites. Depending on your latitude, and the inclination of the satellite, there will be periods where the satellite will be below your horizon. The higher your latitude, and the higher the inclination of the orbit, the more the satellite will be out of reach. So a geosynchronous satellite isn't necessarily available 24 hours a day. On the other hand, the higher inclination will also result in the satellite being at a higher elevation which is a consideration in areas where the Southern view may be partially obscured, and an important consideration for hams at high latitudes. Overall it's a wash - some advantages,

some disadvantages. And the exact situation will vary from location to location, depending on any obstructions towards the South (or North if you're in the Southern hemisphere) and a function of the satellite's RAAN and the season. These factors can all be quantified and a tradeoff study should be performed to select the optimal orbital parameters to serve as many hams as possible.

AMSAT would probably need to get slot approval from the ITU, UN, FCC, and assorted other alphabet soup agencies, but the good news is that our frequencies are so different from commercial, government, and military satellites that we can share slots with their satellites without interference!

There are many slots where multiple satellites share the same longitude, most notably the Astra series (six satellites all stationed at 19.2 degrees East). In the U.S. portion the three DirecTV birds share 101 West with Spacenet 4, AMSC-1, NATO IIA, and GOES 3. The later two are in very highly inclined orbits (14 and 11 degrees) and are probably not fully operational. The DirecTV birds transmit in the 12.2-12.7 Ghz. band, Spacenet 4 is in the 4 and 12 Ghz. bands, AMSC in the 1.2 Ghz band, GOES-3 in the 1.691 Ghz region, and I'm not sure about NATO. And I don't know if seven is even the record holder, there are many geosync slots with multiple operational satellites. It's no big deal to have multiple satellites in the "same" location because space is really, really, really large. The satellites aren't *exactly* in the same physical location, just close to the actual longitude. And each satellite has (if I remember right) a 40 nautical mile 'box' which is considered its 'personal space' and nobody violates anybody else's space - sort of like a crowded subway car.

The "slots" which are worth fighting for in international agreements are for the C and Ku band broadcast frequencies. For the most part commercial firms and countries don't care about anybody else occupying the same slot as long as they aren't using those particular frequencies. It's even technically feasible to have two satellites in the same slot using the same frequencies - if the signals are cross polarized and the 'beams' are aimed different directions (e.g. one satellite transmitting to the U.S., another to a South American country).

As an example, when the U.S. opened up the 12.2-12.7 Ghz. direct broadcast slots (DirecTV, Echostar, and whomever) one of the key agreements was to station the satellites further apart to reduce adjacent satellite interference (which in turn is one of the key reasons why those little silly dishes can be 18").

If the big boys are really that worried about a bunch of amateurs and whether or not our satellite is going to accidentally 'ram' in to theirs, all we have to do is position ourselves half way between two existing satellites (e.g. 98 degrees is halfway between Telstar 5 at 97 degrees and Galaxy 4 at 99 degrees). Calculate how much 'breathing' room that is at geosync altitude and you'll see that satellites accidentally running in to each other isn't really that much of a concern.

The biggest concern is that after our spacecraft has finished its useful service (whatever that's defined as) that we have the capability to push it out of geosynchronous orbit so it isn't a potential piece of space debris or future source of R-F interference.

In our case there won't be any co-adjacent satellite interference (unless Phase 3-D or another similar satellite happens to also be within range by coincidence) so this is even less

of a concern.

We can outperform commercial satellites in terms of automated East-west stationkeeping. A GPS receiver with a high gain \$1.69 salad bowl antenna (remember that geosync is well above the Navstar constellation) could determine our position in space and command thrusters to fire as required to keep us in our slot, with only occasional monitoring by our ground station.

Yes, in most cases we would require some propellant for East-West stationkeeping to stay within our allocated slot, but if we forgo North-South stationkeeping we use one tenth as much fuel - a much more important factor for us than the commercial world. (commercial world is more interested in a true stationary satellite to reduce the costs for the many receivers, we and the military are more interested in a longer life satellite and can use tracking antennas where required).

It's not that big a deal for hams on the ground to use az/el rotors to track an inclined orbit satellite, and quite feasible to come up with a specially shaped satellite dish which requires accurate positioning, but is designed to collect and focus the incoming signal from the satellite while it wanders up and down from the user's perspective.

It cannot be over emphasized that almost all geostationary comsats are retired with all of their transponders and electronics still working or on backups, and only retired due to lack of fuel. In most cases the commercial companies are happy to get a good return on their investment and happy to pay for a new satellite with brand-new improved electronics. As opposed to our desire to have an existing satellite last as long as possible as long as it's usable (vis AO-10, UO-11).

Another factor is the 'lumpiness' of the geosynchronous belt. Since the Earth is not a homogeneous mass there are places where gravitational attraction is greater and lower than others. These 'hills' and 'valleys' can be used as semi-stable points to minimize propellant consumption. ATS-3 has been operating in the valley at 105 West for three decades without any propellant consumption - now that's gas mileage!6

Orbital Slot considerations

The key factors to consider for where to locate the two satellites are spacecraft lifetime and serving as many hams as possible. This analysis assumes that we will use gravitational valleys around 105 West and 75 East, and hills at 162 West and 18 East whenever possible. For obvious reasons it's more stable to position an object at the bottom of a valley than on top of a hill. I am not absolutely sure about the longitudes of the hills and East valley, but they're within a couple of degrees.

One consideration is to start off a spacecraft in a higher consumption propellant location, and move it to one of the semi-stable locations after a couple of years. This could benefit hams in locations which would otherwise be difficult to serve.

Figures 3 through 6 show the four semi-stable locations.

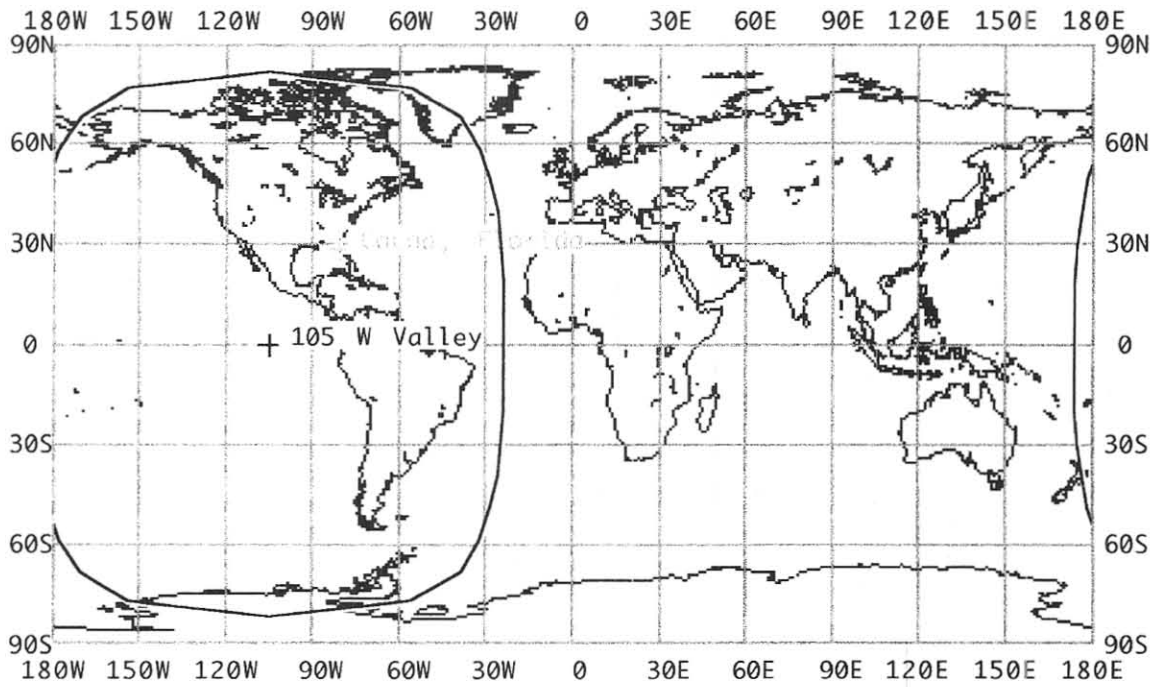


Figure 3 105 West valley

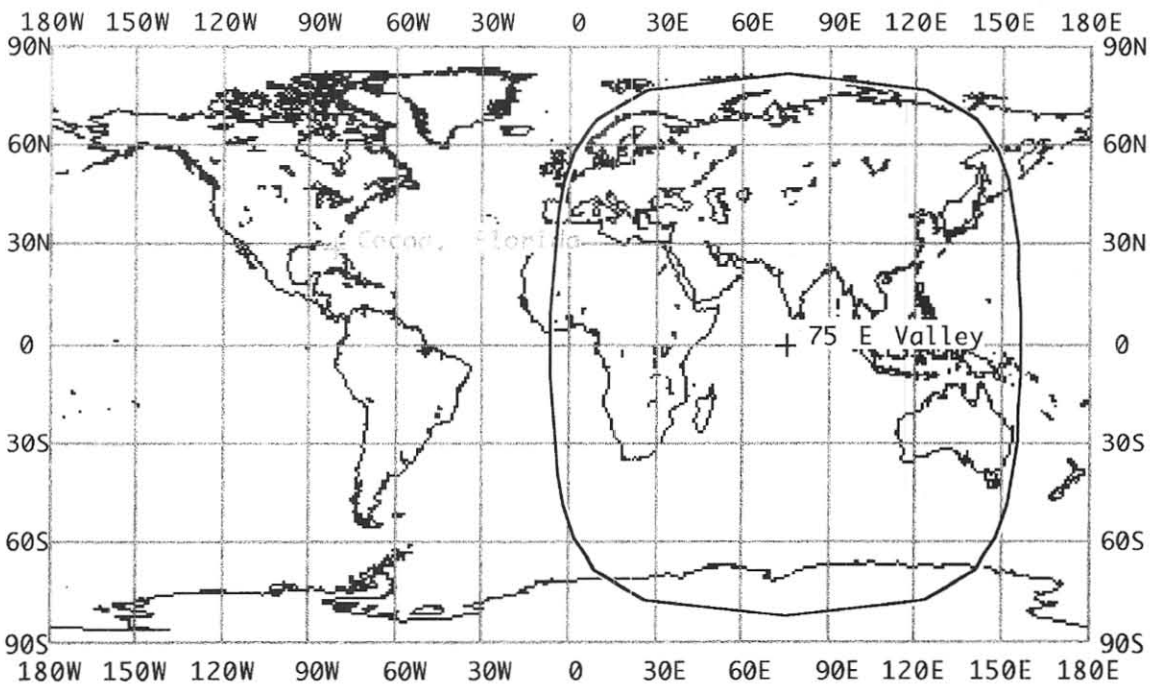


Figure 4 75 East valley

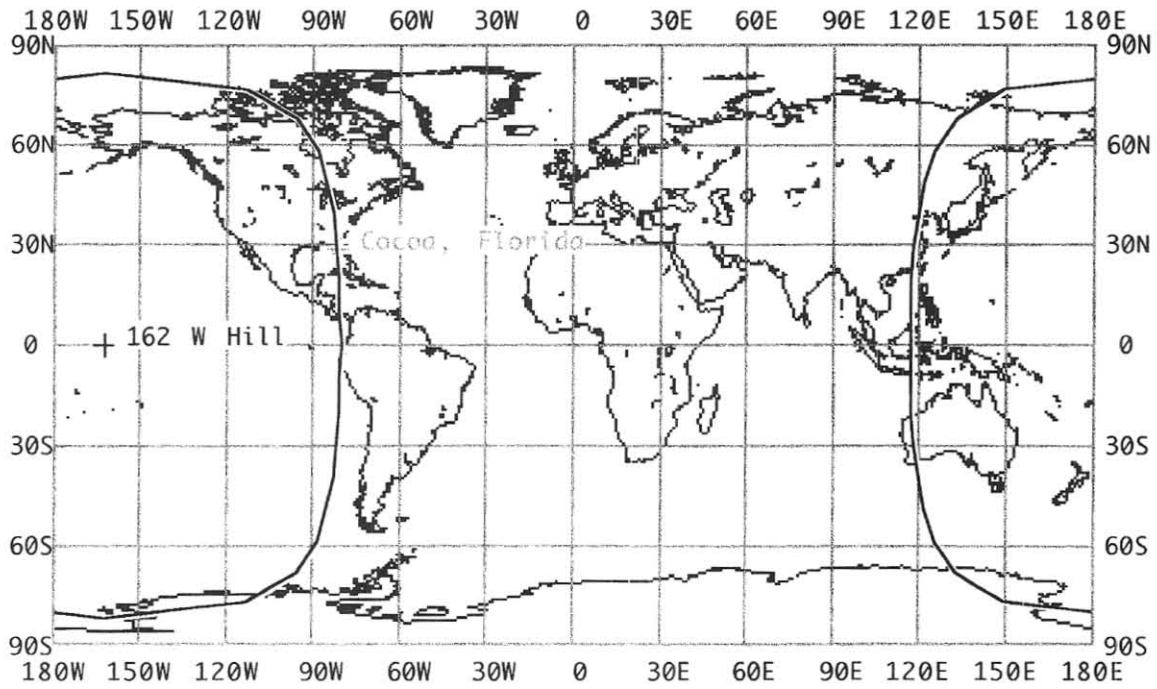


Figure 5: 162 West hill

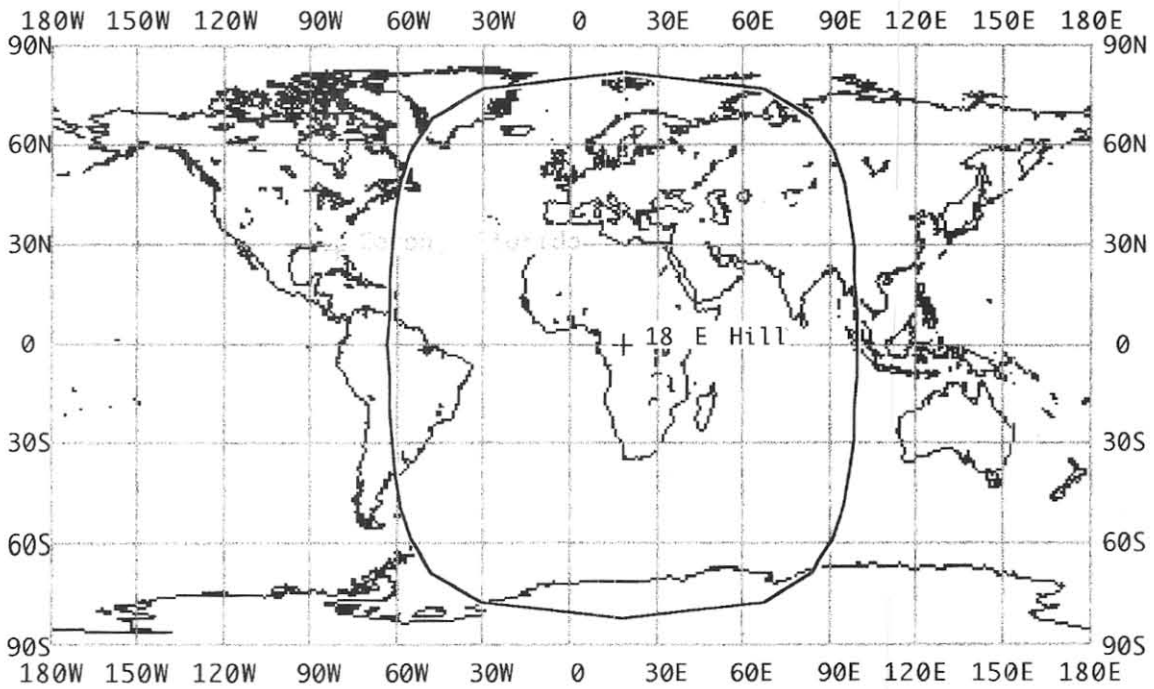


Figure 6: 18 E hill

The 105 West valley has excellent North & South America, but no overlap to Europe. The 75 East valley covers most of Europe, Africa, Asia, and Australia. The 162 West hill gives only Western North America, and bunches of Pacific Ocean. The 18 East hill gives Brazil, Africa, Europe, Western Asia, and lots of Atlantic and Indian Ocean.

It's pretty obvious that the two hills are the less desirable locations due to their excellent coverage of the world's oceans, but less coverage of the land regions.

One excellent pair of potential locations is 105 West Western hemisphere well, and 75 East Eastern hemisphere well. This give the advantages of coverage to most of the land areas of the world, both satellites in the more stable 'valleys', and even some coverage of Hawaii and Alaska. It's disadvantages are no New Zealand, low United Kingdom, no Western Africa, and no location for a ground station which could access both satellites.

If the satellite at 105 West is moved to the East then Alaska goes out of view but eventually Western Africa and the Westernmost portions of Europe (the Iberian peninsula) come in to view. One possible location would be 75 degrees West which gives coverage from Hawaii to Western Europe. As the propellant supply decreases this satellite could be gradually nudged towards the 105 West location.

If the satellite in the 75 degrees East well is moved to the West it would improve coverage to England and Western Europe with the tradeoff of less Australian coverage.

If we eventually launch a third satellite then the on-orbit constellation will be adjusted to maximize the efficiency of the locations for the three satellites. As much as anything else this will probably be controlled by outside factors (e.g. if there's a problem with the propulsion system on one satellite then it will obviously have to remain in its operational location)

Try plugging in the two line element sets in Figure 7, assuming a 10 degree orbital inclination, in to your tracking program to see how much you could use Phase 4 Lite each day.

105 W Valley										
1	99105	97099A	97211.11574445	.00000000	00000	1	00000	1	0	13
2	99105	10.0000	244.4877	00000000	360.0000	0.0000	1.00000000			03
75 E Valley										
1	99075	97100A	97211.11574445	.00000000	00000	1	00000	1	0	12
2	99075	10.0000	64.4877	00000000	360.0000	0.0000	1.00000000			09
162 W Hill										
1	99162	97101A	97211.11574445	.00000000	00000	1	00000	1	0	10
2	99162	10.0000	187.4877	00000000	360.0000	0.0000	1.00000000			02
18 E Hill										
1	99018	97102A	97211.11574445	.00000000	00000	1	00000	1	0	11
2	99018	10.0000	7.4877	00000000	360.0000	0.0000	1.00000000			03

Figure 7 Pseudo elements for semi-stable geosynchronous locations

A policy will have to be established ahead of time to determine what will be done if there's a technical problem with one of the satellites. Will the satellites be preassigned to their Eastern and Western hemisphere locations, or will one location get higher priority due to the efforts of the hams in that portion of the world.

Launch opportunities

One fundamental question is should the two spacecraft be launched together or separately? It's certainly easier to find a single launch opportunity and depending on how the propulsion system is designed a potential for propellant savings. The combined 'stack' would separate from the launch vehicle and use its onboard propulsion system to raise its orbit to geosynchronous altitude. Shortly before reaching geosynchronous altitude the two halves would separate and go to their final destinations. On the other hand, it's less risky to launch the two spacecraft separately. If one satellite's lost in a launch vehicle accident then we still have the second satellite.

As far as specific launch opportunities are concerned there are quite a few choices. New launch vehicles around the world are certainly good candidates. U.S. government launches with excess capacity are also good choices. Whenever a Titan IVB is launched with a DSP early warning satellite 30% of the launch vehicle's capacity is not used. Another permutation is a complementary piggyback mission. Most of the major launch vehicles are in the intermediate class (2500-3500 kgs. to geosynchronous transfer orbit). Not surprisingly this is the range for the majority of commercial communications satellites. However, there are smaller satellites, like the Hughes HS-376 which continue to be manufactured for niche markets. These smaller satellites are only served by the Delta II launch vehicle, and as a partial launch with another satellite on an Ariane 4. If our satellite is sized such that Phase 4 Lite + HS-376 = intermediate class launch it would benefit everybody. The satellite owner would have more choices for potential launches (e.g. more flexibility, more launch vehicle choices) and the launch services provider can open up their market for a new class of satellites. The key question is how much we would have to pay for our portion of the ride.

Launch Vehicle Insurance

NO WAY IN HECK. It's amazing how often this issue is brought up by semi-literate people in the satellite industry.

The purpose for insurance is to mitigate damages in case of a launch accident. Insurance companies are in the business to make money, not lose it. If a given rocket has a 19 out of 20 success rate then the insurance premium will be approximately 14-18% - far over the 5% likelihood of a failure.

The only reason we should ever consider purchasing launch insurance is if a major economic disaster will happen if a failure occurs. While we will cry and certainly be dejected, I can see no reasonable cases where the individual AMSAT members would be economically harmed by the loss of our spacecraft. It's true that manufacturers (i.e. transceivers, antennas, rotors, software, etc.) would have their sales adversely affected by

the loss of a spacecraft - and if Kenwood, Yaesu, and Icom want to donate money to the project for insurance (to insure potential lost sales due to the lack of suitable spacecraft to use their products) then we can gladly accept their donations for a launch insurance fund.

Space insurance people are not dummies, they have qualified engineers on their payrolls with launch industry experience. Rick Hauck, the president of Intec, one of the largest space insurance companies, is a former astronaut. He was the commander of the STS 51-A mission which successfully salvaged two HS-376 satellites.

Current launch premiums for proven launch vehicles and proven satellite designs are in the 14 to 21% range⁷. A highly reliable satellite/launch vehicle combination (e.g. HS-376 and Delta) would get the lowest rates, while a new satellite with a launch vehicle with a worse track record would get a higher rate. It's important to note that the HS-376/Delta combination has had a perfect success rate in the 16 times that permutation has flown, so for each of those missions which were insured the insurance industry has made money.

Contrary to some reports the reason the four Cluster satellites on Ariane 501 were not insured is NOT because it was a test launch. You can obtain insurance for a test launch, for a new satellite design, or even Jimmy Durante's nose or Betty Grable's legs - but the premiums are pretty high. The reason Cluster wasn't insured was because it was a one-of-a-kind scientific program. Scientific spacecraft are MUCH more expensive than commercial comsats (the Cluster series cost about three or four times the equivalent cost of similar mass comsats), so even if you did want insurance the premiums would be incredibly high. But the more important issue is what you would do with the insurance payoff - if you do decide to build new spacecraft with the insurance money then what do you do with the thousands of scientists and other support personnel who plan to use Cluster for the next three years while the replacements are built? How do you keep the project going? For these reasons government-owned satellites are rarely if ever insured. I cannot think of a single case where a government satellite had launch insurance.

Commercial satellite owners obtain insurance primarily in case of 'catastrophic insurance' - similar to the liability insurance for your car if it damages somebody else's property. If there is a failure no matter how unlikely, how much is it going to cost your company in lost revenues because you can't make your commitments to your customers?

More importantly we can build an "insurance" spacecraft for a fraction of the cost of the original - and at a lower rate than insurance premiums. And we should always purchase additional parts whenever it's practical. It's difficult to purchase a single resistor, so when we obtain a package of 50 parts we've got 49 "insurance" components. Spare parts permit us to build a replacement spacecraft more quickly than starting from scratch again and repurchasing another set of parts. This is effectively the equivalent of an insurance policy for a fraction of what launch insurance premiums would cost.

Yes, if somebody offers us an insurance policy with a free premium I will gladly accept. But unless your premium is significantly less than what I think the chances are for the success or failure, it isn't even worth the time to discuss the issue.

Insurance is clearly NOT the way to go.

Potential external funding

The July 14, 1997 issue of "Space News" included an article about how NASA is examining purchasing space on a commercial geostationary direct broadcast satellite for an ozone scientific sensor. The story indicated that NASA is considering purchasing space aboard commercial spacecraft and then offering that space to the scientific community. Since our spacecraft will be in a high inclination orbit it will be more suitable for certain types of sensors (e.g. ones which want to view polar regions or need some kind of 'motion' to detect changes).

The National Science Foundation supports research in Antarctica and needs real-time communications. Several aging communications satellites, including ATS-3 which is three decades old, are used for that purpose⁶. The high inclination is actually a necessity to enable communications with the South Pole. If we can come to a suitable arrangement there's no reason why we couldn't carry transponders just for NSF use, separate from our amateur band transponders.

Educational applications where we could obtain funding include military academies and a dedicated Educational satellite platform. An arrangement could be made with the Department of Defense to exchange a launch opportunity for participation by engineering students at the military academies who could build components or do development work. Congress has indicated a desire for a dedicated educational satellite, and we could support that effort by including transponders for educational applications. It's likely that if this option was chosen we'd probably participate in the design and implementation of the uplink stations and the receivers.

It's important to note that educational applications could take place both on ham frequencies and non ham frequencies, subject to the regulations for each band.

Frequency considerations -

A limited amount of bandwidth is available for amateur radio, and a subset of that allocation is available for amateur spacecraft activities. Recently there have been some complaints about potential sources of interference with spacecraft which are still under construction! Clearly spacecraft must share frequencies, just as hams on the ground have to share frequencies. Higher altitude spacecraft are an exception since their footprints cover a large percentage of the Earth's surface, nevertheless frequency sharing and allocations must be carefully chosen to minimize interference for everybody.

Many of our ham bands are polluted with pirates using our resources for commercial purposes, intermod from pagers, and other forms of interference. In space interference tends to be greater due to the much longer line-of-sight. Moving to higher bands will help minimize most of this interference.

Phase 3-D will encourage hams to use microwave frequencies, and it's hoped that Mode L/S (uplink 1269 Mhz. / downlink 2400 Mhz.) will become a popular mode in the near future. It's logical to assume that these bands will be appropriate for Phase 4. The amount of bandwidth would be a function of the spacecraft size and what we ultimately want to do with Phase 4. The polarization could be either linear or circular polarization, but it's likely

that right hand circular polarization would be used for compatibility with existing OSCAR setups.

It's important to note that these frequencies are below that of commercial C-Band TVRO systems (4 Ghz.), consequently the meshes used for C-Band dishes will be quite adequate.

These frequencies are in bands where amateur radio is a secondary allocation, sharing the band with other users (primarily government radars). This is certainly a concern but hams have been able to co-exist with government users for quite a while and there's no reason to believe that we can't share from geosynchronous altitude.

I'm not completely closed to secondary links in other bands, like 5.6 Ghz. or 10 Ghz. microwave bands, or even a set of cruder VHF/UHF capabilities. However each additional set of transceiver and antennas adds to the spacecraft's complexity. If they are added, then there must be a very strong justification for their inclusion.

If anybody comes up with a reasonable suggestion for additional 'experimenter's modes' then they could certainly be accommodated.

Spacecraft stabilization

There are five types of spacecraft stabilization - active, spin stabilized, gravity gradient, three axis, and magnetic. A sixth, 'tumble' stabilized (e.g. out of control), will not be taken in to consideration.

Active stabilization uses thrusters to keep a spacecraft constantly pointing at a target. This is only practical with short term spacecraft, like the space shuttle, which have the capability to be refueled. It is quite unfeasible for a permanent satellite -- there is no way to use a CO₂ soda cartridge as a long-term propellant source!

The two types of spin stabilization are fully spun, and a separate despun antenna platform. A 'dual spin' design uses a BAPTA (Bearing and Power Transfer Assembly) which connects the communications payload (antennas and feedhorns) to the rest of the spacecraft. The BAPTA is both a mechanical and electrical connection between the spun and despun portions of the spacecraft. An electric motor spins the antenna platform in the opposite direction as the rest of the spacecraft, so from the point-of-view of a user on the ground the antennas appear to remain still while the spacecraft body is spinning the opposite direction. While this maximizes the communications performance it requires a complicated mechanical system with slip rings and space-qualified bearings. It's a potential single-point failure in the spacecraft.

If the entire spacecraft is spun an electronic pointing system must be used to focus the R-F signal towards the Earth. One potential system used on some spacecraft is to build a large number of horn antennas and electronically switch on and off the antennas as they face towards and away from the Earth. This approach was addressed in Bill Tynan W3XO's paper last year⁹. Another approach is to use the spacecraft's spin as part of the antenna's design, sort of a spinning turnstile antenna. This approach has also been flight proven. In either case spin modulation is something which must be dealt with in the transceiver

designs, both on the spacecraft and ground stations.

The key disadvantage to any spin stabilized design is less than half of the spacecraft's solar cells are pointed towards the Sun at any given moment and generating power. However the primary advantages to a spinner are a very inexpensive design and very benign thermal profile.

A gravity gradient spacecraft aligns the spacecraft's long axis with the center of the Earth. The principle is the lower end of the spacecraft, closer to the Earth's center of gravity, is trying to move 'faster' than the upper end, so it stays in a vertical position. Amateur gravity gradient spacecraft include the entire UoSAT series. NASA gravity gradient spacecraft include the space shuttle when it's performing microgravity experiments or minimizing propellant consumption and LDEF (Long Duration Exposure Facility). Gravity varies with the square of the distance from the center of mass, and gravity gradient spacecraft are typically low altitude satellites. Geosynchronous altitude gravity gradient experiments were planned for the ATS-4 and ATS-5 missions, but not accomplished due to unrelated technical problems. The military DODGE (Department of Defense Gravity Experiment) did perform gravity gradient experiments at geosynchronous altitudes, but this needs more research. There have been concerns expressed that the gravity gradient is not very strong at geosync altitudes and again this should be researched.

The advantage of a gravity gradient spacecraft is a stable platform with one axis permanently aimed towards the Earth. The disadvantage is a requirement for a sophisticated thermal control system (e.g. heat pipes) and a steerable solar array to follow the Sun.

Phase 3-D is the first amateur three-axis stabilized spacecraft (excluding the shuttle, Mir, and RS transponders attached to parent satellites). And we've seen how the three-axis requirement has increased the cost and complexity of the project. We need a thermal control system (difficult to manufacture (read: expensive) heat pipes) and are heavily reliant on properly functioning momentum wheels (read: mechanical devices with spinning parts).

The advantages to a three axis stabilized spacecraft include an antenna farm almost permanently pointed at the Earth (read: higher gain), plus solar arrays permanently pointed towards the Sun (read: higher power). The disadvantages include the requirements for a system to desaturate the momentum wheels, sophisticated mechanical and thermal sub-systems (read: expensive) and many potentials for single point failures. The Hubble Space Telescope and Phase 3-D use magnetic torquers to desaturate the momentum wheels, but this isn't viable for satellites at higher altitudes. Most geosync three-axis satellites allocate a portion of their propellant for momentum desaturation.

Magnetic stabilization is not feasible at geosynchronous altitudes because the Earth's magnetic field varies with the cube of the distance from the greatest concentration.

All things considered a spin stabilized spacecraft with electronically despun antennas seems to be the best choice.

Propulsion and propellant choices

We will need propulsion for four separate purposes - the climb from the elliptical geosynchronous transfer orbit to a circular geosync orbit, positioning ourselves in our assigned locations above the equator, maintaining that location, and finally - after there have been enough spacecraft component failures to warrant its retirement a last burst of thrust to push us out of the geosynchronous belt so we aren't a 'road hazard' for other spacecraft.

The transfer from an elliptical 585 x 35,888 km. geosynchronous transfer orbit to a circular geosynchronous orbit is fairly simple. The change in velocity (excluding any inclination change) is 1,437 meters per second. One burn is required if a solid apogee kick motor is used and it's fairly trivial to calculate the amount of impulse required for a given mass satellite and standard transfer orbit parameters. Working backwards it's fairly easy to determine what relatively 'off-the-shelf' solid motors are available. Typically if a liquid engine is used the transfer is done in several small burns. This permits a smaller engine with a lower on-off cycle (read: less expensive) to be used. If there is a technical problem aboard the satellite before the burn begins the ground station can issue a halt command, and permit the spacecraft to go through an additional orbit to give the ground controllers time to think out the situation before the next opportunity for the apogee firing.

If we unexpectedly get more launch vehicle performance than planned (e.g. if it suddenly turns out for some reason that we are the only passenger on the launch vehicle and the company is willing to give us the extra capacity) then we could put more propellant on board (limited by the volume of our tanks and overall strength of the spacecraft structure). If we get a better performance from the launch vehicle than nominal, we will need less propellant to get on station, and the extra propellant extends our mission lifetime. If we get less launch vehicle performance than planned, it's possible that we could still achieve some kind of usable orbit, even if it's not what we originally planned.

If we use a spinning satellite which only performs East-West stationkeeping, we would need four low power thrusters (2 axial and 2 radial), possibly derivatives of the Phase 3-D Arcjet system. My preferable choice would be a monopropellant hydrazine thruster whose performance can be increased by heating the propellant during combustion. Another possibility would be a bipropellant system. As noted previously high pressure gas (e.g. a CO₂ soda dispenser cartridge) is NOT suitable. The actual choice of what kind of thruster would be more a function of what we could find and afford or design and build than anything else.

The standard choice would be a high thrust large solid or liquid propulsion system for the apogee kick burn, and a series of smaller thrusters for the other tasks. However, there is a less expensive choice which should be seriously considered. It's feasible to use an attitude control thruster (properly sized for the task) to nudge a satellite to geosynchronous altitude. This was actually done in the case of the TDRS-1 satellite in 1983 when its Inertial Upper Stage's Orbus 6 apogee motor failed, and the spacecraft controllers had to use TDRS's thimble-size attitude control thrusters to raise it to geosync altitude. The small thrusters were never designed to handle that much of a workload, but their use saved the spacecraft. Quite a feat, but something we could baseline to eliminate a separate apogee transfer system and reduce our hardware cost. With careful selections we may be able to choose (design? build?) thrusters which have enough of a life cycle to permit their use for the apogee raising

burns. The Phase 3-D arcjet would not be suitable as an apogee transfer engine though. Preliminary calculations show that it would take over 187,000 burns to change a geosynchronous transfer orbit in to a geosynchronous orbit - and literally over a century to accomplish! Clearly a higher thrust system must be used!

Power System

With most spin-stabilized spacecraft a telescoping solar array is used. The external cylinder doubles the available surface area for solar cells. This requires a reliable mechanical deployment system, like a worm gear. Figure 8 shows a photo of the solar array deployment motor from the Intelsat 6 series. A deployable array is 'fail-soft'. If the solar arrays fail to extend then the power budget for the spacecraft is reduced by half, not a desirable situation but at least something we could still live with.

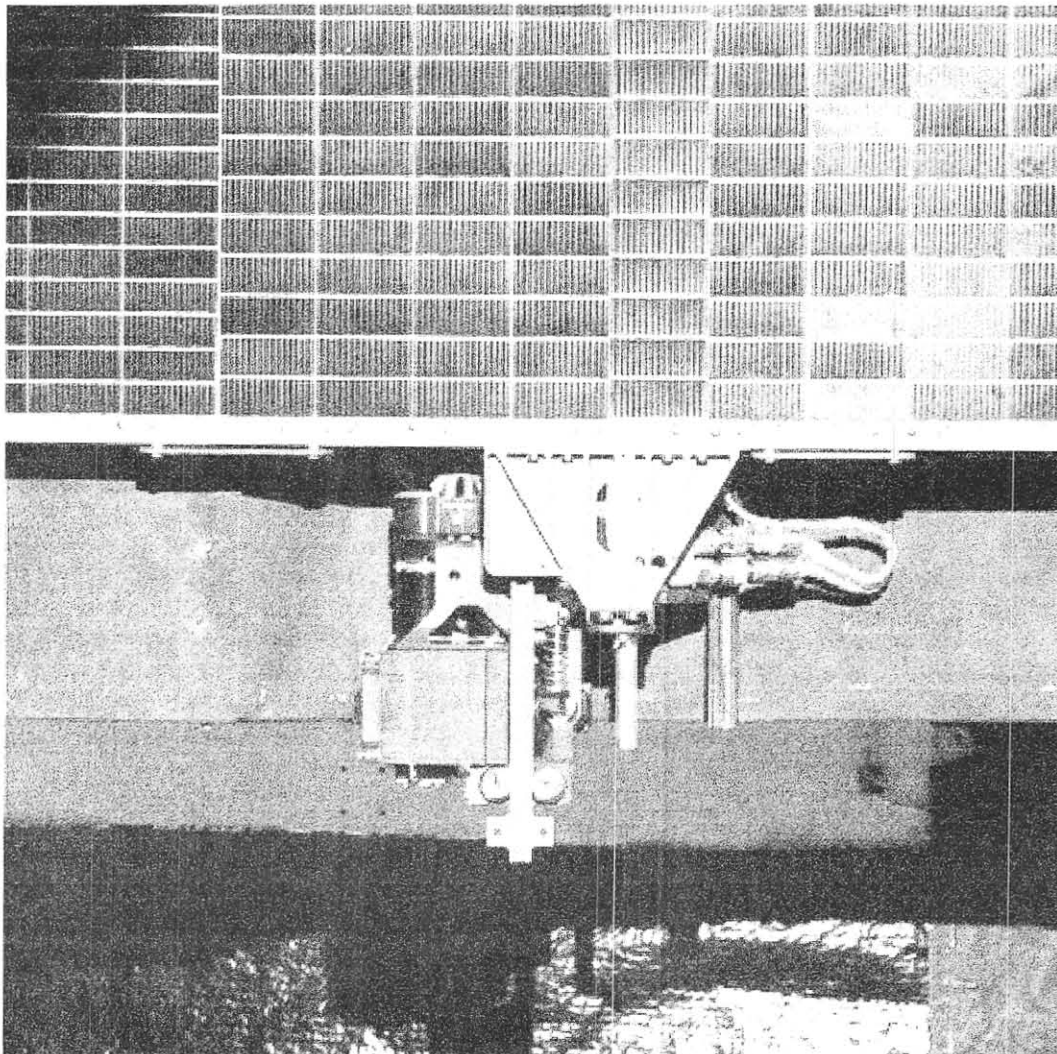


Figure 8 Solar Array deployment motor for Hughes spin stabilized satellite

A true geostationary satellite only encounters eclipses in the Spring and Fall when the Sun, Earth, and satellite are aligned. The maximum eclipse time is about an hour and eclipse season only lasts a couple of weeks. With a highly inclined geosynchronous satellite eclipses are encountered each day.

Fundamentally the power system for Phase 4 Lite will be similar to the Phase 3 satellites - high efficiency solar arrays which power battery charge regulators, and storage batteries (either Ni-Cad or Ni-H₂ depending on what's available). It's highly desirable to protect the batteries with diodes to permit batteries to be isolated when they fail. Eventually if all of the batteries on the spacecraft fail we may be in a situation similar to OSCAR-10, with the spacecraft only operating when it's in sunlight.

Solar cells and batteries age over time and gradually lose efficiency. At the beginning of spacecraft operations we can continue to operate the spacecraft with transponders in operation even while the spacecraft is going through eclipses. As the power system degrades over time we would gradually shift to no communications functions during eclipses, with battery power dedicated to maintaining the spacecraft computer, and possibly the engineering beacons.

Crosslinks between satellites

Via ground stations. Period.

The preferable choice would be a ground station in a country with liberal radio policies as opposed to one where we would be heavily restricted. But one with strong support for amateur radio operators.

The one exception for inter-spacecraft crosslinks will be experiments with Phase 3-D and other amateur platforms in orbit (International Space Station?) If Phase 3-D is in Mode S/U then it would be feasible for a user on the ground to uplink a signal to Phase 4 which would then be retransmitted on Mode S to Phase 3-D and then down to the ground. We could schedule crosslink experiments whenever the satellites are in the appropriate geometries.

If the satellite locations do not permit a ground station in a suitable location (technically, politically, financially) which can view both satellites we may require separate ground stations, linked by a high bandwidth terrestrial connection.

Spacecraft onboard computer

The onboard computer will be much more intelligent than previous amateur spacecraft computers. It will need a fair amount of shielding, error correcting memory, the capability to isolate bad components, and possibly even a backup computer. It should include an automatic 'reset' timer if it doesn't receive any commands within a given period of time. And, most importantly, it should include a 'deadman switch'. If the spacecraft receives no commands or signals from the ground for a fairly long period (e.g. a week) then it should assume that something has gone terribly wrong and if it can't establish communications

with the ground it should command its thrusters to fire to push it out of the geosynchronous belt to avoid the hazard potential to other spacecraft.

The system architecture should have a combination of ROM (Read Only Memory) containing the integral housekeeping information, bootstrap loader, and minimal operational configuration. Its error correcting memory should include enough space to expand the system's capabilities as we develop better operating system programs.

As a fall back it would be desirable to have a backup 'dumb' bent pipe system which could be activated manually or automatically if the primary computer fails.

The computer needs to have a 'power on reset' circuit to restart the computer when it comes out of an eclipse. While this feature will not be required while the batteries are working it will be useful many years later when the batteries eventually fail.

The reason for all of these layers of protection is Telstar 401, and other spacecraft which have been lost due to component failures. Geosynchronous orbit is not a benign environment, and our spacecraft needs to be protected as well as possible against inadvertent failures.

Still, most of the power should reside in the ground stations. It's always easier to upgrade the hardware in your ground station than it is to upgrade a component in space!

GPS and other experiments

GPS is not really necessary since a geosynchronous satellite is very stable in terms of position and orbital elements, but it's quite possible somebody could find a reasonable application (e.g. time signal, orbital determination during transfer orbits, etc.)

Weather observations is an interesting possibility. With a spin-stabilized spacecraft a simple fax machine-style row of diodes can scan the entire sky once each rotation.

Some other possible amateur science experiments include magnetic strength, or particles & fields. More in line with radio experiments would be radio interferometry or radio astronomy activities.

Secondary payloads

As previously noted we could offer space on the spacecraft to the scientific community for suitable payments. There's no reason why we couldn't put up a "This space for rent" sign! Alternately we could trade space aboard our spacecraft for a launch opportunity.

My personal opinion is that it's highly desirable to do other things. When you come down to brass tacks, Phase 3-D is just another communications satellite, with a camera experiment. If we're going to continue to forge new ground, it would be highly desirable to include some form of scientific research on our front line spacecraft.

Certainly one of our key applications will be the retransmissions of NASA TV. We would

have the capability to provide NASA TV to many parts of the world which have not been able to receive it, and hams living under circumstances (e.g. antenna restrictions or spouse complaints) who can't receive it today. This transmission should certainly have a superimposed AMSAT Phase 4 logo to identify piracy by commercial television stations!

Link Margins, estimated weight

TBD - based on the available launch mass

Ground station considerations

One of the key advantages of Phase 4 Lite is you don't need a complicated outdoor antenna setup to get running. Some folks may wish to get by with minimal setups, especially in areas where antennas are restricted. On the other hand, there are always hams which insist on the highest performance equipment. With this project everybody can be satisfied, and there are excellent upgrade paths available for those who wish to start small and upgrade as budget allows. Arbitrarily I've split the users in to three very broad classes, A, B, and C. A class A station can use the satellite continuously, but requires the most sophisticated equipment. Class B stations need less sophisticated hardware, with the tradeoff of less signal strength. Class C stations are minimal setups, which can be often added to existing antennas for little cost.

Class A station - 1 meter (estimate) parabolic dish with az/el positioning capabilities

This is the world-class station for a ham who requires the very best. A parabolic dish is mounted on a computer-controlled az/el mount.

As noted previously at higher latitudes you will not be able to communicate for a small period each day when the satellite's below your horizon.

Class B station - specially shaped fixed antenna which focuses the signal through the satellite's path

A general assumption is satellite dishes are symmetrical. While normally the case it's quite feasible to make unusually shaped dishes which focus the signals from certain directions, and help eliminate signals from others. A roughly rhombus shaped dish with the long axis in a vertical position focuses signals from a satellite in an inclined orbit.

The major advantage to a 'directional' dish is the fixed mount. The disadvantage is the tooling cost to set up the unusual shape of the dish. In addition, as the satellite's inclination increases different shapes will be required for the best coverage while eliminating as much interference as possible.

Class C station - adding a L/S feedhorn to an existing or scrounged TVRO dish

For a causal Phase 4 user a Class C station may be adequate - with the satellite passing within view of the antenna for a couple of hours each day.

For a typical 10 foot (3 meter) home satellite dish the gain in S-Band frequencies is 35.91 db, and the beamwidth is 2.92 degrees.

I haven't done any link margin calculations, but would anticipate that a scrounged .5 to 1 meter dish would be adequate for a minimal setup - quite appealing where a low profile or portable antenna is a necessity.

One important concern would be how to handle duplex communications with the receiver next to the transmitter. A cassegrain dish would permit the receiving feedhorn to be separated from the transmitter, but would limit the availability of suitable surplus hardware.

Portable operations - field day, emergencies, and the like

A .5 to 1 meter antenna could use a simple tripod mount. I've seen fancy several hundred dollar motorized mounts for RV owners who want to receive DBS, but that seems to be overkill. It should be easy to make manual pointing charts and simple wing-nut adjustments to point the antenna the correct direction.

It's possible that the satellite's performance may be high enough to permit omni-directional antennas, or low-profile motorized antennas for mobile applications.

Operations considerations

The satellite will use pure digital operations with a well defined communications protocol. It's too inefficient to just key your radio and take up a chunk of the passband. With an automated computer-controlled assignment system users will be dynamically allocated exactly what bandwidth is required for reliable communications. In effect a 486-class computer will become your "transceiver".

Regrettably hams in less developed areas where inexpensive computers are not readily available will not be able to use Phase 4 Lite, unless the decision is made to add additional simpler capabilities.

Phase 4 Lite will be able to support interactive voice, data, SSTV, FSTV, FAX, CW, - in short anything which can be displayed or generated on your computer, including interactive video teleconferencing.

Before transmitting you will choose a priority level in your 'transceiver' program, ranging from random rag chewing, nets, and permanent communications trunks, up to emergency communications.

When you key your transmitter a 'calling signal' is sent on a specific frequency with your station's ID. (location, call sign, priority, transceiver serial number, etc.) It will also

specify what you want to do on the satellite - talk to a particular party, enter a net (chat room), or just see who you can talk to. It's basically a computerized version of what you do when you normally choose a frequency and key your transmitter.

The satellite will then allocated a particular frequency to you, whether it's in the general calling area, computer storage, or whatever. Frequencies are reallocated as required and based on the priority declared by the calling party.

The user's transceiver/computer will also be usable for other uses, including non-satellite microwave ham work, possibly other bands too, depending on how downverters and transverters are designed and even non-ham computer uses.

I regret that the spacecraft will certainly have to have an 'alligator killer' and other means of self-protection against inconsiderate hams, and non-hams who would abuse our resources. An 'alligator killer' is basically a spectrum analyzer which sweeps through the received signals, monitoring each user's power level. If a user is appreciably higher than others the user is informed with a courtesy beep. And if the level isn't lowered then the offender is isolated with a notch filter.

More importantly every Phase 4 compatible radio will have a built-in serial number. Any commercial company which desires to build compatible transceivers would be assigned banks of serial numbers, an additional serial numbers would be assigned to homebrewers. Violations would result in your serial number being placed on a 'black list' which would be ignored when you try to log on or you would get a screen on your computer announcing that your access to the satellite has been canceled. Whenever used units are sold and the sale is verified the control operators could remove the serial number from the black list - at least until any future violations.

Making the proper hardware available to the ham community

Obviously the Phase 4 Lite ground station will require a fairly specialized I/O board, with similar requirements for the rotors, preamps, etc.

I would like to recommend a multi-tiered approach, similar to the approach which has made the 18" satellite dishes so popular.

In the early project stages AMSAT will accept bids from hardware/transceiver manufacturers who are interested in licensing the necessary information to develop the proper transceivers. These funds, of course, will be used to help build the satellite. In exchange the manufacturer who signs a license will get exclusive access to that proprietary information for a limited period (a specific period time after the satellite launch or until the sales of a given number of units whichever comes first). Overall, I'd expect that this licensing fee would be about 2 to 5% of the retail price of the equipment licensed. After that period other manufacturers will be able to license the data for a lower licensing fee. Eventually after a given period the information will be placed in the public domain to encourage as many competitive manufacturers as possible to enter the field, presumably resulting in lower costs to the individual.

The first manufacturer obviously will have a major marketing advantage, releasing second-

generation hardware while the competition is tooling up for their early units (vis RCA vs. other manufacturers of DSS receivers). So this should be a fairly coveted position among amateur radio hardware manufacturers. However once many different manufacturers are making units competition will ensure lower prices for all (vis \$699 original price for an RCA DSS receiver vs. almost free now). It's important to note that this isn't an exact analogy. The purpose behind a DBS system is to sell you the hardware as inexpensively as possible - at a loss if necessary - and make profits via the sales of the services. With a ham radio system the manufacturer has to recoup its startup costs, and determine how many units it can expect to sell - to a fairly specialized niche market - over the anticipated lifetime of the satellite.

If a manufacturer doesn't want to pay license fees to AMSAT then they're welcome to go at it themselves, or build accessories and other components which would be desirable for a Phase 4 ground station. Any manufacturer who desires would be assigned banks of serial numbers for no charge. However they would not be permitted to put a 'licensed by AMSAT' logo on their products.

A very valuable license would be the receive only video unit, designed to decode and watch NASA TV, and possibly other video channels. This unit would consist of an 18 or 24 inch dish, a low noise amplifier, the equivalent of a single-board 386 class computer, and a video generator. Hopefully it could be built and sold for under \$200. The key market would be hams around the world who wish to watch NASA TV, but cannot for one reason or another (e.g. cannot put up a C-Band dish due to legal or spouse problems, or lives outside of the footprint of the NASA TV transmissions). Additional video channels would be available for other educational applications which are compatible with amateur radio regulations and AMSAT's policies.

Obviously there will be plenty of opportunities for hams who wish to write software, build specialized components, etc. The hobbyist will find plenty to do with Phase 4 Lite!

Couple of components which will be required:

- L-Band transmitters, antennas, amplifiers, etc.
- S-Band downverter, antenna, preamps, etc.
- The specialized DSP, A/D I/O card which will handle all of the signals, send commands to the rotors, etc.
- Transceivers optimized to use these capabilities, possibly even cards which fit within computers.
- An all-in-one semi-portable ground station, similar in size and weight to early 'sewing machine' computers (Compaq, Kaypro, etc.). Basically a combination VGA monitor, 486 class computer, transceiver which can be operated on DC or AC power. This should be available in plug-and-play, assemble yourself, and do-it-yourself kit forms.
- More specialized portable (read: mobile size) radios for general chatting and QSOs. Very simple controls and easy to use, but more specialized in function (e.g. only access to digitized voice 'chat channels' as opposed to high data rate transmissions.)

Homebrewing ground stations

Since the beginning of ham radio there have been complaints about how most hams are 'appliance operators' and not interested in high tech skills. And yes, it doesn't require much technical capability to press a push-to-talk button and work a local repeater. And many hams have the attitude of 'if it's easy everybody will want to do it'.

On the other hand,

Certainly if you enjoy difficulties in spacecraft operations that can be easily accommodated by a software program which only gives you part of the information and requires you to come up with the rest yourself. There's no reason why the rig has to be user-friendly if you want an unfriendly system!

Even though it will probably be less expensive to purchase a specialized Phase 4 transceiver many hams will still prefer to build or design their own stations.

In theory you could purchase the VSLI integrated circuits and homebrew a system from scratch. In practice it would be more practical to purchase a specialized module or board and homebrew the front end.

In any case items like antennas and preamplifiers would certainly be feasible for many hams to design and build on their own.

Controversies:

Most geosync satellites have shaped footprints which concentrate their signals over the areas they wish to serve. In the more sophisticated satellites the footprints closely follow the service area to maximize the spacecraft's efficiency. We could design directional antennas which would increase the signal level for the hams in the footprints. But how would the beam be shaped? Better Northern hemisphere coverage?, better land coverage? Both would benefit certain hams at the expense of reducing the signal levels for other outside of the footprints. It can certainly be argued that there are few hams in the middle of the ocean, but should we reduce coverage to sparsely populated countries or third world countries who do not donate to the Phase 4 project?

To stretch the point further if Alaskan or Hawaiian hams don't contribute enough resources should we not try as much to serve those areas? Or should the decision on whether to serve England or Australia be determined by which country is more successful in its fund raising campaigns?

In a sense the question is should hams 'vote' with their dollars or do we have a moral imperative to support hams in less developed areas?

Certainly you're going to have to know how to use a computer to use Phase 4 Lite. The system will certainly be 'user friendly' - you won't need to be a rocket scientist. However there are many hams in regions where inexpensive computers are not readily available. It may be possible to include additional modes (maybe even mode B) in a much cruder form

to support those hams.

Concerns:

The question has been raised whether or not AMSAT should build 'just another comsat'? In the early days of the space program Project OSCAR and AMSAT could really say that they were breaking new ground, pioneering techniques and capabilities which weren't available in the aerospace community. Now there's less experimenting, and many other organizations who are building inexpensive innovative spacecraft. Certainly it's desirable to keep amateur radio in space, but what are we doing besides building glorified repeaters in space?

If Phase 4 Lite does become a reality will it be so easy to use that it will always be overcrowded? If you're too popular then it becomes impossible to use because it's always over crowded.

On the other hand, if it's too easy to use then it may not appeal to technically oriented hams. There may be interest in developing new communications techniques and experimenting, but how many of us really experiment with handheld 2 meter radios and local repeaters?

It cannot be overstressed that we must protect our resources, whether it's frequencies or the fact that we've got a repeater located in orbit. If it is easy to use, then there are many irresponsible hams who will use it for prohibited purposes (e.g. commercial traffic) and many pirates who would want to use us for free for their communications instead of paying for similar services from a commercial company.

and finally, **spacecraft names**

There have been recent suggestions that future amateur satellites should be named after individuals. Certainly this is an extremely high honor, which should be only bestowed upon individuals whose actions have resulted in world-changing results on a revolutionary level. For a pair of geosynchronous radio satellites, I can think of no more appropriate individuals to honor than Guelielmo Marconi and Arthur C. Clarke.

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Satellite Experimenter's Handbook
Martin Davidoff

Digital Voice Modulation for a Future Generation of Ham Satellites

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With the Phase 3D project nearing completion and launch, it is natural for Amsat to consider what type of projects to pursue in the coming years. Phase 3D should open up satellite operations to many more hams with its high power transmitters and high gain antennas, which are both made possible by its advanced 3 axis stabilized design. The chief disadvantage of Phase 3D is its approximately 400 kilogram mass, which will limit the possibility of Amsat ever being able to obtain a second launch for a possible Phase 3E follow on mission. Phase 3D was specifically designed to take advantage of a once-in-a-lifetime bargain basement launch opportunity that was presented to Amsat as a result of the Ariane 5 test and qualification program. Unless another 400 kilogram launch can be obtained at a price that Amsat groups around the world can afford to pay, Phase 3D will be the first and last of its kind. We therefore must consider how to serve the needs of the amateur satellite community with smaller and lighter satellites that we can launch at an affordable price.

Some persons have argued that we should return to building the simple Mode A Low Earth Orbit (LEO) satellites of days gone by in order to make amateur satellites attractive to a new group of satellite hams, including young people and citizens of developing nations who do not have the ability to order \$2000 radios on their credit cards. This paper will present an alternative view, that instead of going back to the technology of the past, we should look at the advanced technology of the future to see how it can help us build smaller and cheaper satellites which are accessible to a large number of hams including those for whom financial limitations and antenna restrictions have prevented active participation in past Amsat programs.

ANTENNAS are the limiting factor for many hams (including me). As an apartment dweller my ability to operate mode B is nearly impossible. Even hams who live in single family homes are often stymied by restrictive covenants which are becoming difficult to avoid in urban areas. Antennas and their associated mounting structures and rotors also represent a significant portion of the cost of establishing an amateur satellite station. Any technology that can reduce the required antenna size for a satellite ground station will do much to make satellite operation accessible to more hams.

Spacecraft Design Philosophies:

The history of communications satellites has gone through two stages of development so far:

Stage 1. Make the satellite as simple as possible. Keep all the expensive and complicated stuff on the ground where you can fix it. Examples are Telstar, Syncom, C band TV relay satellites, TDRSS, AO-13

Stage 2. Make the satellite larger and more complex to allow the use of smaller, simpler and less expensive ground terminal equipment. Deploy huge solar arrays to provide for high RF output power satellite transponders. Maintain 3 axis pointing control to allow high gain satellite antennas. Examples include the new high power KU band Direct Broadcast TV satellites, ACTS, Milstar and of course Phase 3D.

The time has come for:

Stage 3. Use advanced electronic technology to build smaller, cheaper satellites, cram them full of the latest silicon to allow inexpensive satellites and simple ground station equipment. Use brains instead of brute force. A current example of such an application is the Ku band direct broadcast satellites which have appeared in the past few years. Direct to home TV satellites are included in stage 2 because they rely in part on larger than normal power output to reach smaller receiving dishes, and also in stage 3 because they use digital error correction coding to improve their link margin over a conventional C band analog TV system.

Digital vs Analog modulation:

Hams are already familiar with analog modulation techniques. Frequency Modulation is commonly used on our VHF and UHF bands for local repeater operation, and in space to ground QSOs with the Space Shuttle and space station MIR. Single sideband with suppressed carrier is the defacto standard for the HF bands and for operation through linear satellite transponders, where FM is not welcome because it is not a power efficient mode. Electrical power is the single most precious commodity onboard a satellite, and transponders must be designed to make the most effective use of available power from the solar arrays.

Digital voice modulation is all but unknown in the present amateur radio universe, although you can see daily examples of digital operation in the newest generation of cellular telephone and personal communications devices, which have quickly become a multi-billion dollar business around the world. Many hams have used their background in RF technology to obtain jobs in this booming field, which is having trouble finding engineers and technicians with relevant RF experience due to the fact that US engineering colleges have all but abandoned the teaching of Radio Frequency design courses in favor of more trendy computer related subjects. Indeed, the development and nurturing of technical skills and interest in radio technology by young people may be the sole remaining

justification for amateur radio's existence in the 21st century.

In the commercial communications world, there are virtually no new analog systems being designed, even television broadcasting in North America will soon be making the transition to digital modulation. Amateur radio is falling ever farther behind the cutting edge of technology by its continued reliance on greater than 50 year old analog modulation techniques.

The "R" in RUDAK stands for "Regenerating":

In many respects, the most interesting part of the Phase 3D satellite is the RUDAK, a German acronym for "Regenerating Digital Transponder for Amateur Radio".

An analog transponder converts an uplink signal at a certain frequency to a downlink frequency by mixing with a local oscillator and then retransmitting the signal back to the ground without any other modification. The uplink station must provide sufficient RF transmitter power and antenna gain to provide a strong enough signal to make the round trip up to and back down from the satellite. Noise can enter the signal path during both the uplink and the downlink part of the trip. The satellite transponder front end adds noise to the signal as it arrives at the satellite, just as the user's own receiver adds noise when the signal arrives on the ground. The noise that is added to the uplink signal is amplified and retransmitted back to the ground as part of the downlink signal.

A regenerating transponder actually demodulates the uplink signal to obtain a digital bit stream. The receiver on board the satellite can make the decision between a 0 or a 1 on the incoming signal, and then send a clean stream of regenerated 0's and 1's to the transmitter for downlink to the ground. The uplink signal only needs to make a one way trip up to the satellite, where it is cleaned up before being sent back for the return trip. The demodulated digital signal is retimed and restored to original form. This approach effectively isolates the uplink performance from the downlink performance, preventing the accumulation of noise and distortion over the two links. In contrast, in a linear transponder the thermal noise on the uplink signal directly affects the carrier to noise ratio in the satellite downlink.

An additional consideration is that with an analog transponder one user can "steal" an unfair share of transponder RF downlink power at the expense of other users by increasing his uplink power, since a single transponder AGC is shared by all users in the passband. The nature of digital links is that that they tend to either work perfectly with 100% armchair copy or else they do not work at all, there is no advantage to be gained in running more uplink power than is required for effective

demodulation onboard the satellite. The user will not be able to increase the audio level of his downlink signal by cranking up his uplink power. There is simply no advantage to being an "Alligator" in the digital world.

In addition, a digital transponder potentially allows the use of transmitter identification codes to lock out unauthorized or bothersome users. Each rig could have a unique ID number, the spacecraft could store a list of "deactivated" numbers in its onboard computer, and would refuse to relay any uplink signal that is not carrying a "valid" ID tag in its data stream. This would allow Amsat to maintain some control over the use of its space assets, to assure that the satellite is used only for legitimate amateur radio operation. If certain unlicensed groups should decide to take over the satellite for commercial or illegal purposes, we could exclude only the troublesome users and leave the transponder in operation for properly licensed, responsible hams. Right now, the only option we have in case of abuse is to shut down the transponder entirely and deny it to all users.

The digital receiver will also provide automatic Doppler tracking, which will eliminate one of the more serious objections to the use of microwave frequencies in the amateur satellite service.

Forward Error Correction Coding:

One method of reducing the bit error rate of a digital radio link is by adding extra redundant bits in an organized manner such that a receiver can decode the bit stream to recover the original data. Forward Error Correction (FEC) coding trades off increased signal bandwidth for a reduced transmitter power requirement. The most notable use of FEC is for NASA deep space missions, in which extraordinarily weak radio signals from unmanned space probes travel millions and millions of miles through the solar system to reach receivers on Earth. Transmitter power on these deep space missions is limited to only a few watts, less power than your 25 watt 2 meter mobile rig. The unfortunate failure of the high gain antenna on the Galileo Jupiter mission has forced JPL to conduct the mission entirely on its omnidirectional low gain antennas. In response to this, JPL has developed highly advanced data compression and encoding software which has salvaged much of Galileo's original science mission in spite of the failed antenna. Closer to home, techniques such as Reed-Solomon coding are also used in Compact Disk audio players to detect and correct bit errors caused by scratches in the disks and other defects.

In the microwave satellite bands we amateurs have much more bandwidth available (at least for now) than we presently use, and transmitter power is costly both on the spacecraft and on the ground. Use of coding on satellite links would allow us to trade off our surplus bandwidth for

lower power requirements, which translates to smaller and cheaper satellites. This is unlike the commercial communications world where bandwidth is precious and modulation methods are chosen more for bandwidth efficiency than they are for power reduction. Ham radio technology will thus not be exactly like that of the commercial world because of different priorities in conserving power rather than bandwidth.

The commercial satellite TV market provides an example of how the new digital compression, coding and modulation made Ku band satellite TV a practical option for those who could not erect C-band dishes. Digital technology puts the complexity in a box in your ham shack, not on your roof, or as Tom Clark, W3IWI, once said: "Silicon in your computer can replace aluminum in your antenna."

A complete discussion of error correction coding is far beyond the scope of this paper, the interested reader should consult some of the many textbooks and tutorials that are available.

Digital Voice Encoding:

Modern digital cellular telephones convert human speech to a digital bit stream by use of Linear Predictive Coding (LPC). This is a data compression technique that takes advantage of the fact that human speech is highly redundant. LPC models the human vocal cords as a pulse generator and a white noise source followed by a bank of filters. At the decoder a regular set of pulses for voiced speech or white noise for unvoiced speech is passed through a set of variable gain filters to reconstruct the original speech. The data is transmitted in frames which carry the filter coefficients, energy of excitation, a voicing decision, and pitch value for voiced sounds. This eliminates unnecessary data from the bit stream and allows speech to be reconstructed at the receiver with a minimum amount of data from the transmitter.

The most familiar LPC standard is the European GSM 06.10 cellular telephone standard, which generates a 13 kilobit per second bit stream. This standard is public property and free software to implement GSM on various DSP chips is publicly available. The 13 kilobit standard provides "toll quality" speech which is of similar quality to a regular wired telephone connection. Another public LPC standard is the 2.4 kilobit US Defense Department Standard, LPC-10. As one might expect, the lower bit rate requires that quality of speech transmitted by this technique is less than what the general public expects from their regular telephone service. LPC-10 sounds somewhat "robotic" and artificial, but is not much worse than SSB once you get used to it. There are also many proprietary LPC coding schemes such as Qualcomm's 8 kilobit speech encoder. Development of voice coding

methods is a highly competitive area in which various companies try to reduce bit rate while preserving voice quality. As with FEC, a complete discussion of LPC and CELP (codebook excited linear prediction) is far beyond the scope of this article, and the interested reader should consult appropriate references.

Sample Link Calculations:

In a digital radio link, the link performance is evaluated in terms of the Carrier to Noise ratio, C/No, according to the formula:

$$C/No = EIRP - \text{Path Loss} + \text{RX antenna Gain} \\ + 228.6 \text{ dBW/Hz deg K} - 10 \log_{10} T_{\text{sys}}$$

The carrier to noise ratio is related to the energy per transmitted bit, Eb/No, by:

$$Eb/No = C/No - 10 \log_{10} R \quad \text{where R is the digital bit rate.}$$

As stated previously, a regenerating transponder allows the uplink and downlink performance to be evaluated separately. Starting with the 1269 MHz uplink from the user station to the satellite, and assuming that:

User transmitter power	12 dBW (16 watts)
Ground station antenna gain	3 dB (patch antenna)
Path Loss	-188 dB (46,000 kilometers)
Satellite antenna gain	15 dB
Satellite RX noise temp	-26 dB (Tsys = 440 deg K)
Boltzmann's constant	228.6 dB log ₁₀ (1.38E-23 W/Hz K)

Carrier to Noise ratio C/No	44.6 dB
Required Eb/No	3 dB (rate 1/2, k=7 plus RS)

10 log ₁₀ R	41.6 dB (R=14,400 bits/sec)

From this calculation we see that a 16 watt uplink using an omnidirectional patch antenna and concatenated Reed-Solomon and convolutional coding can support 14.4 kilobits per second when the satellite is at apogee, a rate which will accommodate 13 kilobit GSM speech encoding. However, to reduce the complexity of the satellite, we may decide to use a less heavily coded uplink signal, at the expense of requiring a higher transmit power on the ground. The optimum tradeoff between transmitter RF power and spacecraft complexity needs to be determined by experiment.

For the downlink case, it is clearly advantageous to take full advantage of modern encoding technology, because RF power onboard the satellite is a very scarce commodity and because complex digital decoding systems on

the ground do not impose the same power and mass penalties that they would if carried onboard the satellite.

For the downlink calculation at 435 MHz:

Satellite transmitter power	13 dBW (20 watts)	
Satellite antenna gain	13 dB	
Path Loss	-179 dB	(46,000 kilometers)
Ground station antenna gain	3 dB	(patch antenna)
Satellite RX noise temp	-22.3 dB	($T_{sys} = 170$ deg K)
Boltzmann's constant	228.6 dB	$\log_{10}(1.38E-23 \text{ W/Hz K})$

Carrier to Noise ratio C/No	56.3 dB	
Required Eb/No	3 dB	(rate 1/2, k=7 plus RS)

10 log ₁₀ R	53.3 dB	(R=213 Kbits/sec)

A 20 watt satellite transmitter will thus support 213 kilobits per second to an omnidirectional receiving antenna from a satellite at apogee. If we use 13 kilobit GSM encoding, the downlink will support 16 simultaneous users, at 1.25 watts per user. At the other extreme, if we were to employ 2.4 Kb LPC coding, we could support 88 users at 0.23 watts per user. To accommodate 50 users (the capacity of AO-13) would require 62.5 watts of RF power if we use 13 Kb GSM, or 11.5 watts for 2.4 Kb LPC coding. Thus there is a substantial incentive to invent advanced voice coding schemes to reduce the transmitted bit rate as much as possible while preserving voice quality.

Alternately, if we were to employ higher gain receiving antennas on the ground, we could build a lower power, smaller, cheaper satellite at the expense of requiring steerable antennas on the ground. The 2400 MHz band would be better suited for this purpose, since a high gain antenna would be physically small at this frequency. At some point in the development of this project, the members of Amsat will need to decide if they want to support a small, cheap satellite that requires small tracking antennas (a 2 foot dish or a small helix), or a somewhat larger, more expensive satellite that will support an omnidirectional antenna on the ground.

Digital Downlink Receivers:

Obviously the conventional Icom, Kenwood and Yeasu black boxes, with their limited audio signal bandwidth, will not be adequate for the task of receiving a wideband digital downlink signal of several hundred kilobits or more per second. The commercial market for digital satellite downlinks has spawned much interest by chip manufacturers in producing suitable integrated circuits which can be adapted for amateur radio use. One such chip is the Maxim MAX2101, which can be used to convert a 435

MHz RF signal into a digital bit stream. This chip contains most of what is needed for a high speed digital downlink receiver, with a 400 to 700 MHz RF input range and 6 bit digitized I and Q channels for output. Other chips which may be useful are offered by GEC Plessey and LSI Logic.

Once we have the digital bit stream, we must apply the error correction algorithms and convert the digitized voice signal back to analog form. Phil Karn has shown that the Intel Pentium has computing power equal to many specialized DSP chips and is active in developing error correction decoding software in Pentium assembly language to take maximum advantage of its capability. Those hams who already have a Pentium computer in their shack will be able to use Phil's software to decode the digital downlink. The RUDAK digital downlink on Phase 3D will carry mostly computer traffic, e-mail, file transfers, etc, so most hams will need a computer in their shack to handle all of that in any event. Digital voice will be an experimental mode in the early days of Phase 3D. RUDAK was not specifically designed to handle a heavy load of digital voice traffic, therefore serious use of digital voice in the amateur satellite service (beyond demonstration projects) will probably have to wait for the next generation of satellites.

For portable digital voice operation, and for hams who do not wish to dedicate their shack's computer to such operation, there are special decoder chips such as Qualcomm's Q1900 Viterbi/Trellis Decoder which can be the basis for a complete receiver based on 2 or 3 chips. Once a receiver design goes into widespread production, these receivers should be available for perhaps \$300-\$400 (in today's dollars) around the time that the new generation of satellites are ready to launch. It may also be possible to incorporate the decoding function into the DSP chip which handles the voice encoder. The eventual engineering goal should be to produce a complete satellite ground station that a 12 year old ham could afford to purchase with his paper route money!

SAREX to Ground via Phase 3D, an Early Application:

There is one particular application in which a low power uplink to Phase 3D using an omnidirectional antenna would be especially interesting and useful. The use of digital modulation might permit astronauts aboard the Space Shuttle or the International Space Station to use Phase 3D as a relay satellite to reach amateurs on the ground without using high power amplifiers or steerable antennas. The Sarex program has conducted educational outreach sessions with over 100 schools over the past decade, with students posing questions to astronauts in space. Unfortunately, all of these contacts are limited to 10 to 12 minutes duration while the shuttle is in view of a ground station, but when Phase 3D is at apogee it has line of sight visibility to the space shuttle for about half of each shuttle orbit. This would allow contacts of up to 45 minutes duration. These Sarex to school contacts could also

be retransmitted through the analog transponders of P3D on publicly announced frequencies, which would allow the general ham population to listen to the school contacts in real time with their existing analog radio equipment. The necessary conversion from digital to analog modulation could be done at an Amsat ground station and re-uplinked to P3D, or possibly onboard the P3D satellite if there is sufficient computing power available in the RUDAK transponder. General ham QSO's could also be conducted via P3D as well as the scheduled school contacts.

In Conclusion:

Some Amsat people have called for a return to Mode A low orbit satellites as a way to open up satellite operation to new hams and those in disadvantaged countries. Others propose an utterly complex and largely unworkable system of low orbit satellites working in some global network to offer continuous coverage. This paper was written to offer a third vision of the future, where a small number of relatively inexpensive high altitude satellites can provide coverage to many users for many hours per day, and the ultimate goal of continuous satellite coverage 24 hours per day is reasonably feasible with a manageable number of satellites. The current degree of ground station complexity and expense required to operate Mode B on the high altitude satellites is not a good indication of what will be possible in the future. It is no longer necessary to restrict ourselves to Low Earth Orbit satellites when modern digital coding technology makes it possible to receive digital downlink signals on modest ground antennas from satellites in high orbits.

Some will argue that this plan will result in the obsolescence of much expensive amateur radio satellite gear. They overlook the fact that technical obsolescence is a fact of life in every area. Yet the same people who want to hold on to their expensive commercial ham gear think nothing of buying the latest and fastest new computer every couple of years in order to keep up with advancements in computer technology. But the day will certainly come when your all mode VHF/UHF transceiver will assume its place in the back of your closet right next to that old 80286 computer that you paid so much for back in the "good old days".

Some people will argue that the technology presented in this paper is just so much theoretical hot air and remains to be proven in the real world. They are correct in pointing out that although this technology has been in commercial use for some time now, it is new to the amateur radio world and still needs to be adapted to the needs of the amateur radio service. There is much experimental and development work to be done in the next few years to prove that these ideas are feasible and practical for the average ham. Fortunately, the new Phase 3D satellite includes a very remarkable and far sighted digital communications

experiment which provides an experimental test bed and proving ground to test these ideas in real world conditions by conducting suitable demonstration projects. We need only write the appropriate software for uplink to the satellite, as well as develop new ground station equipment and operational protocols. This is truly an exciting time to be a ham, we have a chance to be in on the ground floor of the coming revolution.

Finally, I did not come here today to ask for your money to develop any of these plans. Your generous support of Phase 3D makes it possible to start the testing phase and feasibility study. Only after we have conducted the necessary experiments to prove the superiority of digital voice encoding in real world satellite operating conditions will the members of Amsat be faced with the decision to go ahead with construction of a new generation of ham satellites. This will probably be shortly after the turn of the century.

I wish to acknowledge many helpful discussions with Phil Karn, KA9Q, in preparing this paper.

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Jason Woodard
Department of Electronics & Computer Science,
University of Southampton, England
http://www-mobile.ecs.soton.ac.uk/speech_codecs/index.html

Data sheet for the Maxim MAX2101 is at:

<http://www.maxim-ic.com/PDF/1057.pdf>

the evaluation kit data sheet is at:

<http://www.maxim-ic.com/PDF/1050.pdf>

Data sheets for Qualcomm VLSI products are at:

<http://www.qualcomm.com/ProdTech/asic/list.html>

The data sheet for the Q1900 provides a good tutorial on Viterbi and Trellis decoders and is worth reading even if one has no interest in using the chip itself.

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Anyone interested in designing and building a satellite will also find the following books very helpful:

Fleeter, Rick, "Micro Space Craft"
Reston, VA : Edge City Press, 1995.

This is a humorous book which is not afraid to say nice things about Amsat. Rick is a longtime Amsat volunteer who has made a career in the space business.

"Space Mission Analysis and Design"
edited by Wiley J. Larson and James R. Wertz.
Boston, Kluwer Academic Publishers, 1992

"Reducing Space Mission Cost"
edited by James R. Wertz and Wiley J. Larson.
Boston, Kluwer Academic Publishers, 1996.

One chapter devoted to Amsat, covering Oscar 1 thru AO-13

"Spacecraft Attitude Determination and Control"

Edited by James R. Wertz.

Dordrecht, Holland, Boston, D. Reidel Pub. Co. 1978

The Bible of spacecraft attitude control, the NASA Goddard library owns 14 copies which are always checked out.

"Space Propulsion Analysis and Design", edited by Ronald W.

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New York, McGraw-Hill, 1995.

"Spacecraft Structures and Mechanisms--From Concept to Launch"

Thomas P. Sarafin, editor and Wiley J. Larson, managing editor.

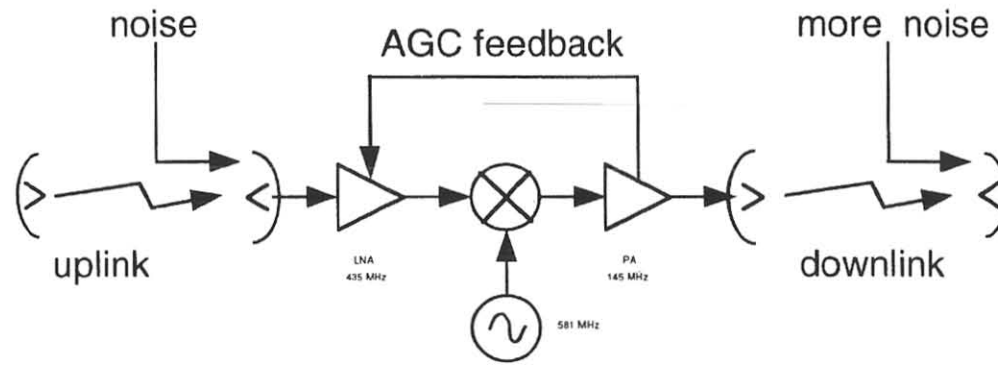
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"Understanding Space : An Introduction to Astronautics"

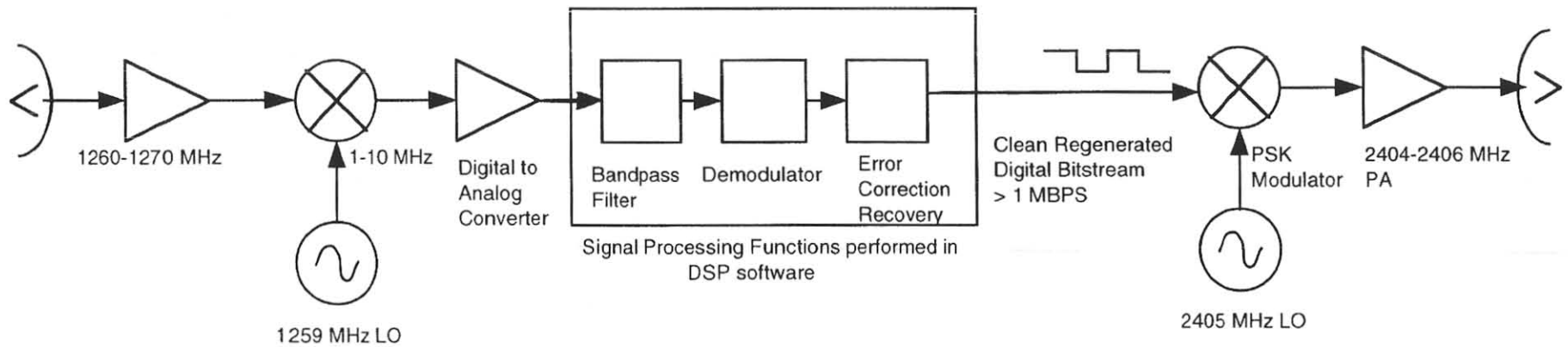
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New York, McGraw-Hill, 1994



ANALOG SATELLITE TRANSPONDER



REGENERATING DIGITAL SATELLITE TRANSPONDER

A Candidate Orbit for Future AMSAT Spacecraft

by Ken Ernandes, N2WWD

ABSTRACT

This paper analyzes the utility of circular low-inclination, Medium-Altitude orbits for amateur radio spacecraft. This orbit type provides much of the coverage footprint realized from either a geosynchronous orbit or apogee of a high-eccentricity [Molniya] orbit. Low inclination medium altitude orbits also provide all-longitude access, with long coverage windows and with revisits on every revolution. As such, almost every potential user has equitable coverage with just a single satellite on orbit. More importantly, additional satellites can be added in a coordinated fashion, providing complementary access. Ultimately, medium altitude orbits can form a three-satellite constellation, yielding 24-hour coverage to most users.

INTRODUCTION

This paper is a follow-on to Bill Tynan, W3XO's *A Possible Phase 3D Follow-on Project*, presented at the 1996 AMSAT Symposium and reprinted in *The AMSAT Journal* (see refs. 1 and 2). The purpose is finding a desirable orbit, providing good coverage to the potential users. The most important consideration is that the orbit's coverage must allow for a three-satellite constellation that provides continuous (or nearly continuous) coverage for the most populated areas of the Earth's surface.

Whether or not an orbit is otherwise considered desirable is subjective, based on the Orbital Design Goals in the next section. These goals are my opinion of what the AMSAT membership wants, based in part on the content of messages posted to the AMSAT-BB Internet mailing list. As such, they are subject to change based on further inputs from the AMSAT membership.

ORBITAL DESIGN GOALS

The following orbital design goals provide a basis for selecting the candidate orbit type presented in this paper. The design goals are:

- (1) Provide an orbit that supports the three-satellite constellation, providing continuous coverage of the populated regions of the Earth's surface.
- (2) Provide a large footprint, with Earth surface coverage comparable to a Phase 3 satellite at apogee.

- (3) Select an orbit that can be achieved from an Ariane (or other available) booster, and is achievable within the delta-V budget of a Phase 3 spacecraft.

- (4) Reduce free-space signal path loss, choosing the lowest feasible altitude that supports the other goals.

- (5) Select an orbit that is generally useful with the launch of the first satellite. As such, provide equitable coverage across all longitudes, preferably with a short revisit schedule. (A short revisit schedule would have contact times distributed over a station's 24-hour local schedule within the span of a week.)

- (6) Select an orbit with minimal perturbative effects to reduce or eliminate satellite stationkeeping requirements.

CANDIDATE ORBIT TYPES

The preliminary spacecraft design proposed by W3XO is somewhat flexible as to the type of orbits in which it could effectively operate. Three orbit types were initially considered: the Geostationary Earth Orbit (GEO), the highly elliptical or Molniya orbit (used by the Phase 3 spacecraft), and the medium altitude orbit. After analyzing these three orbit types, I concluded that the medium-altitude orbit offers the best overall balance of advantages versus disadvantages for the spacecraft system proposed by W3XO. In the next few sections, I shall address each type, providing the reasons why I consider the medium altitude orbit the best choice.

THE GEOSTATIONARY ORBIT

The attractions to the GEO are that ground stations orient their antennas in a constant direction and there is no Doppler shift. However, these attributes have made this orbit type so popular that the geosynchronous "belt" is very crowded with satellites. Therefore, it would be difficult for AMSAT to find three available positions 120° apart in the most "prime real estate" in space.

Furthermore, GEO orbits require periodic stationkeeping maneuvers. These maneuvers are needed to correct orbital changes caused by the Sun and Moon and to prevent collisions with neighboring GEO satellites.

Because of their altitude, GEO orbits are the least efficient (of the three candidate choices) for attitude control magnetorquing against the Earth's magnetic field.

The fact that a GEO orbit remains fixed relative to the Earth's surface also has disadvantages for amateur radio communications. A GEO, by its nature provides no variety in satellite coverage. Therefore participation could only be expected from ground stations that lie well within the footprint. Furthermore, the lack of DX variety may somewhat dampen the enthusiasm of stations that are within the footprint.

Excluded stations could only be counted on for participation in building new satellites, augmenting the constellation (and providing coverage to their area).

THE MOLNIYA ORBIT

The highly-elliptical Molniya was an excellent choice for the AMSAT Phase 3 spacecraft. This orbit type offers a large coverage footprint in an orbit that is readily achievable from a Geosynchronous Transfer Orbit (GTO). Because of the physics of orbital motion, a satellite in an elliptical orbit has a long "hang time" in the higher altitude portions of the orbit. The Molniya orbit also allows for very efficient attitude control magnetorquing in the lower altitude portions of the orbit.

One disadvantage to the Molniya orbit is that it can be very sensitive to the gravitational perturbations imparted by the Sun and the Moon. The most obvious illustration of these effects is the demise of AMSAT OSCAR 13 (AO-13). Extensive planning is required for orbital adjustment maneuvers that ensure a Molniya orbit will not suffer an untimely orbital decay similar to that of AO-13. Furthermore, it can take more than a year to accomplish the actual sequence necessary to establish a survivable Molniya orbit.

A significant disadvantage of the Molniya orbit, specific to W3XO's proposed system design, is the difficulty in providing continuous coverage. Because of the small footprint when the satellite is at perigee, it is likely that six spacecraft would be needed to satisfy the 24-hour coverage requirement.

Furthermore, the electronic feed horn switching proposed by W3XO would be more complex for a Molniya orbit. Switching would need to occur at varying rates to compensate for varying orbital rates between apogee and perigee.

MEDIUM ALTITUDE CIRCULAR ORBITS

This paper proposes the use of low-inclination, medium-altitude circular orbits. The medium altitude is suggested as a balance between a large footprint (goal #2) and minimizing both signal path loss and below-the-horizon revisit intervals (goals #4 and #5 respectively). Circular orbits are suggested since they allow a straightforward continuous coverage constellation design.

The largest gains in Earth surface coverage occur as altitude increases in the range from Low Earth Orbit (LEO) to about a 24000 km altitude as illustrated in figure 1. Increases in altitude above 24000 km provide marginal returns in terms of additional footprint area. The LEO to 24000 km range may be further narrowed since it is impossible to get full coverage from a three-satellite constellation with the altitude below two Earth radii (approximately 12800 km). A 14000 km altitude is suggested as a practical minimum since most coverage gaps are reduced or eliminated at this altitude. Therefore, the

Satellite Footprint Coverage versus Altitude

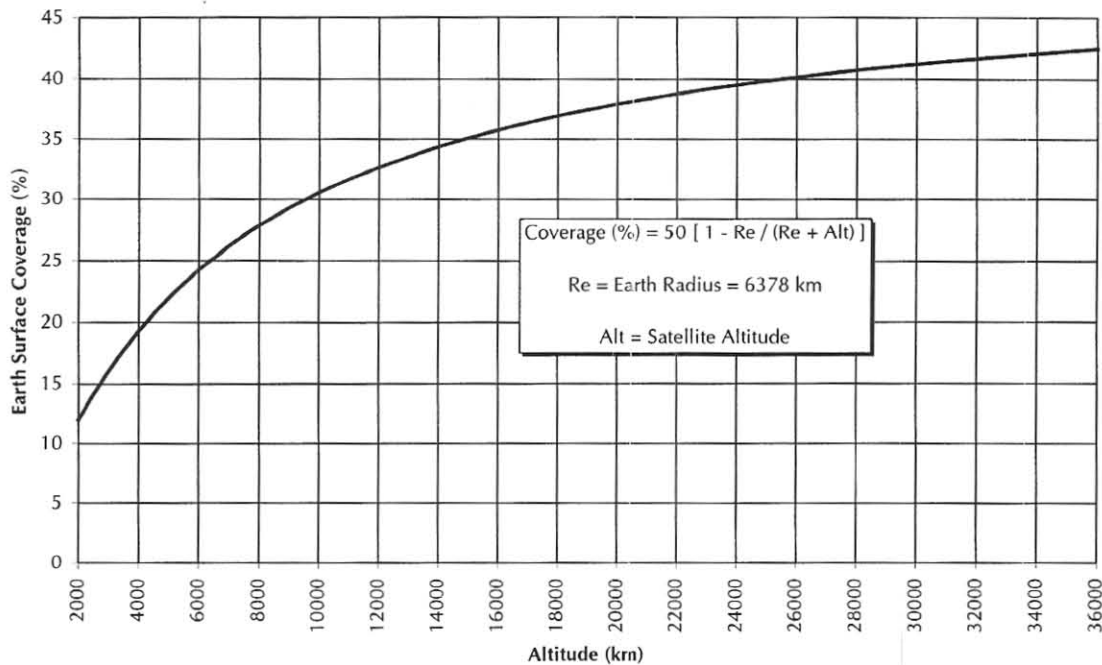


Figure 1., Earth Surface Footprint Coverage as a Function of Altitude

suggested altitude range is 14000 to 24000 km, providing an 8 to 14 hour orbital period.

The other advantage of the medium altitude orbit is that the first satellite orbited provides balanced coverage of the populated areas of the Earth. This satisfies both the desire for DX variety and provides equitable access to all longitudes. Augmenting the constellation with a second and third satellite would likewise be beneficial to all, ultimately closing most or all of the coverage gaps.

CONSTELLATION ARRANGEMENT

Orbital design to get essentially 24-hour global coverage is relatively simple for a medium altitude circular orbit. The method published by J.G. Walker (see ref. 3) and later generalized by A.H. Ballard (see ref. 4) provides an orderly transition of footprint coverage from one satellite to the next.

The essence of a Walker or "Rosette" constellation is providing equal spacing of orbital planes, allowing sufficient overlap at the Equator. Satellite phasing between

adjacent orbital planes is selected to coordinate replacement of one satellite footprint with the next. Orbital inclination is selected to provide coverage overlap at the North and South Poles or the highest latitude in which complete coverage is required.

The specific orbit design for the medium altitude amateur radio constellation places the three-satellites in unique orbital planes separated by 120°. Each satellite is also phased 120° along-track relative to its neighbors. A 10° inclination is used since it provides reasonably high latitude coverage and is standard for an Ariane 5 GTO. Sample constellation Keplerian elements are provided in table 1 for visualization. Figure 2 provides a "snapshot" of the satellite coverage footprints for this constellation.

The middle satellite in the footprint plot is nearly at its lowest latitude. This snapshot was selected for the figure to show that there is an approximately 55° latitude threshold for 24-hour coverage. The footprint also shows partial coverage up to a maximum 85° latitude.

Table 1., Sample Keplerian Elements for a 19000 km Altitude Rosette Constellation

Satellite:	AMS-1	AMS-2	AMS-3
Catalog Number:	99991	99992	99993
Epoch Time:	97200.5	97200.5	97200.5
Element Set:	1	1	1
Inclination:	10.0°	10.0°	10.0°
RA of Node:	0.0°	120.0°	240.0°
Eccentricity:	0.00001	0.00001	0.00001
Arg. of Perigee:	0.0°	0.0°	0.0°
Mean Anomaly:	0.0°	120.0°	240.0°
Mean Motion (rev/day):	2.14740118	2.14740118	2.14740118
Decay Rate (rev/day ²):	0.0	0.0	0.0
Epoch Rev:	1	1	1

19,000 Km Coverage

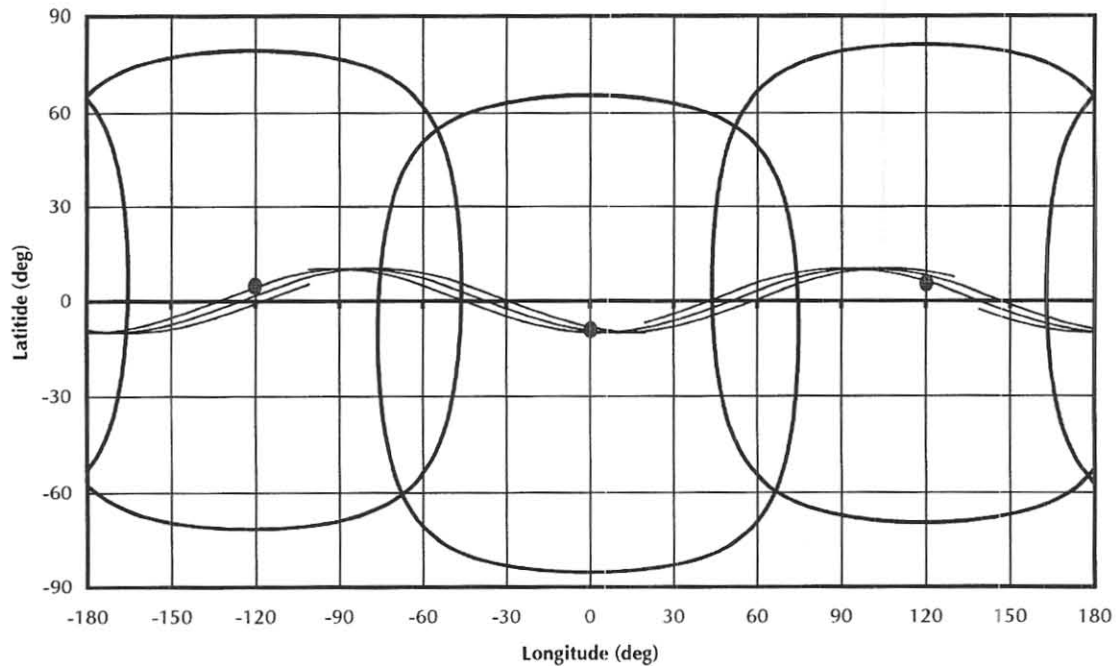


Figure 2., Medium Altitude Rosette Constellation Footprint Snapshot

Note that while the 120° spacing between adjacent orbital planes is ideal, the relatively low 10° inclination makes this a non-sensitive (or low importance) characteristic of the constellation. Therefore, if a trade-off is required to maneuver a new satellite into the constellation, achieving the proper phasing takes priority over getting the exact orbital plane. This provides flexibility when adding satellites to the constellation.

PATH LOSS VERSUS ALTITUDE

Path loss increases with the square of the distance from the satellite to the ground station. At medium altitudes a relatively small decrease in distance can add a few decibels (dB) to the signal strength. Figure 3 plots the *relative loss* (independent of frequency) for the longest path (at horizon) and the shortest path (directly overhead) versus altitude. The actual path loss for any particular frequency is the curve value plus a

**Relative Free Space Path Loss versus Altitude
(Frequency-Dependent Component Excluded)**

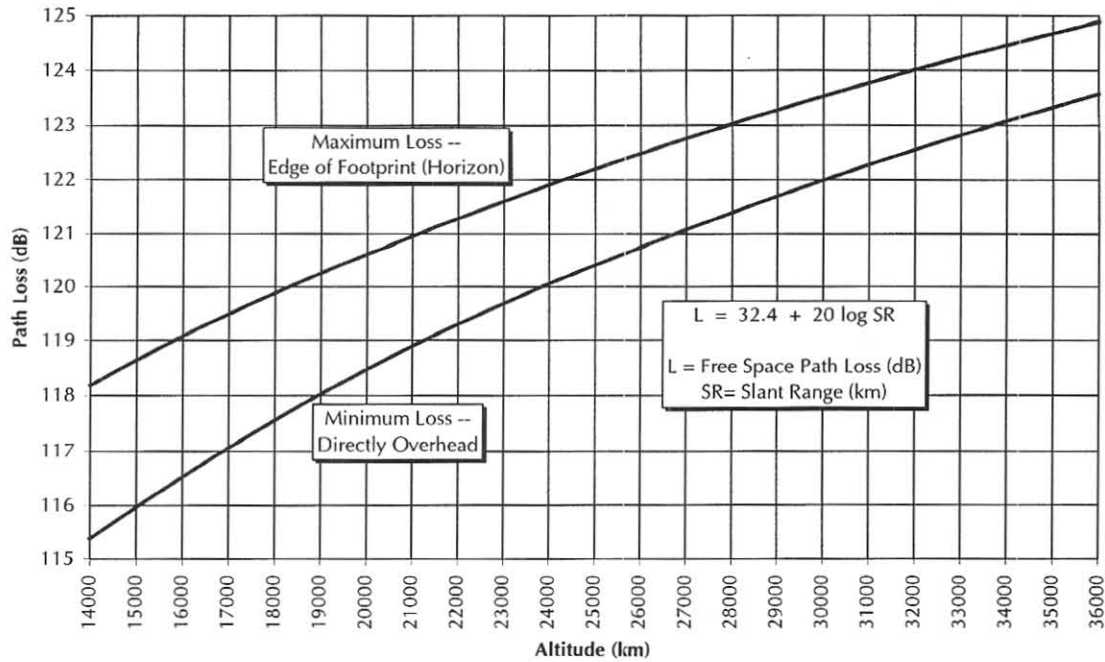


Figure 3., Relative Free-Space Path Loss as a Function of Altitude

20 log f offset (see ref. 5). The relative path loss is sufficient to evaluate path loss differences between two different orbital altitudes. (Note that there is typically 5 dB of path loss difference between a satellite at a 19000 km altitude and one that is at geosynchronous altitude.)

REVISIT INTERVAL VERSUS ALTITUDE

It is unlikely that AMSAT would be able to build and launch a three-satellite medium-altitude constellation in a short time. A realistic scenario is to populate the constellation by building and launching one satellite at a time with some overlap. Given these circumstances, it is important that the first satellite in orbit provide substantial access to as many AMSAT members as possible (consistent with goal #5).

As pointed out earlier, a GEO orbit provides infinitely long contact windows but no coverage variety. Likewise, an orbit at near geosynchronous altitude would provide very long contact windows with coverage varying very slowly. This orbit type also has

extremely long intervals between revisits once the satellite footprint drifts away from a ground station. The long wait between satellite revisits would be undesirable to most.

A satellite in a medium altitude circular orbit with a low inclination revisits most ground stations every revolution. (Stations at very high latitudes are the exception.) The coverage revisit interval is the difference between the orbital period and the average contact window duration. Figure 4 provides a sample contact window for a single satellite at a 19000 km altitude. (These contact windows were computed for a station at approximately 41° North latitude.)

A final consideration of revisit intervals is, if possible, that they begin and end at varying local times within a week (consistent with goal #5). This is best accomplished by choosing an orbit that does not closely repeat its ground track within a week. (There should not be an exact integer number of revolutions for one day -- the sample 19000 km constellation repeats in seven days.) Such a lack of "resonance" depends primarily on

Single Satellite Typical Weekly Timeline

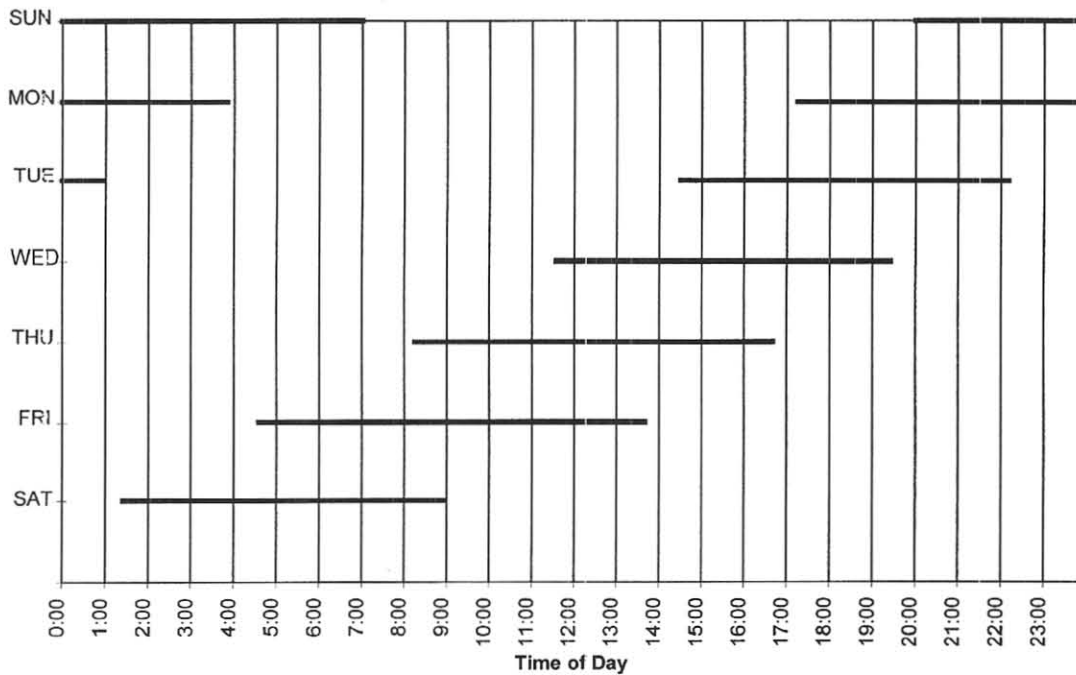


Figure 4., Sample Weekly Schedule for a Single 19000 km Altitude Satellite

orbital altitude.

STATIONKEEPING REQUIREMENTS

Unlike GEO orbits, medium altitude orbits fly through a relatively sparsely populated region of space. Stationkeeping is only necessary to maintain the correct phasing between the satellites, preserving the constellation's coordinated coverage replacement. Loss of a satellite's stationkeeping capability (through propellant exhaustion or system failure) will result in an eventual loss of constellation phasing. Satellite replacement would be necessary to restore 24-hour coverage.

Stationkeeping requirements vary with orbital altitude. It is highly desirable to choose an altitude that provides a stable orbit. A stable orbit minimizes both the frequency of stationkeeping orbital adjustments and the amount of propellant consumption when orbital adjustments are needed. Choosing the optimum altitude for stationkeeping is likely

to be a complicated analysis, so it has been deferred to a later study.

GTO TO FINAL CIRCULAR ORBIT

An important part of evaluating a candidate orbit is identifying a feasible way of getting the spacecraft to that orbit. When analyzing feasibility, one must consider the velocity change (delta-V) required to achieve the orbit. This defines the amount of propellant necessary to go from the orbit provided by the booster to the desired orbit. Overly complicated or risky orbital transfer profiles should be avoided.

Since AMSAT has enjoyed good success in manifesting its spacecraft on European Space Agency (ESA) Ariane boosters, the sample mission profile is designed using this type of launch. More specifically, the mission profile assumes a GTO. An Ariane 5 GTO has a 280 km perigee, a 35786 km apogee, and a 10° inclination (see ref. 6).

Delta-V From Ariane GTO

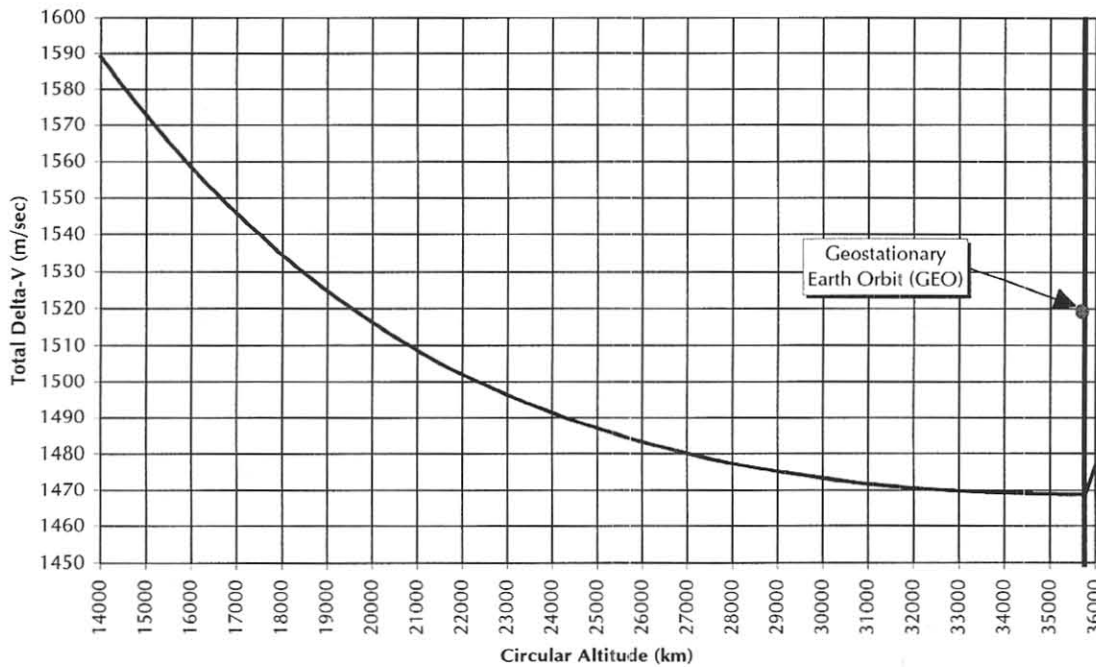


Figure 5., Delta-V Requirements from an Ariane 5 GTO to a Circular Orbit

A medium altitude circular orbit can be achieved from a GTO using two thruster firings. The first thruster firing is done at apogee of the GTO, raising perigee to the [final] circular orbital altitude. The second thruster firing is done at perigee, lowering apogee and establishing the circular orbit. Figure 5 illustrates the delta-V required for various circular altitudes. Note that because of the high apogee of the GTO, the higher altitude orbits are more economical from a delta-V standpoint than are lower altitude orbits. Note also that the inclination change that brings the GEO inclination down to 0° increases the delta-V requirement for this orbit type as indicated on the chart. In actual practice, a non-zero inclination (such as 5°) would be selected. The delta-V requirement to establish a geosynchronous orbit with a 5° inclination from an Ariane GTO is approximately 1482 m/sec.

The first satellite can be brought on station relatively quickly (days or weeks) after insertion into the GTO. Subsequent satellites require more time since we will expect our satellite to be a secondary payload for the

launch. Since the primary payload generally specifies the launch window, we will accept whatever orbital plane is established by the GTO. Time will be required for the GTO's orbital plane to drift relative to the other satellite(s) in the constellation until the correct arrangement occurs. The timing of the burns will then be selected to achieve the proper phasing with the constellation.

Practicality may require using multiple smaller burns to accommodate thruster constraints and achieving the correct constellation phasing in a more timely fashion.

While the spacecraft proposed by W3XO is only preliminary, the satellites could be designed to operate while in the GTO. This provides useful capability during the "waiting" interval before the satellite can be maneuvered into its specified position in the constellation.

SUMMARY AND CONCLUSIONS

A low-inclination, medium-altitude circular orbit readily accommodates a three-satellite Rosette Constellation, providing continuous coverage to all but high latitude users. For the 19000 km example, the constellation gives continuous coverage for stations at latitudes within about 55° of the equator. Higher latitude stations begin to develop coverage gaps that increase in duration and frequency as you approach either pole. (No coverage is available for the example constellation for stations with latitudes greater than 85° .)

The proposed orbit provides desirable coverage with reasonably equitable access as formation of the constellation begins with the orbiting of the first and second satellites. The orbits, including constellation phasing arrangements, are achievable from an Ariane 5 GTO. The 19000 km altitude constellation was selected as an example that satisfied the defined goals. However, the stationkeeping requirements for a constellation at this altitude were not analyzed. Should AMSAT decide to pursue use of this orbit for a Phase 3D follow-on project, final constellation design will require further analysis of latitude coverage and stationkeeping requirements to determine the best altitude.

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Selecting Orbits for LEO Constellations: SSB/CW communications

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Abstract

Those interested in selecting orbits for satellites operating in the Amateur Satellite Service face a number of questions. These include, "Can we get there?", "Will the environment be harsh or relatively benign?" and "Do we want to go there?"¹ Techniques for evaluating constraints related to orbit accessibility and spacecraft environment are straightforward. However, there are no standard approaches for evaluating how desirable an orbit will be to potential users or for comparing options.

This paper discusses the current status of an ongoing project to identify quantitative criteria and procedures for rating the desirability of specific orbits from the perspective of a user operating in the Amateur Satellite Service. The emphasis here is on SSB/CW analog missions and orbits realistically within the reach of the radio amateur satellite program.

Several measures are discussed. These include Total Coverage Factor, which describes total quantity of service, and Average Daily Access Time, which characterizes the geographical distribution of service. Examples apply the measures to both single spacecraft and constellations. Orbits investigated include Low Earth, Intermediate Circular, Geosynchronous, and Molniya types. Software for calculating ADAT for constellations is published here so readers can evaluate other constellations of interest. Since radio amateurs have only had an opportunity to work with a limited selection of orbits, some of the results may be surprising.

Background

During the early days of the OSCAR program the orbit selection aspect of mission planning was very primitive. When a launch opportunity arose the main question facing AMSAT was whether the target orbit was minimally acceptable for real time communications via an analog transponder. In recent years the situation has changed in a very fundamental way. Now that AMSAT has demonstrated its ability to build and operate space propulsion systems the problem of picking the "best" orbit within the constraints present has become a real concern.

I first became interested in the problem in the late 1980's. My early efforts focused on identifying quantitative measures which could be used to rate and/or compare potential orbits for *individual spacecraft*. Results and software tools were made available in the early 1990's.^{2,3,4} In recent years I realized the importance of extending this work to include constellations of spacecraft, a topic which receives considerable attention here. The first measure of interest is Total Coverage Factor.

Total Coverage Factor

The Instantaneous Coverage Area (A) of a satellite is given by the formula

$$A = (1/2)(\text{surface area of earth})[h/(R+h)]$$

where R is the radius of the earth and h is the

instantaneous height of the spacecraft above the surface of the earth. Instantaneous Coverage Factor (ICF) is a dimensionless quantity defined as the Instantaneous Coverage Area divided by the surface area of the entire earth.

The "average" value of the Instantaneous Coverage Factor (using averaging procedures described later) is called Total Coverage Factor (TCF).

TCF is essentially a measure of the *total quantity* of service being provided. The maximum TCF that can be obtained from a single satellite is 0.5 which is produced by a spacecraft in a circular orbit having an infinite height. A constellation consisting of a large number of spacecraft positioned so that everyone on earth will see at least one spacecraft 24 hours per day has a TCF of 1.0.

Some brief examples help explain the nature of TCF. A TCF of 0.425 can be produced by an infinite number of orbits. One (geostationary) provides ground stations on 42.5 percent of the earth with 24 hour coverage. Another (equal distribution orbit) provides coverage to every ground station on the earth for 612 minutes (42.5 percent of a day) each day. Other TCF = .425 orbits will distribute the same quantity of service in a manner between these two extremes by increasing the coverage time given to some ground stations and reducing that given to others.

Halving TCF halves the service provided, doubling TCF doubles it. For example, a TCF of 0.85 (double 0.425) means we could provide ground stations on 85 percent (double 42.5) of the earth with 24 hour coverage, or provide every ground station on the earth with 1224 minutes (double 612) of coverage, assuming that an orbit or constellation producing these specific distributions exists.

In most cases spacecraft configurations producing the two extremes -- fixed service area or equal service distribution -- do not exist but they help explain what TCF represents.

For circular orbits TCF and ICF are equal and given by

$$\text{TCF} = (1/2)[h/(R+h)]$$

Eq. 1 Circular orbit

Note that doubling the height does *not* double TCF.

For elliptical orbits TCF is obtained from ICF by averaging over one complete orbit. The average is obtained by dividing the orbit up into an infinite number of segments of *equal time* interval and computing TCF using the height, h_i , at the middle of each segment. For calculations we must approximate TCF using a finite number of segments. In this paper we use 1000.

$$\text{TCF} = (1/2) \sum_i h_i/(R+h_i)$$

Eq. 2 Elliptical orbit

A ground station is considered to have access to a constellation when at least one of the spacecraft forming the constellation is in view. TCF for constellations is also defined as the average ICF but the averaging procedure, explained later in this paper, is more complex due to the fact that overlap areas (covered by two or more spacecraft) must only be counted once.

Now that we have a measure of total quantity of service provided by a satellite or constellation we need to describe how the service is distributed to ground stations. For this we introduce the measure Average Daily Access Time.

Average Daily Access Time

Average Daily Access Time (ADAT) refers to the average amount of time each ground station has access to a given satellite or constellation each day. For most situations of interest ADAT depends only on the users latitude. These include circular orbits where ascending nodes are uniformly distributed, constellations made up of such satellites, and satellites in elliptical orbits satisfying the uniform distribution of nodes criteria if the argument of perigee is constant (or changing very slowly).

Graphs of ADAT vs. ground station latitude (ADAT profiles) for an existing satellite

show which users are getting the best service. When planing future missions such curves enable designers to choose values for height and inclination that will produce the desired distribution of service. The discussions accompanying Figures 2 through 8 provide numerous examples.

Table 1 & Figure 1: Discussion

Table 1 and Figure 1 contain tabular and graphical data presenting TCF values for most satellites and constellations discussed in this paper. The curve in Figure 1 is based on Eq. 1. It shows TCF as a function of height for satellites in circular orbits. A number of specific satellites and constellations have been placed on this curve using the following procedures.

Satellites in circular orbits are shown on this curve at their natural position. Satellites in elliptical orbits have been placed on the curve with respect to their TCF values. As a result one sees that, for example, AO-13 has the same TCF as a satellite in a circular orbit at a height of about 19,000 km. The vertical line segments associated with elliptical orbits extend between instantaneous coverage factors at apogee and perigee.

Constellations are placed on the TCF vs. height curve with respect to their TCF values. This shows, for example, that a satellite in a circular orbit having a height of 10,000 km provides approximately the same total service as a single plane constellation of 3 RS-15 like spacecraft. Satellites in a given plane of a constellation are assumed to have slightly different heights so that their relative position will vary with time. As a result, all possible configurations of spacecraft in each orbital plane are equally likely.

The TCF vs. height curve of Figure 1 can be roughly divided into 3 regions, an initial region extending up to 5000 km with steep slope where increases in height provide a substantial increase in TCF, a transition region between 5000 km and 15,000 km, and a region above 15,000 km with very shallow slope where increases in height have only a small effect on TCF.

Selecting the ideal height for a satellite involves a tradeoff between TCF, which we want to maximize, and path loss, which we wish to minimize. In the initial region (steep slope) a small increase in height (and path loss) produces a substantial increase in TCF so there's good reason to increase height. However, the radiation environment between about 2000 km and 8000 km is very harsh so considerations related to spacecraft reliability and longevity generally cause designers to avoid this range. RS-15, which has a height just above 2000 km, represents about the best we can do in the initial region.

Note the difference between a "low" (600 km) LEO satellite and a "high" (2000 km) LEO satellite. A single satellite at 2000 km (TCF = .12) provides roughly three times the total service provided by one at 600 km (TCF = .043). The difference between RS-15 (TCF = .121) and AO-13 (TCF = .377) is nearly identical. The tendency of many users to talk about the performance of "LEO satellites" as if they form a homogeneous group is very misleading!

Satellites having heights between 8000 km and 11,000 km are frequently referred to as being in an Intermediate Circular Orbit (ICO). These heights, which are just above the high radiation region, have a number of features that make them very desirable to radio amateurs. They provide high TCF with modest path loss. One satellite from this region (labeled ICO-50) is included in this study. For additional information on ICO-50 see Figure 8. ICO spacecraft are sometimes referred to as being medium earth orbit (MEO) satellites. No matter what we call them we face two major technical questions when we consider whether they have a place in the future Amateur Satellite Service. First, do we have the ability to place a satellite in such an orbit? And second, can spin stabilization based on torquing coils be used to provide attitude control at this height? Rough estimates suggest that both these questions can be answered affirmatively.

Figure 2: Discussion

ADAT profiles for several Radio Amateur LEO spacecraft in circular orbits are

Table 1. Total Coverage Factor (TCF) and related data for several satellites and constellations of interest.

Spacecraft (or constellation)	apogee height *1	perigee height *2	maximum coverage *3	minimum coverage *4	TCF
US Shuttle (STS)	300 km	---			.023
AO-16	800 km	---			.056
RS-15	2030 km	---			.121
RS-15 constellations *5					
2 spacecraft, 1 plane	2030 km	---	.242	.121	.218
2 s/c, 2 planes	2030 km	---	.242	.121	.230
3 s/c, 1 plane	2030 km	---	.363	.121	.297
4 s/c, 1 plane	2030 km	---	.484	.121	.360
4 s/c, 2 planes	2030 km	---	.484	.121	.400
6 s/c, 1 plane	2030 km	---	.726	.121	.451
6 s/c, 2 planes	2030 km	---	.726	.121	.525
8 s/c, 1 plane	2030 km	---	.968	.121	.512
8 s/c, 2 planes	2030 km	---	.968	.121	.620
AO-13	36,333 km	2471 km	.426	.141	.377
P3D	47,700 km	4030 km	.441	.194	.401
Geostationary	35,870 km	---			.425
ICO-50 *6	10,392 km	---			.310
ICO-50 constellation					
2 s/c, 1 plane	10,392 km	---	.620	.310	.511

*1 Mean height for nominally circular orbits.

*2 Only listed for elliptical orbits.

*3 Elliptical orbits: Coverage at apogee .
Constellations (circular orbits): Coverage when overlap does not occur.
A configuration where overlap does not occur may not exist.

*4 Elliptical orbits: Coverage at perigee.
Constellations (circular orbits): Coverage when satellites are aligned.

*5 Description specifies total number of spacecraft and number of planes. Example: 8 s/c, 2 planes describes a constellation of 8 spacecraft in two planes with 4 spacecraft in each plane.
When two planes are specified the planes are at right angles.
No station keeping in plane -- all satellite positions are random.

*6 (I)ntermediate (C)ircular (O)rbit having an inclination of 50 degrees.

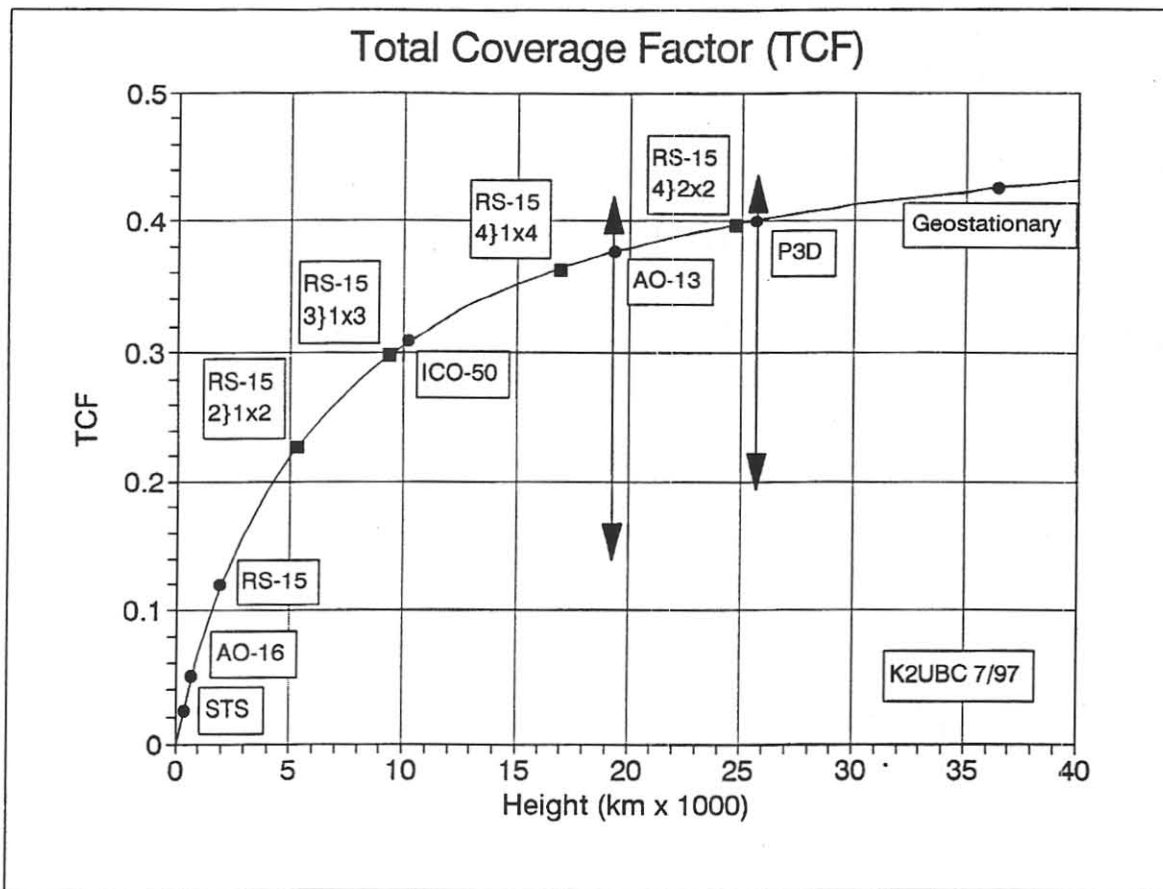


Figure 1. The curve shows Total Coverage Factor (TCF) as a function of spacecraft height for circular orbits. Single spacecraft (round bullets) and constellations (square bullets) have been placed on the curve according to TCF value (circular orbits) or average TCF value (elliptical orbits and constellations). Vertical lines associated with elliptical orbits extend from TCF at perigee to TCF at apogee. See text and Table 1 for additional information.

shown in Figure 2. The Figure illustrates how satellite height and inclination have a very pronounced effect on the service these spacecraft provide. For example, the curves show why one ground station, at 35° N latitude, can report that Mir and AO-16 provide about the same amount of service while another ground station, at 60° N, states that AO-16 provides 300 percent more access time than Mir. Similarly, a ground station at 30° N might state that RS-15 provides 300 percent more service than AO-16 while one at 60° N says the advantage is more like 50 percent. The main conclusion is that most users perceptions of the desirability of specific orbits are heavily influenced by their personal experience at a specific latitude with a very limited selection of spacecraft orbits.

Figure 3: Discussion

Although Figure 2 contains a number of clues as to the way in which inclination and height affect how ground station access time is distributed, a more systematic look at the situation is needed to ferret out this behavior. This is provided in Figures 3 and 4. Figure 3 shows how orbit inclination affects the ADAT profile. It's based on a circular orbit with a height similar to that of RS-15 (2030 km). For a circular orbit TCF depends only on height so all curves shown have the same TCF value; i.e., all orbits are providing the same quantity of service. The only difference is in how the available service is distributed. Follow the transition from the 30° inclination which heavily favors low latitude

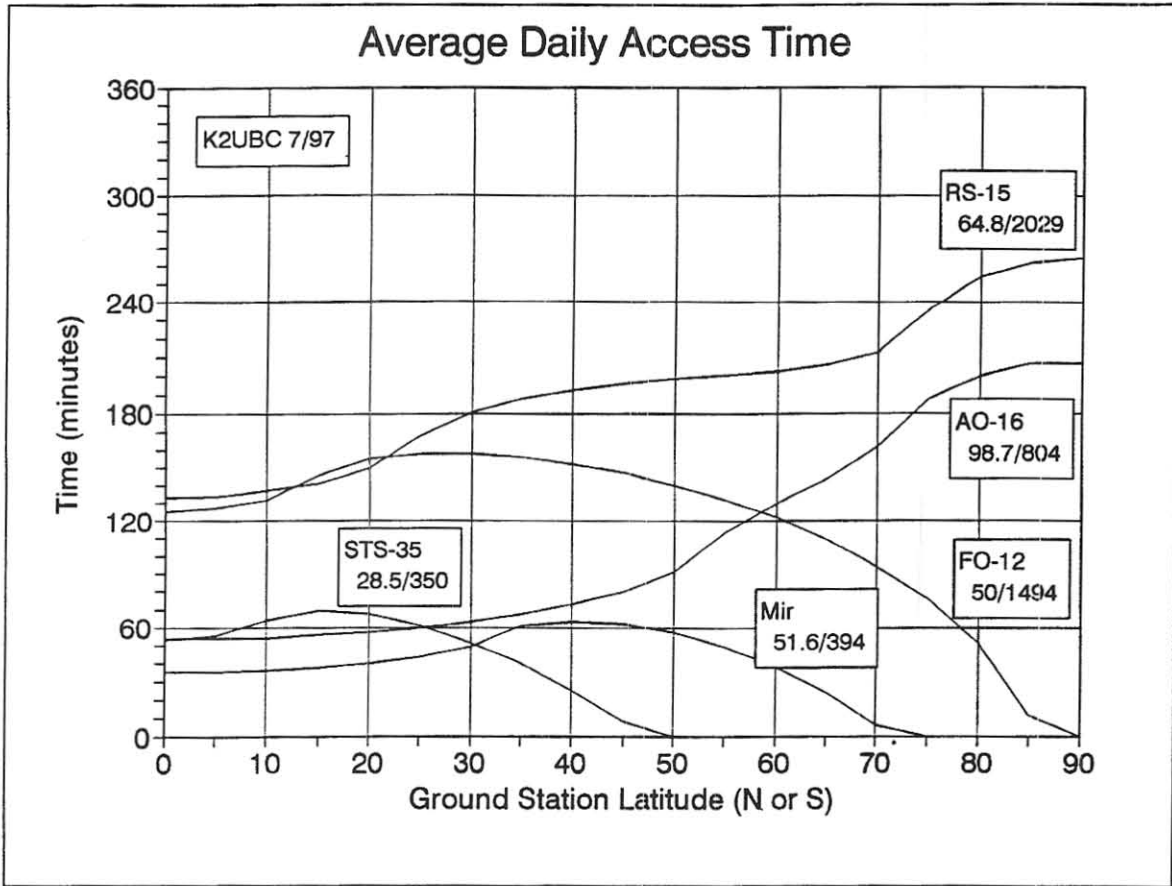


Figure 2. The figure shows Average Daily Access Time as a function of Ground Station Latitude for five representative satellites. The numerical values listed with each satellite represent orbit inclination in degrees and height in kms.

stations to the 80° inclination which heavily favors ground stations at high latitudes. Note especially the 60° inclination which produces a reasonably equitable distribution of service. Finally, note that the choice of inclination has very little impact on ground stations near 35° N.

Figure 4: Discussion

This figure shows how height affects ADAT distribution for circular orbits. It's based on an RS-15 like example (inclination = 64.8 degrees). Starting at a height of 2000 km the height is decreased in increments of 20 percent. One conclusion is that in the LEO region height, which has a major effect on quantity of service, has only a modest effect on how this service is

distributed. However, the orbit inclination value producing the most equitable distribution of service does vary slightly with height.

Figure 5: Discussion

Figure 5 shows the ADAT distributions for single plane constellations of spacecraft having RS-15 type orbits. The lower curve shows the ADAT profile for a single satellite. The other curves are obtained by adding additional spacecraft, one at a time, to the orbital plane. Each curve shows the average amount of time a ground station will have access to at least one spacecraft in the constellation each day. The mathematical model used to prepare this curve assumes that each spacecraft is positioned

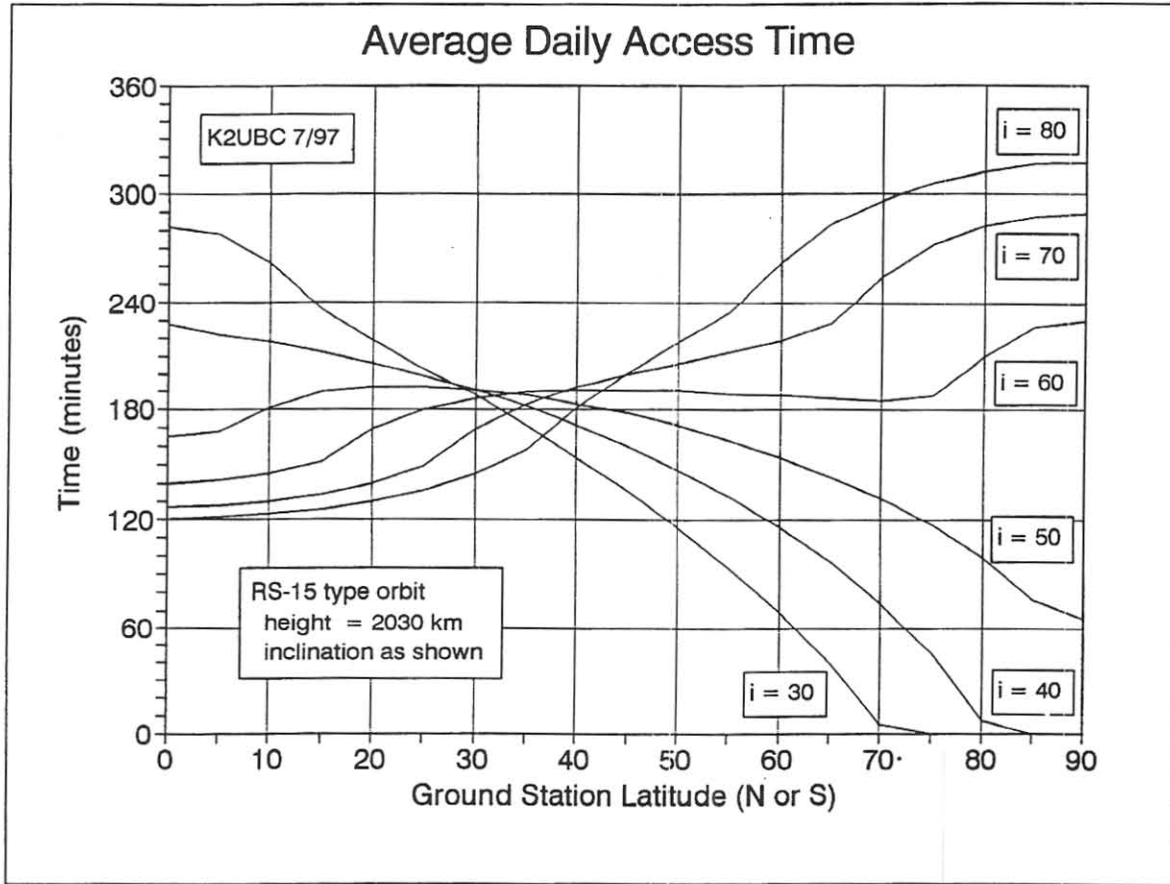


Figure 3. The figure uses an RS-15 type orbit (TCF = 0.121) to illustrate how orbit inclination affects the distribution of access time. Note that changing the inclination does not change TCF.

randomly in the orbital plane. For this to occur the spacecraft must be in slightly different orbits so that their periods will not be identical. This is easily accomplished. In fact, it's very difficult to avoid. Even if the spacecraft are released from a single launch vehicle the springs in the ejection mechanism are never exactly the same.

Note how the marginal increase in access time decreases as the number of spacecraft in the plane increases. For a station at 40° N the first spacecraft provides about 195 minutes of access time; the eighth spacecraft only provides an additional 50 minutes. This is due to overlapping of coverage areas. After a certain point adding additional spacecraft to the same plane provides very little increase in service. At a height of 2000 km using more than about 6 spacecraft in a

single plane doesn't appear to compensate for the additional effort.

Note that 6 spacecraft can provide 720 minutes (12 hours) of access time per day to a station at 50° N.

The "average" in ADAT refers to a mathematical procedure and does not always reflect what a ground station actually sees. With a constellation of only two spacecraft a ground station will clearly notice how daily access time slowly cycles between the ADAT associated with one satellite and twice this value depending on the degree of overlap. With three spacecraft observed ADAT values begin to stabilize near the predicted values. And, with four or more spacecraft, the ADAT values provide an accurate picture of day to day performance.

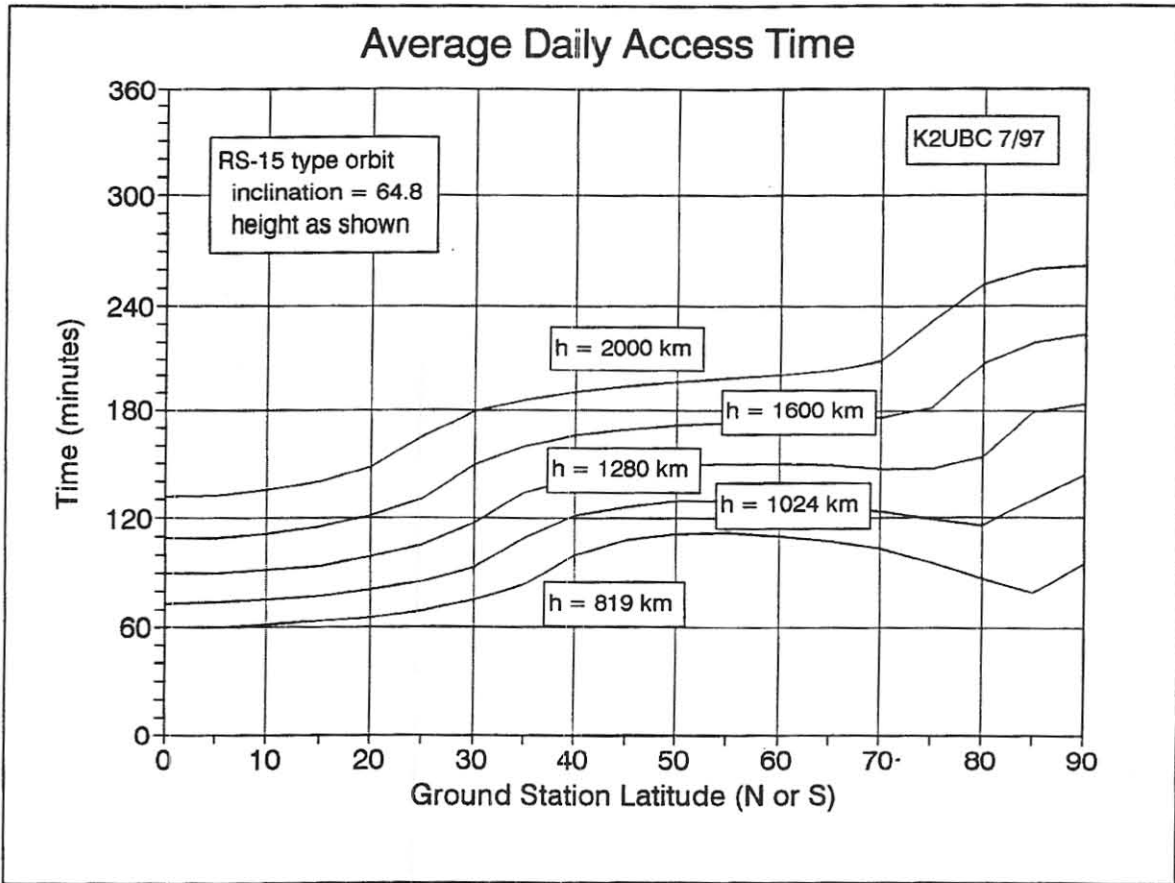


Figure 4. This figure uses an RS-15 type orbit to illustrate how satellite height affects the distribution of access time. Starting at 2000 km the height is decreased in increments of 20 percent.

Figure 6: Discussion

Suppose we wish to add 4 spacecraft to the 4 satellite constellation shown in Figure 5. Two ways of accomplishing this are: [B] add the 4 spacecraft to the same plane, [A] add the 4 spacecraft to a second plane at right angles to the first. Figure 6 compares the performance resulting from these two approaches and quantifies the service advantage of the additional plane. Note that the two plane configuration with eight spacecraft provides ground stations between 30° N and 60° N with about 15 hours a day of service! And, this can be accomplished using simple spacecraft that do *not* contain any means for station keeping.

Two additional facts not shown in the

figure deserve mention here.

First, another computer run was made using 8 spacecraft in 2 planes in a very similar configuration except for the fact that the angle between the orbital planes was set to 60° instead of 90°. As expected, the resulting ADAT curve lies between the cases labeled [A] and [B]. However, it's much closer to curve [A]. In fact, between the equator and 25° N they nearly coincide. The conclusion is: To get the advantages associated with a two plane constellation it's not necessary that the angle between the two planes be close to 90° -- any angle above 60° provides most of the benefit.

Second, the benefit gained by using two planes over a single plane increases as the number

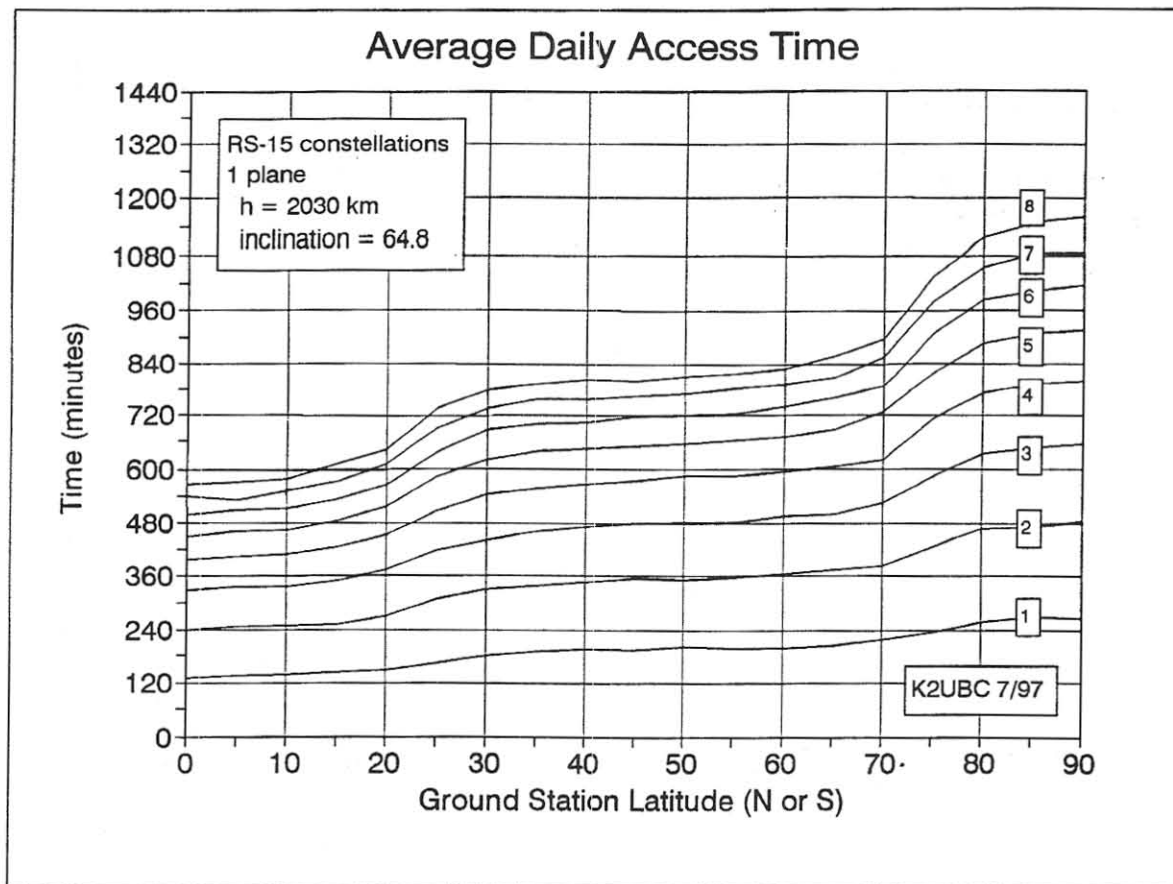


Figure 5. This figure provides Average Daily Access Time data for single plane constellations of spacecraft in RS-15 type orbits (satellite positions in the plane are assumed to be random). With constellations access is defined as a ground station reporting one or more satellites visible.

of spacecraft increases. The data presented in Table 1 suggests that opting for two planes isn't worth the additional effort when a total of only two or four spacecraft are being considered.

Figure 7: Discussion

Figure 7, which shows the P3D 3/2 ADAT profile for various arguments of perigee, was initially prepared for a P3D design meeting in 1991 just after the proposal of the 3/2 (three revolutions in two days) orbit. It may be of considerable interest in the near future since current plans are to allow the argument of perigee to drift to its final position over the next few years. This graph is being repeated here to

enable readers to compare the service that P3D will provide to that which could be obtained from satellite systems mentioned elsewhere in this paper. The comparison follows in Figure 8.

Figure 8: Discussion

Figure 8 compares the service provided by a number of satellite systems. These include: P3D with an argument of perigee set to 210°, two constellations using RS-15 like orbits (a single RS-15 ADAT profile is also included for reference), a single ICO-50 spacecraft, and a constellation (one plane) of two ICO-50 spacecraft. The implications of this data are open to interpretation. One could argue that a

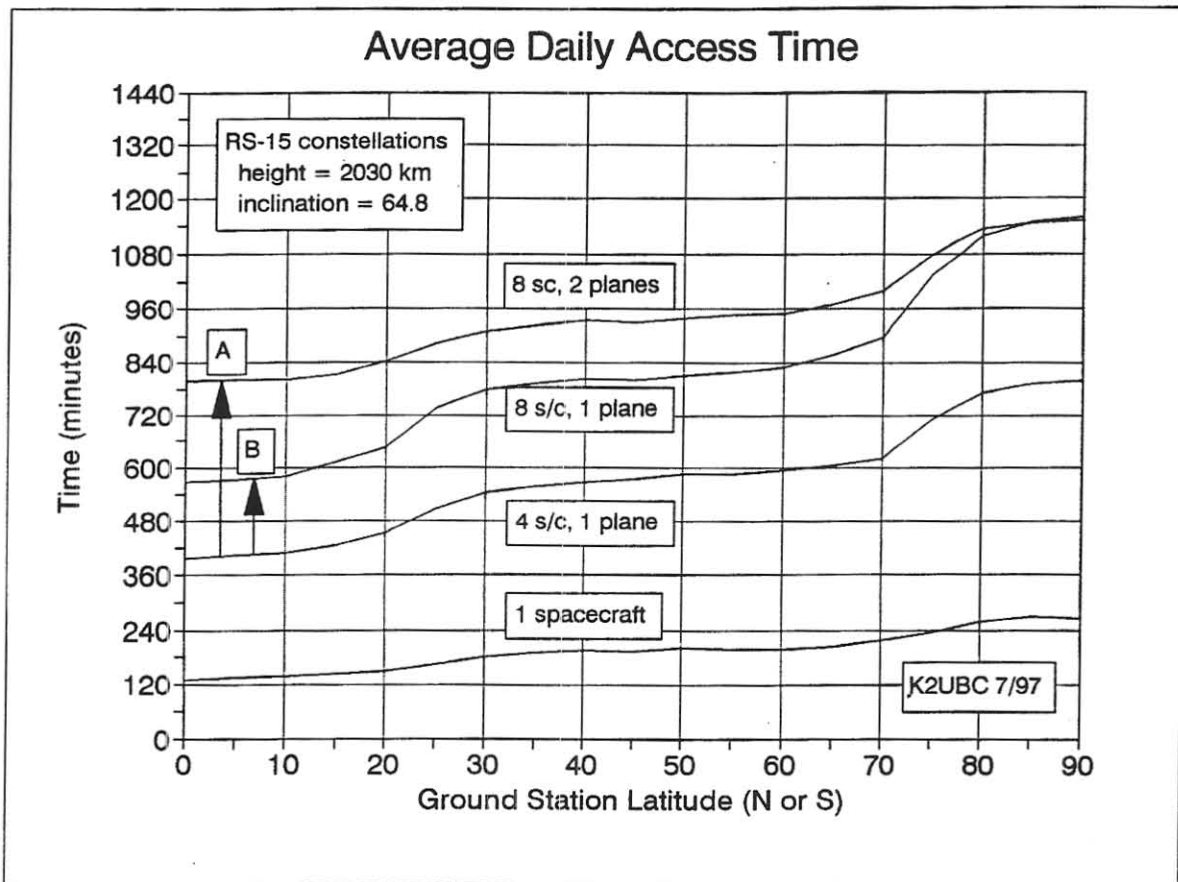


Figure 6. This figure provides Average Daily Access Time data for selected constellations of spacecraft in RS-15 type orbits. [A] and [B] show the result of switching from a single plane constellation of 4 satellites to one of 8 satellites. In [A] the 4 new satellites are in a plane perpendicular to the initial plane. In [B] the 4 new satellites are introduced into the initial plane. See Figure 8 for related information.

constellation of 6 spacecraft in RS-15 like orbits or two spacecraft in ICO-50 orbits will provide the same *quantity* of service as P3D to Northern Hemisphere ground stations and far more service to Southern Hemisphere ground stations. There will, of course, be significant differences in the characteristics of the service being provided. These differences include cost of placing the system in orbit, maximum communications range, path loss, Doppler shift rates, etc. These factors are extremely important but they are not being covered here since the object of this paper is to quantify characteristics related to *quantity* and *distribution* of service, especially with respect to constellations.

Mathematical Techniques: ADAT

A computationally efficient method of computing an ADAT profile for a satellite in a circular orbit was presented in 1990². The method was extended to cover elliptical orbits in 1991⁴.

The method consists of dividing one complete revolution (orbit) of the satellite of interest into a finite number, n , of segments of equal time interval ($\Delta t = \text{Period}/n$). For each ground station latitude of interest (k) the probability ($P_{i,k}$) that the satellite is in range during a particular orbit segment (i) is obtained

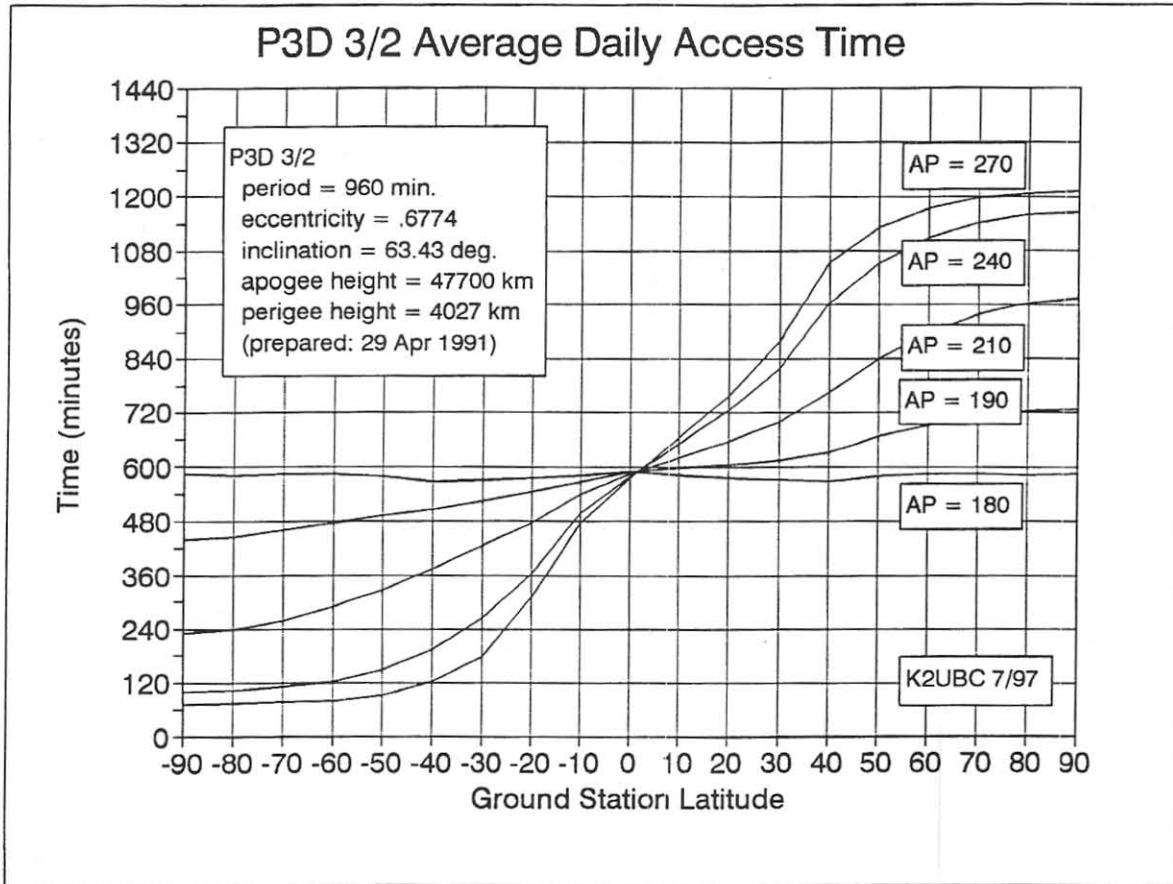


Figure 7. This figure, first published in 1991, shows how the final value selected for the P3D 3/2 argument of perigee will affect the distribution of ground station access time.

by computing the width (in degrees of longitude) of the ground stations acquisition circle corresponding to the subsatellite point latitude and height at the center of the orbit segment (GSwidth(i,k)) and dividing this number by 360°. Summing the product $P_i \times \Delta t$ over one complete orbit we obtain the average access time for one orbit. Multiplying by the number of orbits per day (the Mean Motion) gives ADAT for the latitude of interest.

$$ADAT(k) = MM \sum_{i=1}^n P_{i,k} \times \Delta t_i$$

where

$$P_{i,k} = GSwidth(i,k) / 360^\circ$$

- k = latitude of ground station
- i = orbit segment (goes from 1 to n)
- n = number of discrete segments in one revolution
- ADAT(k) = ADAT at latitude k
- MM = Mean Motion
- $P_{i,k}$ = Probability that the satellite is in range of the ground station (at latitude k) during orbit segment i
- GSwidth(i,k) = width of ground station acquisition circle (in degrees of longitude) corresponding to subsatellite latitude and height of satellite at center of segment i

The technique for calculating ADAT just outlined applies to both circular and elliptical

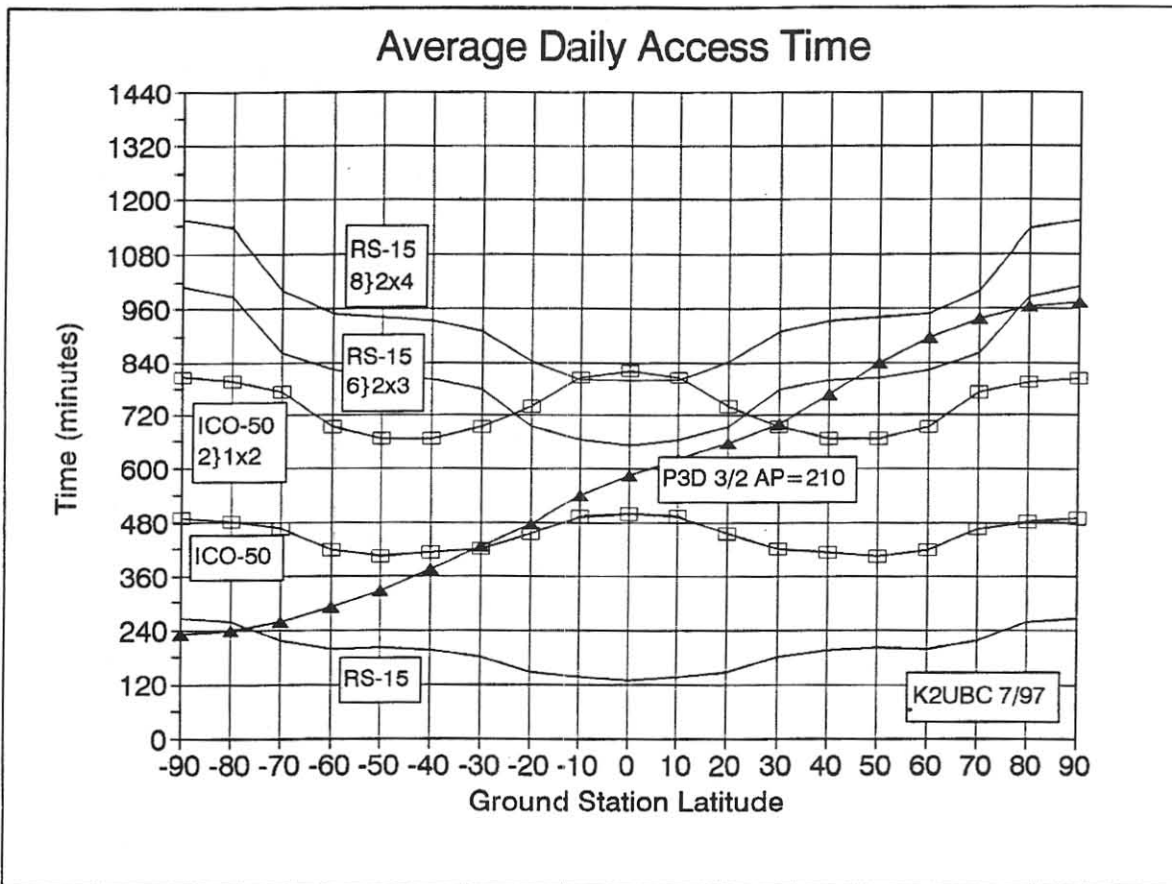


Figure 8. This figure compares the projected Average Daily Access Time for the P3D 3/2 orbit to the service that could be provided by several possible future radio amateur projects including single spacecraft and constellations.

orbits. However, a computer program focusing on circular orbits is easier to implement because (1) the acquisition circle for the ground station does not have to be recomputed for each orbit segment because the satellite height is constant and (2) calculating the subsatellite point latitude at the center of each orbit segment is simpler.

Unfortunately, the method for computing ADAT just outlined can not be modified to apply to constellations. As a result I had to develop an entirely different approach to cover multisatellite systems. The approach adopted uses a technique called a Monte Carlo simulation.

The Monte Carlo simulation proceeds as follows. For a given ground station and constellation one chooses the equator intersection

of the first orbital plane constellation randomly (if a second orbital plane is involved it is set at a fixed offset angle). Next, the locations of all satellites are chosen randomly (with respect to time) with the constraint that they're in the appropriate plane. Finally, we check to see if at least one spacecraft is in range. This is repeated a large number of times (40,000 times in this study). We then obtain the probability that at least one satellite is in range at any time by dividing the total number of trials where at least one satellite has been found to be in range by 40,000. Multiplying the result by 1440 (the number of minutes per day) yields ADAT for the GS latitude being investigated. Studying a single configuration of satellites requires roughly 40,000 trials x 19 ground stations (five degree increments from the equator to the pole) x number of

spacecraft in configuration. For an eight satellite constellation this amounts to about eight million calculations of whether a specific spacecraft is in range. To do these calculations in a reasonable amount of time (my lifetime) the orbit is treated as a discrete variable. 1000 segments were used. This makes it possible to create a lookup table involving sines and cosines of the subsatellite positions at the center of each segment and replace, in the case of the example just mentioned, 16,000,000 sine and cosine calculations with 2000 calculations and a lookup table.

A computer program implementing the Monte Carlo discrete segment approach is shown as Table 2. This program was used for all ADAT calculations in this paper. All reported studies involved 40,000 trials and 1000 orbit segments. Sample outputs are shown in Figure 9 and Table 2.

The use of statistical methods like the Monte Carlo method and the replacement of continuous variables by discrete variables leads to "jitter" in the results. The level of this "statistical noise" can be estimated by running a specific constellation several times using: different sets of random numbers, more and less trials, and more and less orbit segments. Results for single spacecraft using the Monte Carlo method were also cross checked with the earlier method. All these tests lead me to believe that 40,000 trials and 1000 orbit segments produce results having a percentage error of less than +/- 2 percent better than 97 percent of the time.

Mathematical Techniques: TCF

The method used to calculate TCF for single satellites was discussed earlier in this paper. It cannot be generalized to constellations. To calculate TCF for constellations we must turn to an alternative method for single spacecraft which can be generalized. One can calculate an average ADAT for a particular orbit by summing ADAT values (in minutes) for ground stations at all latitudes using a weighing factor consisting of the surface area of latitude belt associated with each ground station divided by the surface area of the earth. Dividing this average ADAT by 1440

(the number of minutes in a day) produces TCF.

TCF for constellations is calculated using the procedure just described. For constellations one must therefore first compute ADAT using the Monte Carlo approach. This data is then used to obtain an average ADAT which is then transformed into TCF. All TCF values for constellations specified in this paper use this approach. All TCF values for single satellites were checked using this approach.

Table 2: The Program ADAT2P

The program ADAT2P provides ADAT profiles for constellations consisting of one or two planes with multiple satellites per plane. It assumes that all satellites are in circular orbits and that all satellites in a given plane have the same nominal orbit. As written it also assumes that when 2 planes are used both planes contain the same number of spacecraft but this can easily be changed.

The program was written in MS-BASIC using a very limited set of operations. I have done this for two simple reasons: more people can read and port MS-BASIC to other languages than any other language and copies of MS-BASIC are available to more people around the world than any other single language. The fact that other languages may run faster, be easier to use, etc., is essentially irrelevant here.

Lines marked *** should be changed to change the constellation. Lines marked ** may also be changed. The program contains a number of features designed to confirm proper operation. These include (1) a screen counter used to determine the run time of particular parts of the program and (2) primitive screen graphics routines that plot (i) the orbits being investigated on a cartesian grid and (ii) the location of every satellite calculated to be in range of the ground station at the latitude currently being studied as the program goes through its 40,000 trials. These features can be eliminated to reduce running time.

Despite the dramatic increase in speed obtained by treating the orbit as a discrete variable the present incarnation of this program

takes a great deal of time to run. Using my old 33 MHz 386, obtaining ADAT data for a single constellation takes about six hours. Producing the 8 curves shown in Figure 5 required about 48 hours. The run time can be cut by a factor of 10 to 100 by using a faster machine, a compiled language, and optimizing the code but reducing run time is not one of my current objectives.

Other Satellite Performance Measures

The object of this paper was to quantify satellite orbit characteristics related to *quantity* and *distribution* of service, especially with respect to constellations and to introduce radio amateurs to some constellations and orbits that might play a role in the future of the Amateur Satellite Service. The specific measures discussed were TCF and ADAT. A related measure, Mean Time to Next Access for single spacecraft, was treated in an earlier paper.⁴

Work has also begun on two additional performance measures but neither is ready for publication. (Unfortunately I have a full time job and an addiction to regular paychecks). The first is DXfactor which is a numerical quantity which specifies the percentage of the earth a specific ground station will eventually have access to via a specific satellite or constellation and provides a picture (or a list of grid squares) detailing which regions of the earth will never be in view. For high inclination LEO spacecraft this is an easy problem to solve in closed form but it turns out to be rather complex in the general case. The second performance measure is blackout duration probability which enables one to make predictions

Figure 9. Graphics screen output of ADAT2P. Shows all subsatellite points determined to be in range of ground station at 50° N latitude during 10,000 trials using a constellation of 8 RS-15 like spacecraft in 2 planes, one with an inclination of 64.8°, the other with an inclination of 30°.

like: the likelihood of not having any access to a satellite in a given constellation within the next 180 minutes is less than 2.7 percent.

References

1. For a good introduction to the orbit selection aspect of mission planning see: T. Clark and V. Riportella, "Mission Planning (Phase III Orbit Alternatives)," *Orbit*, August/September 1981, pp 11-16.
2. M. Davidoff, "An Efficient Method For Calculating Average Daily Access Time," Proceedings of the 5th AMSAT-UK Colloquium, 26-29 July, 1990, pp 57-63. Contains BASIC program for calculating ADAT for circular orbits.
3. M. Davidoff, AMSAT Technical Report dated 27 Sept. 1990. Reproduced in *Satellite Journal*, Nov. 1990. Contains BASIC program for calculating ADAT for elliptical orbits.
4. M. Davidoff, "Selecting Orbits for Radio Amateur Satellite Missions," Proceedings of the 6th AMSAT-UK Colloquium, 25-28 July, 1991, pp 1-16. Contains updated BASIC programs for calculating ADAT for circular orbits (ADATCIRC) and elliptical orbits (ADATEL). Also contains program for calculating GCF for elliptical orbits (GCFEL). Note that TCF is half the GCF value.

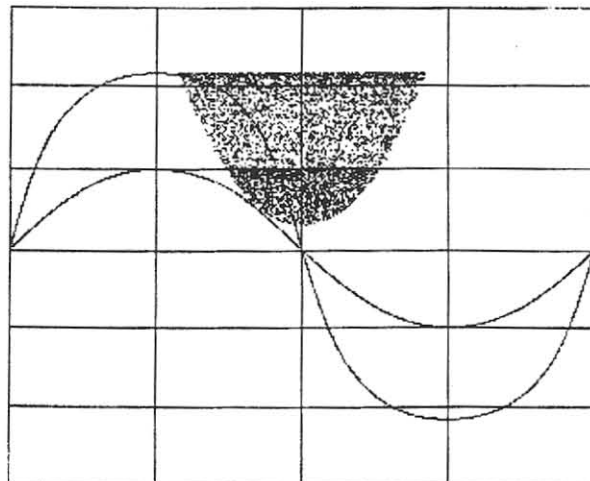


Table 2. Program ADAT2P

```

10 ' Program: ADAT2P (ADAT: Constellations, 1 or 2 planes, circular orbits)
20 ' Last update: 25 June 1997
30 RANDOMIZE TIMER
40 '
50 ' Constants, Conversion Factors, Functions, Initialization, Etc.
60   PI = 3.14159 : TWOPI = 2*PI : HALFPI = PI/2
70   RTOD = 180/PI : DTOR = PI/180
80   RE = 6371 ' km (mean radius of earth)
90   DEF FNACOS(Z) = HALFPI - ATN(Z/SQR(1-Z*Z))
100 '
110 ' System Description
120   NPLANES = 1 ' Number of planes (1 or 2) ***
130   TNSAT = 8 ' Maximum number of satellites in each plane ***
140   DIM INCLINATION(2), INCL(2), SININCL(2)
150   DIM MM(2), HEIGHT(2), PERIOD(2), BETAMAX(2), COSBMAX(2)
160   N12 = 90 * DTOR ' Angle between planes 1 and 2 **
170   NSCEN = 40000! ' No. of scenarios **
180   TM = 1000 ' No. of segments per orbit **
190   DIM LAT(2, TM), LNG(2, TM), SINLAT(2, TM), COSLAT(2, TM)
200 '
210 ' Description of Orbits and Ground Station Parameters
220   MM(1) = 11.27504 ' Mean motion (rev/day) plane 1 (RS15) ***
230   IF NPLANES = 2 THEN MM(2) = 11.27504 ' Mean motion plane 2 ***
240   INCLINATION(1) = 64.83 ' degrees plane 1 ***
250   IF NPLANES = 2 THEN INCLINATION(2) = 30 ' plane 2 ***
260   ELEVATION = 0 ' Satellite above this angle is in range of GS
270   ELEV = ELEVATION*DTOR
290 '
300 FOR PLANE = 1 TO NPLANES
310   INCL(PLANE) = INCLINATION(PLANE)*DTOR
320   SININCL(PLANE) = SIN(INCL(PLANE))
330   PERIOD(PLANE) = 1440/MM(PLANE)
340   HEIGHT(PLANE) = 331.25*PERIOD(PLANE)^(2/3) - RE
350   BETAMAX(PLANE) = FNACOS(COS(ELEV)*RE/(RE+HEIGHT(PLANE))) - ELEV
360   COSBMAX(PLANE) = COS(BETAMAX(PLANE))
370 NEXT PLANE
380 '
390 ' Set up ground track look up table for s/c in both planes
400 FOR PLANE = 1 TO NPLANES
410   S1 = 1 : IF INCLINATION(PLANE) > 90 THEN S1 = -1
420   FOR THETA = 0 TO (TM - 1)
430     TH = (THETA/TM)*TWOPI
440     X = SININCL(PLANE)*SIN(TH)
450     LAT = ATN(X/SQR(1-X*X))
460     IF X*X > .9999 THEN LAT = SGN(X)*HALFPI
470     S2 = 1 : IF TH > PI THEN S2 = -1
480     Y = COS(TH)/COS(LAT)
490     IF Y > .99999 THEN LNG = 0 : GOTO 530
500     IF Y < -.99999 THEN LNG = PI : GOTO 530
510     LNG = S1*S2*FNACOS(Y)
520     IF S2 = -1 THEN LNG = LNG + TWOPI
530     LNG(PLANE, THETA) = LNG : LAT(PLANE, THETA) = LAT
540     SINLAT(PLANE, THETA) = SIN(LAT)
550     COSLAT(PLANE, THETA) = COS(LAT)
560   NEXT THETA
570 NEXT PLANE
580 '
590 ' Subsection to graph ground tracks to check previous work
600 SCREEN 9 'Use screen 12 with QB
610 WINDOW (-270, -120) - (450, 120)
620 FOR HL = -90 TO 90 STEP 30 : LINE (0, HL) - (360, HL) : NEXT HL
630 FOR VL = 0 TO 360 STEP 90 : LINE (VL, 90) - (VL, -90) : NEXT VL
640 FOR K1 = 0 TO TM-1
650   PSET (LNG(1, K1)*RTOD, LAT(1, K1)*RTOD)
660   PSET (LNG(2, K1)*RTOD, LAT(2, K1)*RTOD)
670 NEXT K1
680 PRINT "GS Latitude", "ADAT" ' Heading for screen display
690 PRINT "-----", "-----"

```

Table 2 (continued)

```

700 '
710 FOR NSAT = 1 TO TNSAT ' Constellation (# of s/c in each plane)          **
720   TA$ = TIME$
730 ' Subroutine to print heading
740   LPRINT : LPRINT : LPRINT
750   LPRINT "ADAT for Constellations (program ADAT2p)",
760   LPRINT "   date: "; DATE$
770   LPRINT "   Total number of s/c: "; NSAT*NPLANES
780   LPRINT "   Number of planes: "; NPLANES
790   LPRINT "   Number of spacecraft per plane: "; NSAT
800   LPRINT "   Number of scenarios checked: "; NSCEN
810   LPRINT "   Number of discrete orbit sections: "; TM
820   LPRINT
830   LPRINT,, " Plane 1 ", " Plane 2 "
840   LPRINT,, " ----- ", " ----- "
850   LPRINT "   Mean motion [rev./day] ", MM(1), MM(2)
860   LPRINT "   Mean altitude [km]", INT(HEIGHT(1)), INT(HEIGHT(2))
870   LPRINT "   Period [minutes]", PERIOD(1), PERIOD(2)
880   LPRINT "   Inclination [degrees]", INCLINATION(1), INCLINATION(2)
890   LPRINT : LPRINT
900   LPRINT "GS Lat", "ADAT"
910   LPRINT "-----", "-----"
920 '
930 ' Main Program calculation =====
940 FOR GSLAT = 0 TO 90 STEP 5 ' Modify at times          **
950   SINGSLAT = SIN(GSLAT*DTOR) : COSGSLAT = COS(GSLAT*DTOR)
960   SUM = 0 : SUM2 = 0 : FF = 0
970   FOR K = 1 TO NSCEN ' check all scenarios
980     LOCATE 1,73 : PRINT K
990     SUM = SUM + 1
1000    LNGX1 = RND*TWOPI : LNGX2 = LNGX1 + N12
1010    FOR J1= 1 TO NSAT : THTA(J1) = INT(RND*TM) : NEXT J1
1020    FOR M1 = 1 TO NSAT ' check all s/c in plane 1
1030      Z1 = SINGSLAT*SINLAT(1,THTA(M1))
1040      Z2 = COSGSLAT*COSLAT(1,THTA(M1))*COS(LNG(1,THTA(M1))+LNGX1)
1050      IF (Z1+Z2) >= COSBMAX(1) THEN SUM2=SUM2+1 : FF = 1
1060      IF FF=1 THEN LG = LNG(1,THTA(M1))+LNGX1 + PI : LT = LAT(1,THTA(M1))
1070      IF FF=1 AND LG > TWOPI THEN LG = LG-TWOPI
1075      IF FF=1 AND LG > TWOPI THEN LG = LG-TWOPI
1080      IF FF=1 THEN PSET(LG*RTOD, LT*RTOD) : FF=0 : GOTO 1200
1090    NEXT M1 ' Proceed to next s/c in plane 1
1100    IF NPLANES = 1 THEN GOTO 1200 ' skip over plane 2
1110    FOR J2= 1 TO NSAT : THTA(J2) = INT(RND*TM) : NEXT J2
1120    FOR M2 = 1 TO NSAT ' check all s/c in plane 2
1130      Z1 = SINGSLAT*SINLAT(2,THTA(M2))
1140      Z2 = COSGSLAT*COSLAT(2,THTA(M2))*COS(LNG(2,THTA(M2))+LNGX2)
1150      IF (Z1+Z2) >= COSBMAX(2) THEN SUM2=SUM2+1 : FF = 1
1160      IF FF=1 THEN LG = LNG(2,THTA(M2))+LNGX2 + PI : LT = LAT(2,THTA(M2))
1170      IF FF=1 AND LG > TWOPI THEN LG = LG-TWOPI
1175      IF FF=1 AND LG > TWOPI THEN LG = LG-TWOPI
1180      IF FF=1 THEN PSET(LG*RTOD, LT*RTOD) : FF=0 : GOTO 1200
1190    NEXT M2 ' Proceed to next s/c in plane 2
1200  NEXT K ' Proceed to next scenario
1210  ADAT = (SUM2/SUM)*1440
1220  LPRINT USING "#####. "; GSLAT; : LPRINT USING "#####. "; ADAT
1230  LOCATE (3+(GSLAT/5)),1 : PRINT GSLAT, : PRINT USING "#####. "; ADAT
1240 NEXT GSLAT ' =====
1250 '
1260 LPRINT : LPRINT "run time: "; TA$; " --> "; TIME$
1270 NEXT NSAT ' Proceed to next constellation
1280 END

```

Table 3. Sample of printed output of program ADAT2P

ADAT for Constellations (program ADAT2p) date: 06-30-1997
 Total number of s/c: 8
 Number of planes: 2
 Number of spacecraft per plane: 4
 Number of scenarios checked: 40000
 Number of discrete orbit sections: 1000

	Plane 1	Plane 2
	-----	-----
Mean motion[rev./day]	11.27504	11.27504
Mean altitude [km]	2029	2029
Period [minutes]	127.7157	127.7157
Inclination [degrees]	64.83	30

GS Lat	ADAT
-----	----
0.	1025.2
5.	1018.8
10.	998.6
15.	956.4
20.	927.4
25.	921.7
30.	895.6
35.	876.8
40.	847.0
45.	820.3
50.	782.2
55.	753.2
60.	711.2
65.	664.8
70.	638.8
75.	716.5
80.	775.5
85.	797.1
90.	792.0

run time: 16:50:59 --> 04:37:31

Amateur Radio On-board the International Space Station

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Abstract

Amateur radio has had a substantial presence in human space flight since the mid-1980s. For over 15 years, amateur radio space enthusiasts in the U.S., Russia, and Germany have worked diligently to develop, deploy and coordinate operations of on-orbit amateur radio stations on the U.S. Space Shuttle and the Russian space station Mir. Human space flight is expected to change in the near future as the aerospace community rapidly evolves its focus towards operations on the International Space Station (ISS). The international amateur radio community is progressing in lock-step with the aerospace community to make amateur radio a permanent fixture on ISS. This paper will summarize the status of the ISS program, the development of a transportable station for initial use on-board ISS, and the opportunities and plans for implementing a permanent amateur radio station on-board the ISS.

Ham Radio and the Human Space Flight Connection

Amateur radio has had a significant human presence in space starting with a flight on board the space shuttle orbiter Columbia on the STS-9 mission late in 1983. At that time, astronaut Owen Garriott, W5LFL, provided an unprecedented level of excitement to the amateur community by talking to hams on the ground using a 2-meter FM transceiver. These modest beginnings 14 years ago have led to a significant, nearly continuous presence of ham radio in human-tended space vehicles today.

With twenty-four flights to date, the Shuttle Amateur Radio Experiment (SAREX) has become the most flown payload on board the

Space Shuttle. The primary goal of SAREX is to pique student's interest in science, technology and communications by allowing schools around the world to talk with the astronauts during Shuttle missions. The crew also uses the equipment for a limited number of personal chats with close friends or family members and to talk to hams on the ground during their break times. SAREX was the first to demonstrate crew-tended 2 meter voice, packet radio from space, crew tended amateur television uplinks and Slow Scan TV uplinks and downlinks.

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

The world's space flight community is now concentrating a significant amount of their resources on the development and implementation of an International Space Station (ISS.) The ISS has gone through a number of name and configuration changes since its first inception in 1985. The current design calls for modular components from a number of countries to be lofted on board Russian expendable rockets and the United States Space Shuttle. Construction is planned to begin in 1998 with permanent human residence to start in 2002.

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

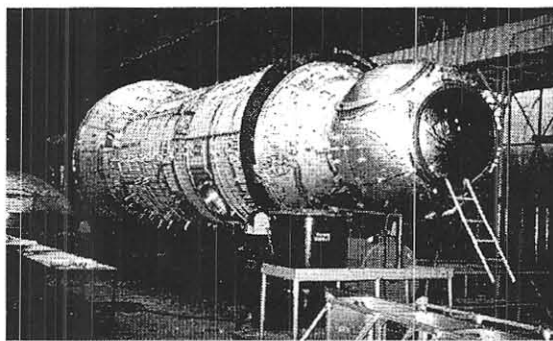
In November of 1996 a meeting was held at Johnson Space Center in Houston, Texas with international representatives from eight national amateur radio organizations. This meeting served to initiate the dialog on the development of a permanent amateur radio station on ISS. The outcome of the meeting was a Memorandum Of Understanding (MOU) that states that the groups would work together to coordinate the development of one amateur radio plan for the ISS. Since NASA is the coordinating agency for ISS, it was decided to have the SAREX Working Group coordinate requests and plans with the ISS project management. This included seeking official sanction and allocation of space for amateur radio equipment.

At the time of this writing, an international "hardware committee" is being established which will define the permanent ham station for ISS, given the space and power resources obtained from the ISS project by the SAREX Working Group. On-board space for the permanent ISS facility is expected to become available late in the ISS construction project (around 2002). In the interim, the SAREX working group has been charged with implementing a "transportable station" which can be launched in late 1998.

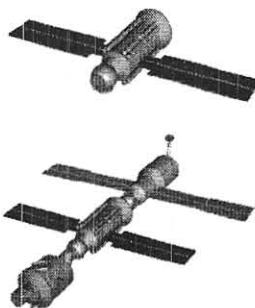
ISS Development Status

Preparations of flight hardware for the ISS are progressing fairly well. The first component of the ISS is the Russian Functional Cargo Block (FCB). See figure 1. This should be launched on a Russian launch vehicle in June of 1998. The FCB will provide initial attitude control and power for the ISS.

In December of 1998 a shuttle flight to ISS, called the "2A.1 Logistics flight," will carry supplies to ISS. The SAREX working group has arranged for the launch of an initial "transportable station," very similar to the



Functional Cargo Block readied for Flight
Figure 1

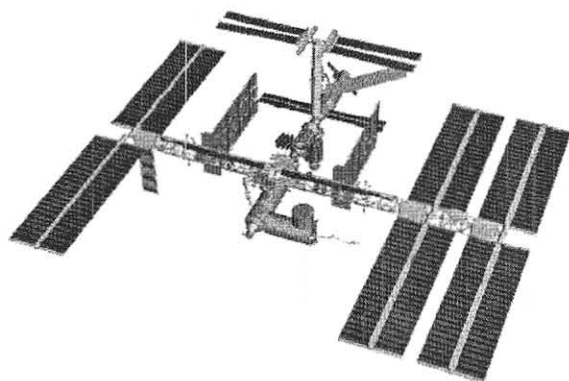


Functional Cargo Block (FCB)
on-orbit configuration
June 1998

2A.1 Logistics Flight
December 1998

current SAREX equipment, on that flight. This will provide a temporary ham radio capability on board the ISS. Current plans call for 2m and 70cm FM capability through an external antenna. There will be a packet bulletin board system, primarily for the personal use of the crew. Hopefully, the BBS will allow the crew to post status messages for the ham community.

Several years later on flight UF-4, (figure 2) currently scheduled for January 2002, the working group has arranged for space on board an "EXPRESS Pallet." EXPRESS Pallets are mounted external to the station, and it is expected that there will be room for a fairly sophisticated "OSCAR like" payload. A request is in progress for permanent rack space in the "habitation module" which is to be launched on flight 16A no later than

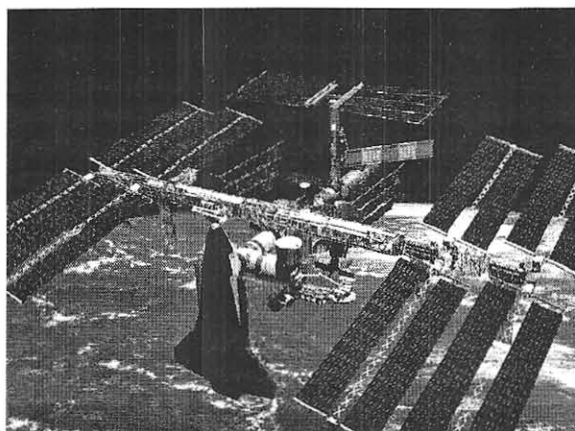


International Space Station
UF-4 January 2002
Figure 2

December of 2002. See figure 3. The request includes access to external antennas and access to the ISS computer systems for status information.

Transportable Station Plans

The current SAREX configurations support FM voice, an automated packet robot, amateur television uplink, and slow scan television capabilities. The "packet robot" sends beacons and issues serial numbers for connects but has no other functionality. The initial plan for a transportable station uses



International Space Station
On-Orbit Configuration, Late 2002
Figure 3

intrinsically safe commercial 2m and 70cm hand held radios from Ericsson. These radios are extremely rugged and will not pose a hazard on the Space Shuttle or ISS. The radios are very simple to operate, with text displays for frequency configurations. They can be reprogrammed on orbit with software compatible with the laptop computers planned for use on board the ISS. Initially, these radios will be used with externally mounted antennas to provide a low power voice communication capability.

The packet bulletin board system on Mir has proven to be incredibly valuable for educational and recreational activities. The primary problems observed with the Mir packet system is the limited memory space for messages and the fact that only a single connection can be made at a time. Hams unfamiliar with Mir packet operating practices have been known to lock up the system over an entire pass because the single connection does not time out for approximately 5 minutes. The Terminal Node Controller (TNC) that is being qualified for the ISS transportable station is the PicoPacket TNC from PacComm corporation. PacComm TNCs are also used on board Mir so the user interface for the Mir and ISS systems will be close if not identical. The transportable station on ISS is expected to include 1 megabyte of memory to alleviate the current memory problems. The PicoPacket will also support multiple connections so this should ease some

of the problems that have been seen when connecting to Mir. Our Russian colleagues are working hard to assure that feedthroughs and external antennas are available early in the ISS assembly process. Additional transportable hardware is being discussed but has not been defined at this time. It will probably be desirable, for instance, to upgrade the transportable station with a multimode transceiver to enhance voice and data operations on ISS.

A Permanent Amateur Radio Station on the ISS

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

Permanent station derived requirements:

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

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

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

The briefing also suggested external allocations for four "microsat class" payloads that could be changed out. This would allow schools and universities to develop stand alone payloads and not have to worry about attitude control, or power concerns. This allocation has been made on an EXPRESS Pallet scheduled for a flight in 2002. It will be incumbent upon the hardware committee to rapidly formulate plans to effectively utilize this space before it gets reallocated to another project.

Plans for utilizing these resources are expected to come in the form of proposals to the international hardware committee. At the time of this writing, the German SAFEX group have generated a proposed contribution to the ARISS project. This proposal is described at the world-wide-web site: http://www.op.dlr.de/~df0vr/ariss_e1.htm It will be the responsibility of the committee to evaluate the technical merit and feasibility of the proposals and generate a final integrated plan for the ISS. Elements of the final plan will be implemented and supported by the international community. Those wishing to review the status of the various ISS hardware proposals are welcome to peruse the world-wide-web site: <http://garc.gsfc.nasa.gov/~ariss/ariss.html>

The U.S. Proposal

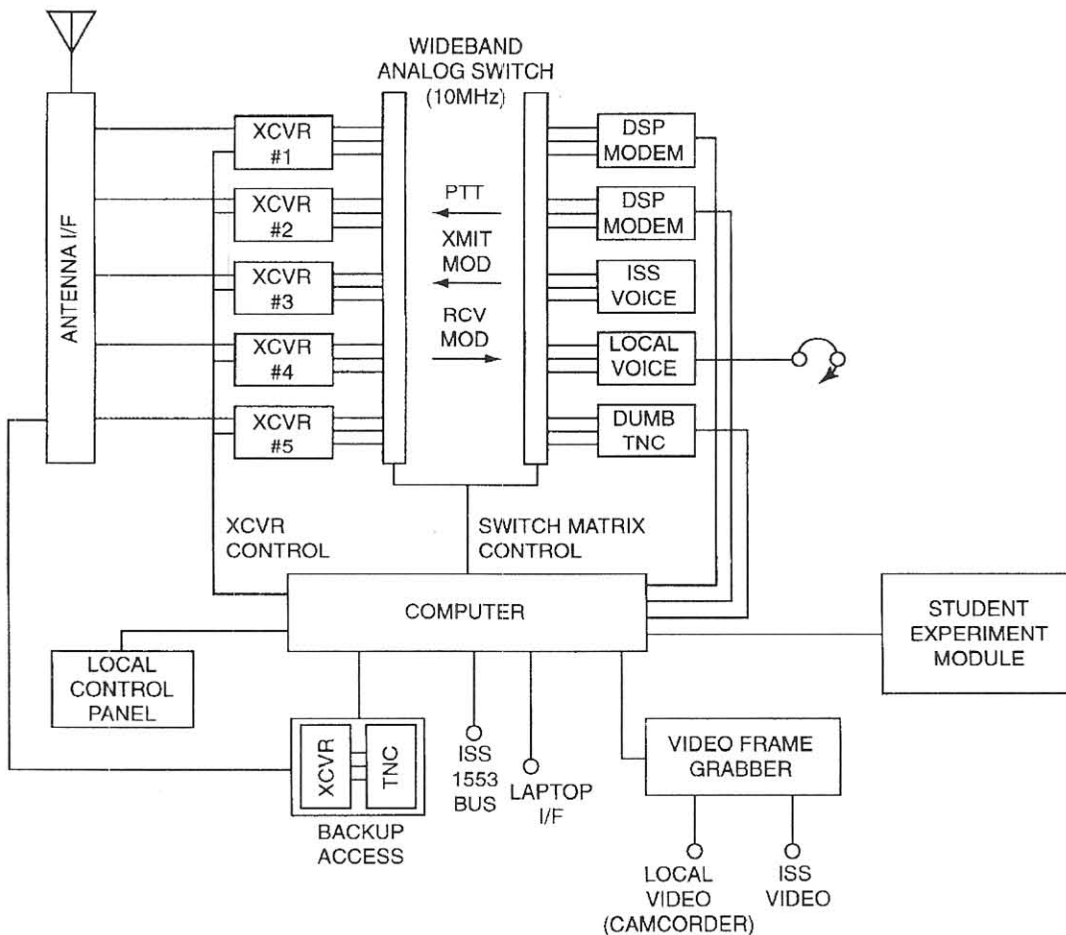
The U.S. would like to provide the basic rack and interconnection infrastructure for the ISS

amateur radio station. This makes a great deal of sense as the SAREX Working Group are the coordinating interface with the NASA ISS program office. The basic idea is to develop a system with modular equipment slots and standard interfaces that are tied together with a computer controlled matrix. The matrix can handle voice/data signals and can handle RF switching. Interchangeable modules means that repairs and upgrades are easily handled on orbit. This modularity also means that it is easy for many different organizations to make contributions of hardware and software to the ISS amateur radio station. One module has tentatively been designated as a "student experiment" module. Potentially, schools could design an experiment module for this space and then gather the data and control the experiment from their own groundstation or collaboration of ground stations with other schools.

Matrix switching would be handled by a master computer that would also serve as the interface to the control stations on the ground.

A perennial problem for Mir and SAREX has been the inability to control hardware configurations from the ground. This capability will allow the crew to offload the responsibility of day to day maintenance of the system to a network of amateur control stations. The network of amateur ground stations is a well established practice that has proven its value over the years in the OSCAR program as well as for SAREX.

Figure 4 illustrates the ARISS Hardware Concept presented by Dr. Ron Parise, WA4SIR, at the 1997 Dayton Hamvention. The station is organized into three major sections. The radio frequency section (top left of the figure) consists of a number of replaceable transceivers that have a standard interface to a wideband analog switch. Multiple external antennas have been requested, so hopefully the use of multi-band duplexers will not be necessary. The wideband analog switch will connect multiple signal sources to the transceivers. Many different data sources are possible: digital

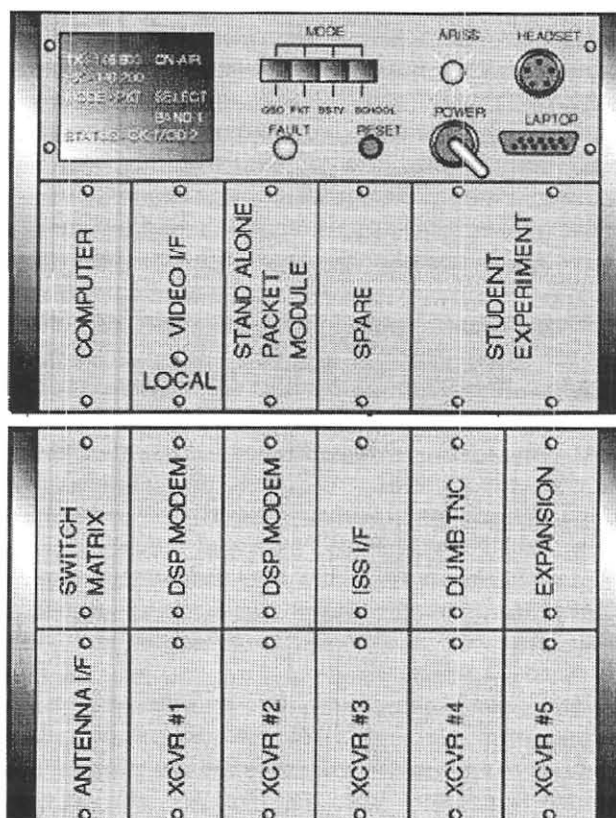


ARISS Hardware Concept
Figure 4

modes, analog voice, and amateur television for instance. The use of the analog switch provides a very powerful capability for reconfiguring the ARISS station. Transceivers could be tied together to form cross band repeaters. Stand alone bulletin board systems could provide specialized services. Moreover, the modular design permits that addition of modes and capabilities as the technologies and the interests of the amateur community change.

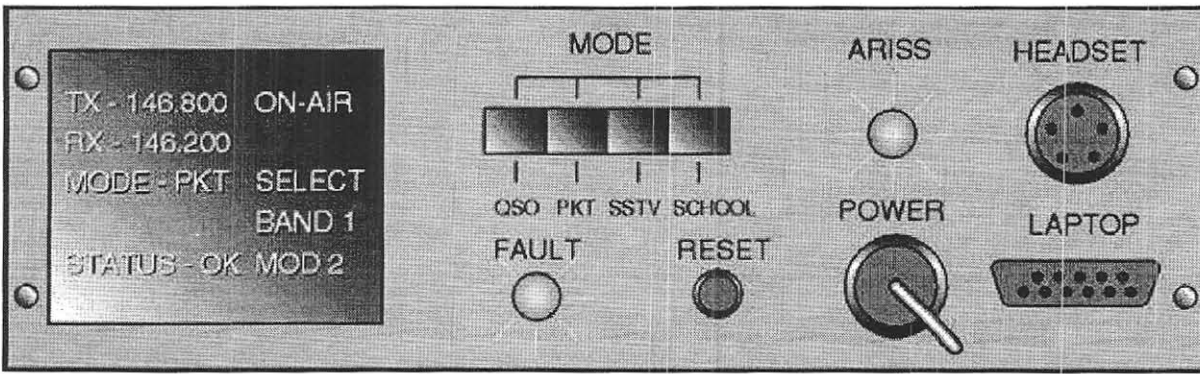
Control of the transceivers, data sources, and the analog multiplexer will be provided by a master housekeeping computer. This will most likely be a fairly powerful personal computer running a multi-tasking operating system, such as LINUX. This computer will provide basic functions, like control of the analog matrix and the crew interface via the front panel. It would also provide a platform to control and run interface software for the replaceable data modules. This computer will control the interfaces with the ISS systems. We expect to be able to receive housekeeping data via the ISS Mil Std-1553 data bus. Housekeeping data is under discussion, but should include orbital and attitude information. Interfaces have been requested to the ISS intercom and video networks. Ideally the data available will also include status reports concerning activities aboard the ISS. The control computer will also include a dedicated "backup" transceiver and TNC to provide a "back door" for reconfiguring the ARISS station. Normally this backup will be used for beaoning, but would be available for any emergency activities that cannot be performed through the regular control channels.

Figure 5 depicts the ARISS Preliminary Rack Configuration. The ISS management team reacted quite favorably to our briefing the use of 24 inches of standard 19 inch wide rack space in the habitation module. The top half would be used for housekeeping and control functions. The bottom half would contain the modules to be proposed, designed, and built by the worldwide amateur radio community. The dedicated crew interface is mounted at the very top of the proposed configuration. A



ARISS Preliminary Rack Configuration
Figure 5

liquid crystal display (LCD) would provide software reconfigurable status information to the crew. A set of standard "mode" switches (possibly with built in LCD labels) would allow the crew to easily configure for standard operating modes: a school contact for instance. See figure 6. The switches would be read by software in the control computer, so the use of LCD labeled switches (or a touch screen LCD) would provide a wide degree of flexibility. A master reset switch will be provided to allow the crew to do a "hard" reset of the system without having to power cycle the unit. The radiation environment in the ISS orbit is not expected to be severe, but there may be radiation induced Single Event Upsets (SEU) that will require periodic reset of the computer systems. There will also be a significant amount of software running in the master computer, and the possibility of bugs requiring a hardware reset should not be overlooked. A headset jack will be provided to allow a crew member to operate ARISS



Control Panel
Figure 6

from the front panel. Discussions are ongoing about the possibilities for controlling ARISS via the ISS intercom system. Naturally, the permanent ARISS station can be used as a repeater link to the transportable station. The crew can use the 2m and 70cm voice and packet capability of the transportable station as an inter-vehicle communications link to access various features of the permanent station.

Below the user interface panel, are modules designed to support the overhead and housekeeping functions of the ARISS station. The housekeeping computer will be in a modular unit to allow replacement in case of failure and easy upgrade. A student experiment module is planned that would be periodically changed out and would be controlled via the housekeeping computer. This would be a supplement to the experiment sites available on the external EXPRESS Pallet. The bottom half of the rack will consist of the transceiver and data modules supplied by the groups selected from proposals to the international hardware committee. These units will be designed with standard mechanical, electrical, and control interfaces to allow for changeout in case of problems or for expansion.

Conclusions

The historic use of amateur radio on the Space Shuttle and Mir to support educational outreach, crew personal contacts and interaction with terrestrial-based hams will become even more important when the

international aerospace community migrates to the International Space Station. The ARISS international partners are working hard to transform the dream of a permanent amateur radio station on the international space station into a reality.

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