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CORPORATION

PROCEEDINGS OF THE
AMSAT-NA

19th Space Symposium
and **AMSAT-NA** Annual Meeting

October 5-8
2001
Decatur, Georgia

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Welcome to Atlanta.

It gives me a great deal of pleasure to welcome you to Atlanta and to the nineteenth AMSAT Space Symposium. Since we last met in Portland Maine many things have happened which affect AMSAT as follows.

At our Board of Directors meeting in October 2000, the need for a new satellite program was first discussed, and it was agreed that the BoD would meet again in February 2001 to start the process by trying to define the satellites capabilities.

In November 2000, P3D was launched on Ariane 507 with a perfect trajectory. Our first notification of any trouble , with the re-named AO-40, was when the 70 CMS beacon failed to transmit.

However the 2M beacon was soon put into operation and all appeared to be functioning well. Down loads of the beacon telemetry gave every indication that the onboard systems were working, except for the U-band transmitter. In Mid December it seemed that we were destined for failure, as a number of problems arose with the propulsion system, giving a higher than required perigee then losing complete contact with the satellite and the fear that we might have many satellites in orbit instead of just one! Several attempts were made to contact AO-40, but they failed.

On Christmas day 2000, a miracle happened or so it seemed. the New Zealand Control station made contact with AO-40, using L and S bands. Slowly and carefully since then the world wide AMSAT network of controllers have nursed AO-40 back to health, and this effort is continuing to this day. My sincere thanks and congratulations to Karl, and Peter in Germany as well as to Stacey, James, Graham and Ian the world wide controllers.

While all this high drama was proceeding, the International Space Station received it's first crew, Expedition One. Amateur Radio on the International Space Station became a reality. Years of hard work and preparation by Frank Bauer, his staff and cohorts at NASA, Will Marchant and Lou McFadin meant that amateur Radio Operators all over the world could communicate with the ISS crews.

When the first Space Tourist, Dennis Tito, went aboard ISS with his amateur radio qualification in place, he was able to talk to his family courtesy of ARISS and AMSAT.

Now many schools are able to participate via ham radio with ISS, and Parkway Central High School, in Chesterfield, Missouri have produced a CD showing their contact with ISS assisted by Roy Welch W0SL.

A special "thank you" must goto Susan Helms for her many Amateur Radio Contacts from ISS, especially on Field Day 2001.

Now back to February 2001 again, the AMSAT BoD met to discuss the next AMSAT Project which is to be a simple satellite with V,U,L & S bands, and

possibly a digital transponder using the L & S bands. Following these discussions by the BoD, the AMSAT-NA project committee met in Denver Co to start the detailed planning, and to invite other people from overseas to join in the project. The SSB functions of this satellite will complement the functions of AO-40, and when launched should provide almost continuous coverage around the world. More and up-to-date details of the project will be available during this symposium. During the remainder of 2001, we will be starting a major campaign to raise funds for the new satellite, your assistance is required, for without your help there can be no AMSAT satellites. With your assistance the sky and beyond is not even the limit.

Enjoy your week-end, it is a pleasure to see you here.

Robin Haighton. VE3FRH
President AMSAT

AO-40 Telemetry from Generation to Interpretation

G. Gould Smith, WA4SXM
AMSAT Symposium 2001
Atlanta, GA

I. **What is telemetry?**

Telemetry is a word coined from the Greek roots tele (distance) and meter (to measure) - to measure from a distance. The first recorded use of the word was in the May 1885 issue of *Electrician* magazine. This was also the same year that a galvanometer was able to be deflected at a distance of 18 miles. It was nine years before Marconi demonstrated on the Salisbury Plain in England that he could generate and receive a radio signal 2 miles away. Telemetry was transmitted to the receiving station by wire for may years, until it was practical to send it via a wireless RF transmission. The most common uses of telemetry are for power plant monitoring, meteorological data, medical applications, manned and unmanned space flights. Aerospace telemetry dates from the 1930s when balloon-borne radiosondes would send temperature, humidity and barometric pressure data back to earth via radio. Satellite telemetry began in 1957 with the orbiting of the Russian satellite Sputnik. Amateur satellite telemetry quickly followed in 1961 with OSCAR 1 sending 'HI' in CW. The CW transmission rate was proportional to the spacecraft temperature. The 'HI' has traditionally been a part of nearly all amateur satellite telemetry since then, including AO-40.

Telemetry Basics

Telemetry or measuring a device from a distance involves five basic functions:
  1) sampling what is to be measured (Section I) ;
  2) converting these measurements to some standard format (Section II);
  3) transmitting the data (section II);
  4) receiving, recovering and processing the data (Section III & IV);
  5) displaying, recording and analyzing the information (Section IV).

This paper will deal specifically with how to perform these five functions with AO-40 telemetry, but these operations basically apply to all types of telemetry.

Two useful resources for AO-40 telemetry are: 1) Dr. Karl Meinzer's book about the IPS operating system used aboard the Phase 3 spacecraft, "IPS High Level Programming of Small Systems", available from AMSAT-UK and AMSAT-NA.; and 2) a basic introduction to amateur satellite telemetry is the 1991 book "Decoding Telemetry from the Amateur Satellites", available from AMSAT-UK.

I. **Sampling what is to be measured**

Telemetry data points are selected to best characterize the current state of the spacecraft at a particular point in time. There is a tradeoff between the number of locations to be sampled and how often they can be sampled. A great deal of thought and experience go into selecting the number of locations, the actual location sampled and the type of data

that is sampled. Telemetry is the only real-time, on-site information that ground control stations have to monitor, understand and explain the actions of the spacecraft. There are basically four types of analog data that can be sampled: voltage, current, temperature and pressure. A number of additional data types can be monitored, but these are generally converted to voltage, current or resistance values. The digital telemetry channels set, record or present the current state settings of satellite systems -- generally ON or OFF. Sometimes these digital states are used to set specific levels of operation in the satellite systems, like transmit power.

Analog measurements

Transducers are devices that convert energy from one form into another, i.e. temperature into voltage, pressure into voltage. Other common sensors include humidity, blood pressure, heart rate, altitude, light sensors, breathing rate, fluid flow, mechanical stress and acceleration. ADC (analog to digital converter) devices sample temperature, pressure, voltage, current and position values, then store these values as numeric data (digital data) inside the sampling device. Each of the designated analog points in the spacecraft is assigned a memory location in the system (IHU, Integrated Housekeeping Unit) memory. The system uProcessor (uP) goes through each of the sampled points, reads the current digital value from the ADC, then stores this value into the assigned memory location. The sampling method for telemetry data on AO-40 is called time division multiplexing, each location is assigned a set time window in which its location is sampled. The uP samples it and moves on to sample the next location until it reads them all. The data is then packaged and transmitted. When the operating system determines that it is time to sample the points again, the uP begins the process again of sampling the sensors, storing the data, and finally transmitting it.
Think of this process like a clock, with each second as a different telemetry point and the second hand as the uP reading the data from each point as it passes over the second dot on the clock. The hand returns to 12 and starts all over again. On AO-40 the uProcessor is the second hand, it goes through a loop that accesses each sampling device, reads the digital value stored in the device, then writes this data into the appropriate IHU memory location.

Once all of the locations are sampled the telemetry data block is built and transmitted. This gives a complete snapshot of the system at a particular point in time. The samples are actually all not at the same instant (the uP can only talk to one device at a time), but are captured within a very short period of time. The multiplexer samples the sensors at a rate of 50 channels/sec. This is the tradeoff needed because the uP is needed to perform an number of other important operations. The number of samples and how often they are sampled is all part of the system design. The more locations to sample the more time it takes to sample them and the longer time needed to transmit the additional data. The uP has a number of other tasks to take care of in addition to telemetry, so only a portion of its time can be spent on telemetry. The transmission rate is also an important consideration, as it is also controlled by the IHU. AO-40 takes a little over 13 seconds to send each data block, so the sample rate cannot be any faster that the block transmission time. The system only samples the sensors and compiles the data points just before transmission. Any events that happen in between samples are missed. It is also

important to understand that the spacecraft can change quite a bit between samples. Do not make erroneous assumptions about the solar cell voltages or the AGC values being linear measurements, these values can go up and down in between the 26 seconds or so between A block receptions.

II. Converting the data to a standard format

The AO-40 design team decided to use the tested and proven IPS operating system and its telemetry format. The telemetry is sent in blocks of 512 data bytes at a rate of 400 bps using PSK modulation. This same format was used on the other Phase 3 spacecraft, AO-10 and AO-13. This decision also took into account that all of the command stations and other interested ground stations would have the necessary demodulating and control equipment in place.

II.1 AO-40 Telemetry Specification

A complete description of the telemetry used on AO-40 can be found at URL:
http://www.amsat-dl.com/p3d/tlmspec.txt

I encourage all those interested to print it out, read it and make notes. Rather than re-hash this well-written and understandable document, I will review a few basic pieces of AO-40 telemetry format and then marry this information to some of the AO-40 graphical information. In addition to the telemetry specification an integral part of understanding the telemetry is understanding the satellite operating system. AO-40 uses the **IPS** (Interpreter for Process Structures) operating system which manages the IHU (Integrated Housekeeping Unit). IPS was designed by Dr. Karl Meinzer in 1978 as a non-processor specific language for real-time control. I was ported to the COSMAC 1802 uProcessor, used in the Phase 3 spacecraft. It has had assemblers written for the 8080, 6800 and 6502 processor as well. There has been discussion that an assembler that runs on the PC may be available in the future. This document was recently re-published by James Miller, G3RUH (AO-10, AO-13 and AO-40 command station) and is available from AMSAT or from James. The telemetry specification also contains an excellent Glossary that defines about 100 three letter acronyms (TLAs) and terms used in describing AO-40 telemetry This Glossary is necessary to understand the specification and this paper.

II.2 Some additional definitions

ASCII - 7-bit code (American Standard Code for Information Interchange) for English characters that maps each character, numeral, special character and operator to a decimal number between 0-127 or a hexadecimal number between #0 - #7F.
Hex, Hexadecimal - base 16 numbering system. Designated by a # in front of the numerals in this text, the telemetry spec and the P3T display. It is composed of the numerals 0,1,2,3,4,5,6,7,8,9,A,B,C,D,E and F (these correspond to decimal values 0–15).
Phase 3 - an AMSAT designation for the third series of AMSAT satellites, these in high elliptical orbit. P3 satellites are AO-10 (P3-B), AO-13 (P3-C) and AO-40 (P3-D). P3-A went into the Atlantic after a problem with the Ariane launch rocket.
II.3 AO-40 Telemetry blocks
AO-40 transmits telemetry in blocks or packets. Each block is preceded by a synchronization sequence and terminated by a checksum. Inter-block characters are the

ASCII #50 character. There are approximately 130 inter-block characters sent between blocks, but this can vary.

	bytes	
Sync:	4	#39 #15 #ED #30
Block data:	512	
CRCC:	2	
Inter-block:	~130	#50 or the <P> ASCII character (0101 0000)

Data is transmitted at 400 bps rate or 50 bytes/sec.

```
          Sync              0.080  sec
          Data             10.240  sec
          CRCC              0.040  sec
          Inter-block      ~2.600  sec
                          ~12.96   sec total block time
```
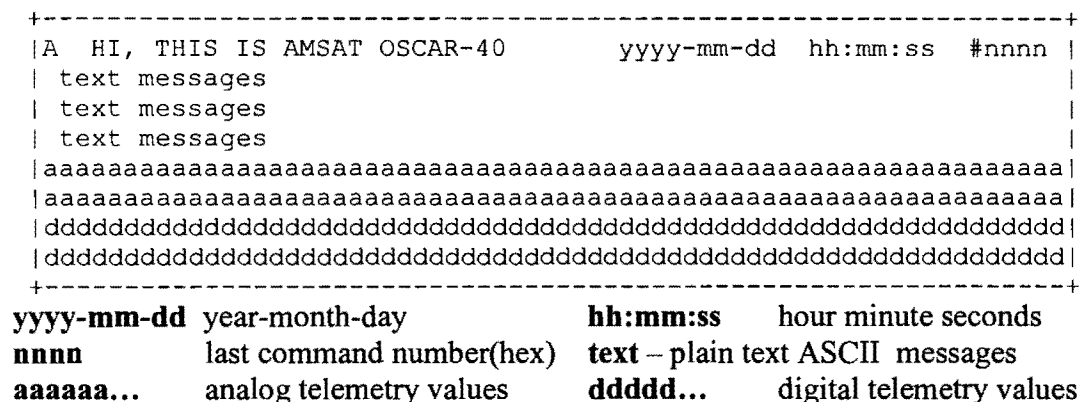
The IPS book makes a number of things clear as to why some of the telemetry values are what they are. It is interesting to note that 400 bps was selected because it is faster than the standard 300 bps modem rate and still compatible with the standard program storage method of the time – the cassette tape. The IPS book also provides reasons for the block size of 512 bytes. 1) It is a standard hex boundary; 2) it is half of the scratch ram available to generate the screen; and 3) it works with the standard computer display of the time – a TV set. One block is one half the fixed video memory assigned for the uProcessor – 16 lines by 64 characters (1024 characters). Thus, two data blocks fit on the TV screen.

The AO-40 telemetry blocks generally follow the format below. The block itself is 512 bytes long. Block types are identified by the first data byte followed by a space.

Figure A. Basic A block telemetry format

```
+--------------------------------------------------------------------------+
|A  HI, THIS IS AMSAT OSCAR-40         yyyy-mm-dd  hh:mm:ss   #nnnn |
| text messages                                                            |
| text messages                                                            |
| text messages                                                            |
| aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa |
| aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa |
| ddddddddddddddddddddddddddddddddddddddddddddddddddddddddddddddddddddddddd |
| ddddddddddddddddddddddddddddddddddddddddddddddddddddddddddddddddddddddddd |
+--------------------------------------------------------------------------+
```

yyyy-mm-dd year-month-day   **hh:mm:ss**   hour minute seconds
nnnn   last command number(hex)   **text** – plain text ASCII messages
aaaaaa...   analog telemetry values   **ddddd...**   digital telemetry values

Phase 3 Telemetry Block Types: A, E, K, L, M, N, X, D, Q, Y, and others used as command acknowledgements(CmdAck)

A Blocks are the most important and the most common. They generally alternate with the other block types. They contain 64 bytes in the header line, 192 bytes of optional text, 128 bytes or channels of analog data and 128 bytes/channels of digital data. The text data is padded filler bytes of #20 (appropriately the space character). Figure C points out the problem of using data without a checksum, the data appears to be valid, but no values can be trusted if any are known to be bad. Note the inverse A. It signals a bad block

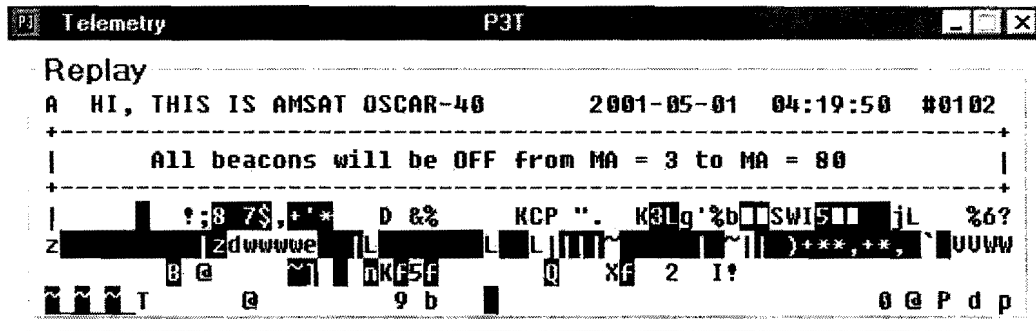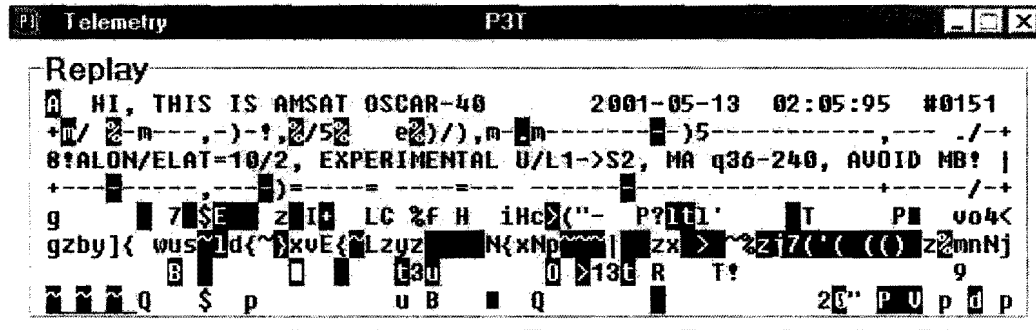**Figure B**. Sample A block

Figure C. Sample bad A block

E blocks or event blocks carry historical data and are basically the same format as the A block. They capture the state of the spacecraft during an event. E blocks differ from A blocks in 4 ways.   1) E block identifier;
                    2) Date, time and command number refer to the time of the event;
                    3) no text message; and
                    4) the EVENT number replaces the text area.

The E blocks generally alternate with the K,L,M,N message blocks between A blocks. There are 16 (#0 - #F) different events stored. These E blocks sequence through the sixteen events (#0 - #F) and then repeat. See Figure N. for a graphical description of this sequence. Those blocks without event data have Event 0 and a 1978 date. Once the 16 event blocks have recorded events you should not see any more empty blocks. The last 16 events will be continually transmitted with any new events replacing the oldest event block.
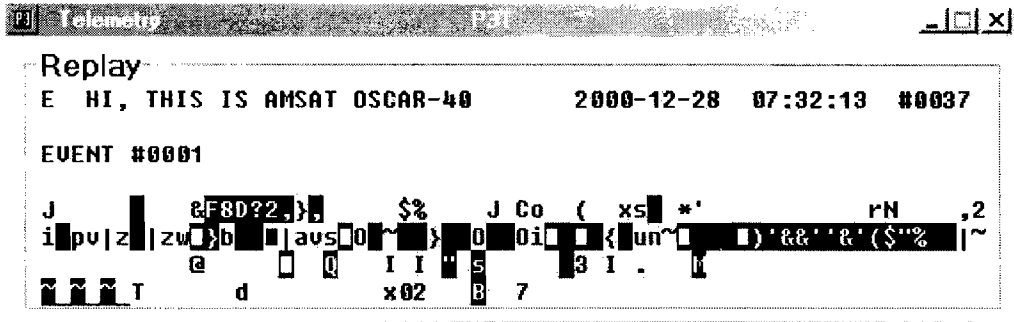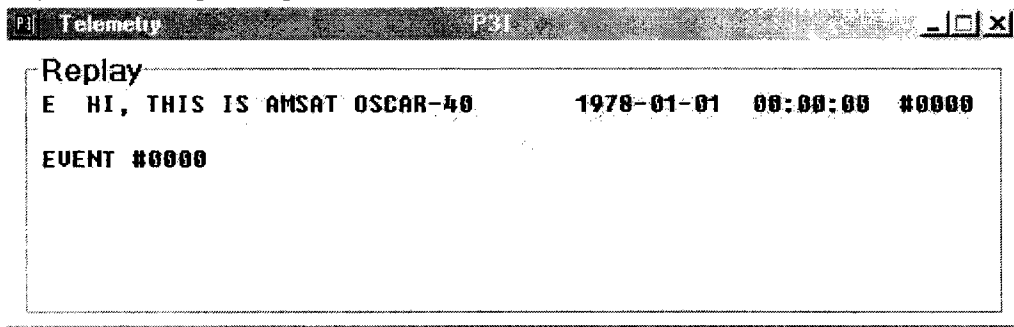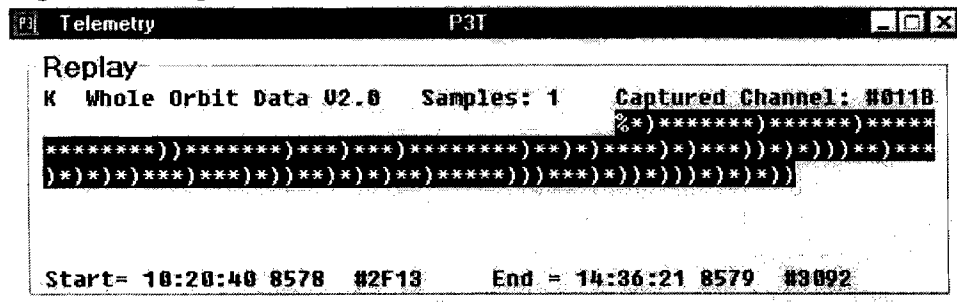
Figure D. Sample E block, event 0001

Figure E. Sample empty E block, event block waiting for an event

K, L, M, N blocks are message blocks. These were used to send messages between command stations on the earlier Phase 3 satellites, as well as broadcast messages to the satellite community. Today they are used just for the broadcast function and for data. Since these broadcast messages are plain text, they use the 7-bit ASCII characters, with the 8th bit used to highlight a character. No CR/LF is sent with the text data, the display should insert the CR/LF after every 64 characters. When the satellite schedule is distributed on the AMSAT BB, the schedule is copied in this format. Use non-proportional fonts (like Courier) to display and to print the schedule. This will make the schedule line up correctly.

Figure F. Sample K, L, M and N blocks

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Whole Orbit Data

The K, L M and N message blocks also can contain Whole Orbit Data (WOD), data from one of the telemetry channels for one or more orbits. This data is extremely useful to the command stations to be able to chart exactly what happened to the channel of interest during an entire orbit or more.

Samples define the sample interval in MA units, 1 means that there is a sample every MA or 256 samples per orbit. Channel is the hexadecimal channel number that is being sampled. The data area will hold 384 samples -> 1.5 orbits at a 1 sample rate. The data block is initialized with the #20 <space>character. The last line has the Start and Last date/time, AMSAT day (0 = 1 Jan 1978), and the hex orbit number(least significant byte of the orbit number since the orbit number is > 256) and the MA. If the data collection is on going the word Last is used, if data collection has stopped then End is used. If the sampling rate is other than 1, the sample is taken on MAs evenly divisible by the sample rate.

X blocks are used during upload operations for the operating system. The third byte is a letter (A, B, C ...) which indicates the latest block of approximately 15 successfully received.
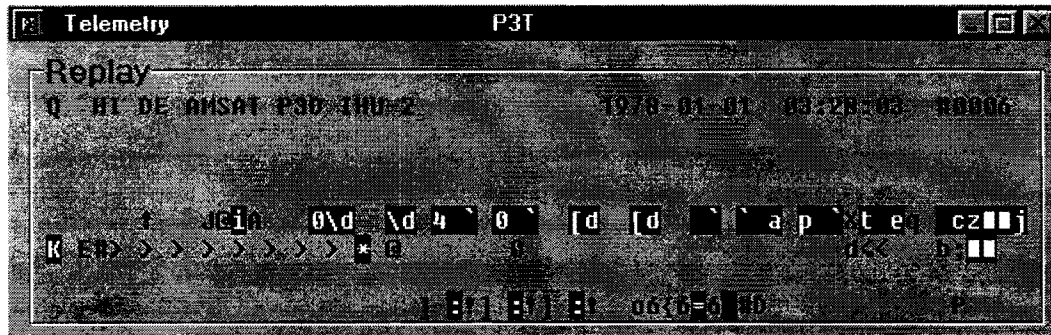
D blocks contain data dumps in 500 byte data packets plus 12 byte housekeeping bytes. These are used to transfer YACE pictures in JPEG format and experimental data.
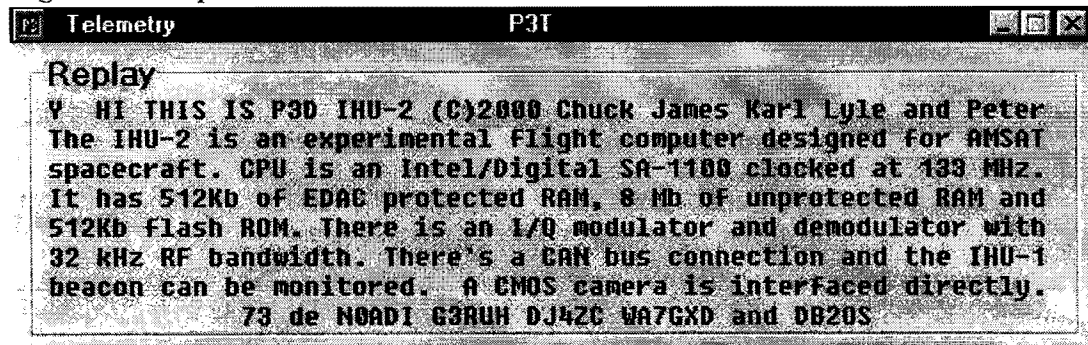
Figure H. Sample D block
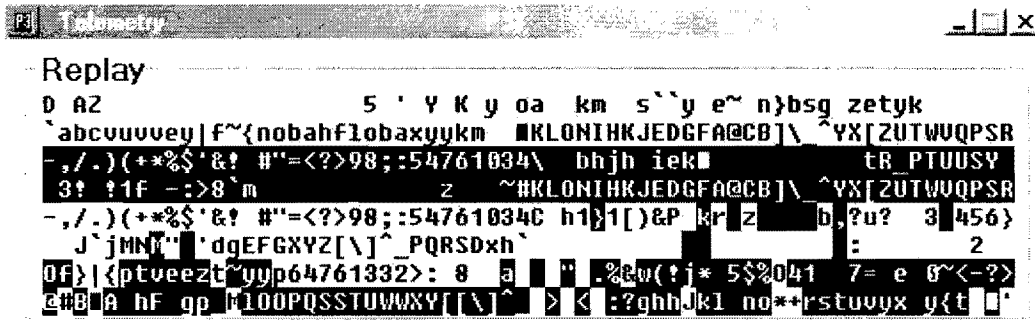
Q blocks are 'A' blocks from the IHU-2. Same format as the 'A' block, but from a different source.

Figure I. Sample Q block

Y blocks are 'K' blocks from the IHU-2. Same format as the 'K' message block.

Figure J. Sample Y block

Other blocks are command acknowledgements (CmdAcks). These acknowledge the correct reception of a command and its execution. CmdAck blocks also send Nak or not acknowledge data when the command checksum was not correct. These Ack blocks are mostly blank with data in the last line. Lines that begin with IPS-D1 signify a valid command reception by IHU-1. CmdAck blocks with data lines beginning IPS-EM mean a valid command was received by IHU-2. The date following the IPS-xx information is the build date of the flight software, and the hex number following this is the number of the command being confirmed. Each correctly received command increases the command number by one. These confirmation numbers are also found in the top line of the A blocks. Blocks with KE in the lower right signify that the CRCC failed at the spacecraft and the command was not executed.

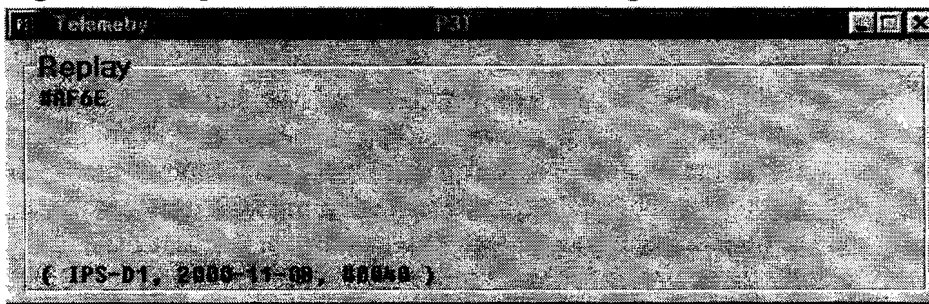**Figure K.** Sample IHU-1 Command Acknowledge block

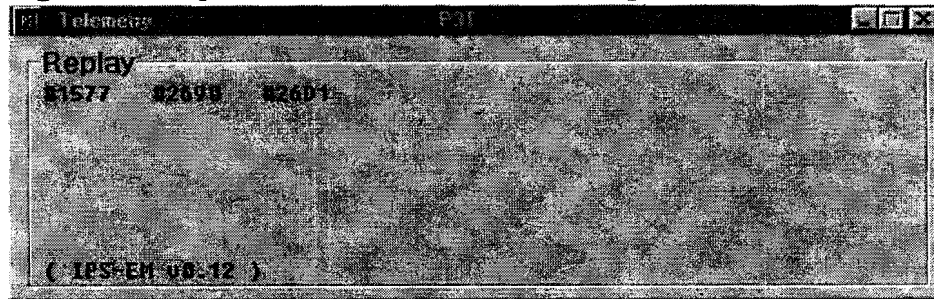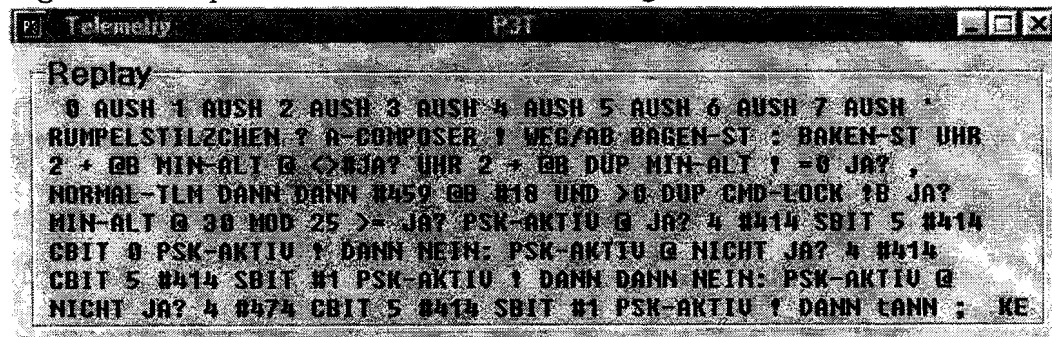**Figure L.** Sample IHU-2 Command Acknowledge block

Figure M. Sample invalid Command Acknowledge block

II.4 Typical telemetry block sequence

The A block data is very important and is transmitted every other block. A blocks contain all of the analog and digital data points. This information contains the Status, Matrix, Navigation, Power and, Temperature values as well as the hardware settings. Message blocks (K, L, M, & N) and event blocks (E) alternate with the A blocks. X, D and command acknowledge blocks are inserted into the sequence as they are received.

**Figure N. General AO-40 telemetry block sequence**

A, E(#1), A, L, A, E(#2), A, M, A, E(#3), A, N, A, X, A, E(#4),
A, K, A, E(#5), A , L, A, E(#6), A, M, A, E(#7), A, N, A, E(#8),
A, K, A, E(#9), A, L, A, E(#A), A, M, A, E(#B), A, N, A, E(#C),
A, K, A, E(#D), A, L, A, E(#E), A, M, A, E(#F), A, N, A, E(#0),
A, K, A, E(#1), A, L, A, ...

I.5 Telemetry block timing

How often the blocks are sent can be changed by the AO-40 command team. Checking the time stamps on the A blocks shows that they generally appear every 26 - 28 sec. Since the A blocks alternate with the E and K-N blocks, this makes each block occur about every 13.5 sec which agrees with block timing described in the telemetry block section. The variable can be the number of inter-block characters sent because the uProcessor is busy. Generally there are 10 A blocks sent per MA unit (256 MA units per orbit).

Sometimes it is necessary to monitor the spacecraft condition more often than every 26 seconds. So the command stations use the ALL A command to changes the block transmission sequence to send only A blocks for an hour. There is also an ALL E command to send only E blocks and a NORMAL TLM command to return to the standard alternating block format shown in Figure N. Looking at the Orbit Summary data that Paul Willmott, VP9MU compiled for orbit 370, we see the ALL A command was issued a few times during the orbit, around MA 54-59, 96, 108 and MA 113-126. See Figure O.

Figure O. A block data during orbit 370
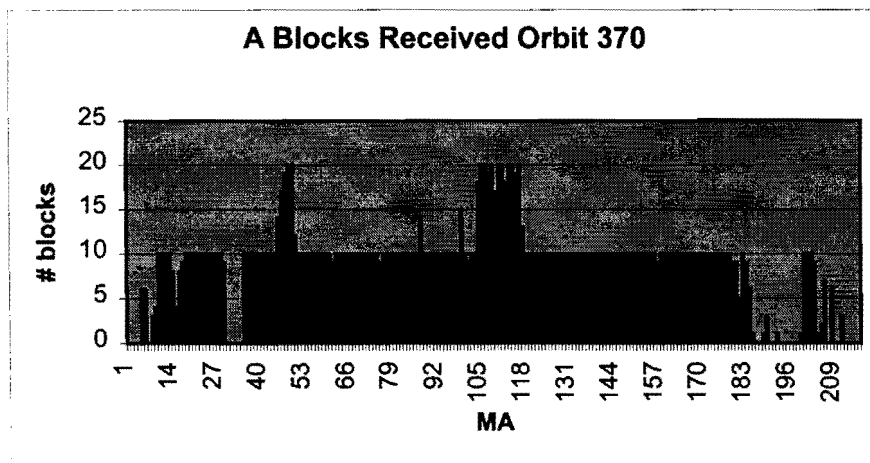
III. Telemetry transmission

The telemetry data is transmitted on the AO-40 beacons. There are three beacons, the General Beacon, the Engineering beacon and the Middle beacon. In August 2001 the S2 transmitter is the primary transmitter. The S1 transmitter abruptly stopped in August and has not been able to be restarted as of this writing.

AO-40 Beacon frequencies and information

	GB	MB	EB
13cm S2	2401.173 MHz	2401.323 MHz	2401.573 MHz
13cm S1	2400.188 MHz	2400.338 MHz	2400.588 MHz

The GB, MB and EB are generated in the IF path and feed into the matrix.. The GB and the EB are outside of the operating band for the V Tx (2m) band. The V transmitter has a filter that does not allow out of band transmissions, so the MB is inserted in to the middle of the operating band. The S2-Tx only uses the MB. Peter, DB2OS says that there were a limited number of Matrix crosspoints and the decision was made which to use. The S1 Tx was to use the GB to free some of the RF output. The MB is about 10 dB stronger than the GB. IHU-1 and IHU-2 share the MB. When IHU-2 is off the MB automatically carries the IHU-1 telemetry.
By definition the GB on the spacecraft is always ON in the telemetry. There are logically two beacons on the spacecraft the EB and the GB. The EB is copied to the MB when IHU-2 is OFF, when IHU-2 is ON it controls the MB. The telemetry reports the Beacon Mode as PSK/EB. This is a legacy issue from AO-13 when the EB also transmitted telemetry data in RTTY and CW modes, AO-40 only uses PSK.

IV. Telemetry data recovery
IV.1 Receiving AO-40 telemetry
There are three ways to receive AO-40 telemetry:
1) Receive it live off the air
2) Receive it live via the internet from the Goddard server
3) Retrieve the archive data

Unless you are familiar with satellite telemetry, the best place to start your telemetry investigation is choice #3, retrieve the archive data. Once you are comfortable using the telemetry output, you can move to acquiring it directly over the air. Otherwise you will be trying to learn two tools at once and not able to reasonably determine where any problems might lie.

IV.1.1 Receive it over the air

The telemetry data is transmitted on one of the three beacons. Most commonly this has been the Middle Beacon on the S2 transmitter at 2401.323 MHz ±Doppler. There are three basic components to receiving AO-40 telemetry:

> ➢ Receiving the signal
> ➢ Demodulating the signal
> ➢ Decoding the telemetry data

IV.1.1.1 Receiving the signal

Receiving a signal at 2.4 GHz from a satellite requires a little different approach than satellite signals from lower frequencies. Many of us haven't directly received any amateur radio signals higher than 430 MHz before, so this may be new territory. The antennas have smaller beamwidths, so they must be pointed more accurately. Transferring the signal efficiently between the antenna and the receiver is quite a challenge. Transmission line technology at 2.4 GHz is in a different league than 70cm signals. The best solution is to downconvert the signal to a frequency range that is more efficient to transmit using the more common transmission line. A very important factor that you may not have had to worry about before is Noise Figure. There have been numerous discussions on the AMSAT bulletin board and undoubtedly this will be a source of a number of papers and discussions at the AMSAT Symposium. Setting up a 2.4 GHz satellite receiving system is too large a topic to cover in this paper, so I will stick to the basics and point to references.

The basic theme is to have an antenna that receives the 2.4 GHz signal, amplify it immediately, convert it to a VHF IF (at the antenna, so as little loss as possible), then transfer the VHF signal to the receiver.

The link budget spreadsheet by Gene Marcus, W4PM/GM4YRE is an excellent tool to help you optimize your downlink (and uplink) to determine the current noise figure into your receiver and how changes will effect the noise figure. This is found at:

http://home.hiwaay.net/~mmarcus/download/ao40.xls

IV.1.1.2 Finding the telemetry signal

The 400 bps PSK modulation sounds like a 'buzz saw' or a 'roaring' sound, normally with amplitude fluctuations. An additional characteristic to help you identify the signal from 'birdies' is a tone for about 2.6 seconds every 10.5 seconds. The telemetry is 518 bytes of variable data followed by about 130 inter-block characters, then another data block. This cycle takes about 13 seconds from the start of one block to the start of the next block. The inter-block character sequence is the same character (#50), so this produces a seemingly constant tone during the time it is transmitted. Once you can recognize and tune the signal move on to demodulating the telemetry. The Doppler shift at 2401 MHz appears faster than at 70cm or 2m. I find the Doppler shift for AO-40 to run around 91 Hz per min. Each MA unit is 2.77 minutes long. My downconverter takes the 2401 MHz signal and outputs a signal on 145 MHz. Below is a chart I use to help locate the S2 MB (2401.323 MHz). These reading are taken at 36° north:

S2 MB Frequency (downconverted)	MA
145.294	10
145.296	15
145.299	20
145.304	30
145.306	35
145.312	52
145.314	58
145.316	68
145.317	74

IV.1.2 Demodulating the signal

The choices are DSP modems, G3RUH or PSK-1 modems and soundcard demodulators. I have used all three and for I don't think you can beat the AO40RCV soundcard demodulator. It has the most reliable copy over a wide bandwidth, works well with weak signals, it is easy to setup and to use, and it is free. It runs on PCs only. The AMSAT AO-40 site has excellent references and links for those wanting to use or information about DSP units, modems and the sound card demodulators. Check it out:

http://www.amsat.org/amsat/sats/ao40/ao40-tlm.html

IV.1.2.1 AO40RCV

Moe Wheatley, AE4JY, has provided the amateur satellite community an excellent tool for AO-40 telemetry demodulation. This program not only decodes the 400 bps PSK telemetry using a common PC soundcard, but saves the data in standard format for the archives, converts the telemetry data for display and can do a TCP/IP feed to P3T.

IV.1.2.1.1 Using AO40RCV as a demodulator

Simply take the audio output from your receiver (fixed audio is preferable) into the soundcard Line In. Place the soundcard in RECORD mode. Tune in the AO-40 beacon. Run AO40RCV (the current version is v1.3). When the signal is tuned in well and is strong enough, the meter on the top left of the AO40RCV display should generally display a vertical line (see Figure P). With the AO-40 telemetry beacon audio into the soundcard, click Adj. Level on the AO4-RCV top menu, this brings up the sound card 'Input Level' adjustments. Set the input level of the soundcard line in to put the AO-40 signal about half scale on the AO40RCV signal level display (the top, lined part of the display, see Figure P). The 'waterfall' portion of the display is the blue background with the white data on the bottom of the display screen (see Figure P). If the sound level is too high the waterfall data display will turn yellow instead of white. Turn the receiver audio down or reduce the soundcard input level to return to a white data display. The signal display area represents the receiver signals in a band about 15 kHz wide. The AO-40 signal consists of two main lobes (the two outer bumps around the center line in

Figure P.) that are about 8 kHz wide. The program will track the signal until it moves out of the receiver passband. So, unlike the DSP and modem demodulator that require constant tuning to produce good data, this program requires you to re-tune far less often. As always, READ the documentation that comes with the program. There are many additional features that are explained well and you should fine useful.

Figure P. AO40 RCV demodulator display
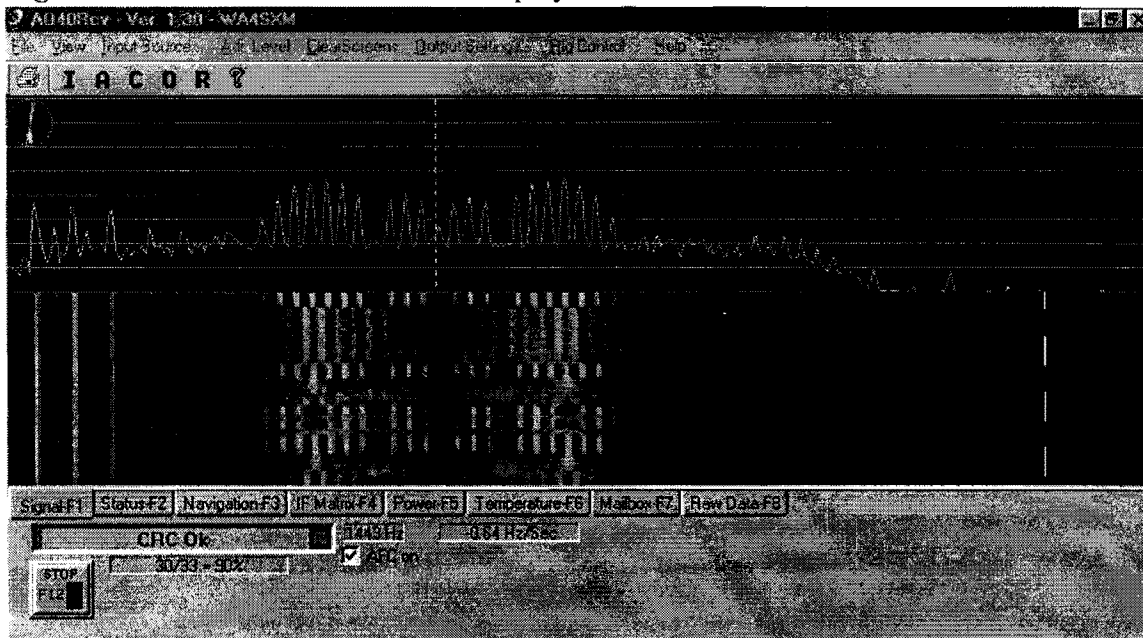
The tabs below the waterfall change the display screen. The default screen is the Signal screen (shown above). The other tabs show the decoded telemetry by group similar to the P3T software: Status, Navigation, IF Matrix, Power, Temperature, Mailbox (Message blocks). The last tab, Raw Data displays the last received block of 512 bytes as raw hex data in a table. The Signal screen also shows you the progress of each telemetry block as it is being received and the status of the last block received (CRC OK or Bad). Below the block progress bar is a count of the total number of blocks received, total CRC OK blocks and the percentage of good blocks. You can easily transfer this data directly to Stacey's P3T program for decoding and display. You must TCP/IP installed on your computer. On the AO40RCV program go to Network Server setup, Enable Server, select a port (1024 is good), select the P3T format. Next run P3T and turn on its TCP/IP as a client, use the address 127.0.0.1 and port 1024 and you should be in business. The AO40RCV Help has more instructions for

After receiving the telemetry, take the logged data file you generated, zip it and send it to the data archives at:

ao40-archive@amsat.org.

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IV.1.3 Telemetry via the Goddard Internet feed

If you don't have your 2.4 GHz receive system up or the satellite is over another part of the world, there is an extremely useful service that provides a means of getting real-time telemetry (if someone is feeding the server) – The Goddard Internet feed.

> First connect to the Internet.
> Run the P3T telemetry display program,
> Select the TCP/IP selection from the Main Menu.
> Click on Remote Client   - you will be client of the Goddard server
> Enter the Goddard server address   128.183.143.104   Port 1024
> Click the Connect button
> If you see Connect to: 128.183.143.104 at the bottom of the TCP/IP box
>> you have received an Ack from the server. If you get a connection error,
>> then Click TCP/IP Off, then Click Remote Client and Connect again
> If someone is sending data to the server, you will see the P3T boxes fill with data

Figure Q. Sample TCIP/IP connection to Goddard using P3T software
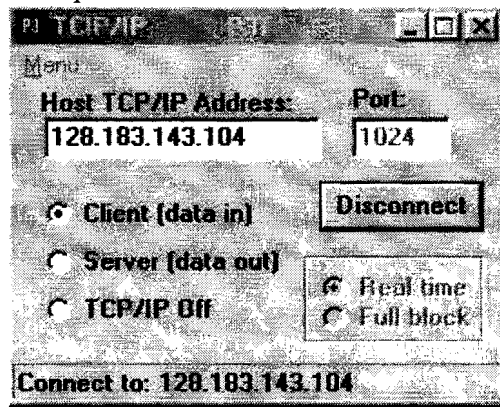
The major problem with this mode is that if no one is feeding the server, no one gets any data. Do your part, when you are receiving a good data stream, send it to the Goddard server so that others can share your data.

IV.1.3.1 Serving your telemetry to others

If you are receiving the telemetry well, it is helpful to the satellite users in other parts of the world if you become a Server to the Goddard Server. Sending your telemetry to be distributed all over the world is a very useful service and much appreciated by others not in the footprint of the satellite or without receiving equipment. If you are using the P3T software to display your received telemetry, it is a simple thing to share this data.

> Connect your computer to the Internet.
> Be demodulating AO-40 telemetry live
> Run the P3T program
> Select TCP/IP from the main P3T MENU,
> Select Server [data out], if there is no data to decode the bottom of the box will
>> say listening…
> Setup the Goddard address and port as above
> Click the Connect button.

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If Connect to: 128.183.143.104 shows up in the bottom of the TCP/IP box, you are connected and serving the world

IV.2 The AO-40 Archives

Paul Willmott, VP9MU leads a group of about 50 stations worldwide that operate as the main capture stations for AO-40 telemetry. They are known as the telemetry group. This dedicated, unpublicized team of volunteers is the reason that we have such a complete data archive of AO-40 telemetry and the reason that we know so much about what is happening on the spacecraft. They collect data all hours of the day, zip it up and email it to Paul who collates the data for every orbit for the telemetry archives. Thanks, Paul. .

The telemetry group contributes about 80% of the data found in the telemetry archives. So, it is very important that other stations contribute to the archive to maintain as complete a record as possible. A through description on capturing data and contributing to the telemetry archive is found at:

        http://www.amsat.org/amsat/sats/ao40/capture_notes.txt

IV.2.1 Basic settings for contributing to the archives
All stations worldwide are encouraged to capture and submit AO-40 telemetry data
Use AO40RCV or P3T to capture telemetry because these programs capture the data in the preferred format   Paul prefers to have the raw files only (CRCC OK and CRCC Bad in one file) rather then separate .raw and .tlm file (duplicate data).
Basic settings for capturing data for the archives are:

        514 byte modem (to capture the checksum)
        Ignore CRCC (to save all blocks received, regardless of CRCC)
        Capture All blocks (so that the WOD blocks can be included)

IV.2.2 The archive files
The archives contain only CRCC OK files, except for a few passes in late Dec 2000. All of the raw data files submitted are burned onto CDs by Paul to maintain a true archive of the received data. Paul reported that sometimes the command stations request the raw files to help them look for clues to problems encountered aboard the spacecraft. The archive data do not have the CRCC bytes included, since the blocks have already been checked. All of the blocks from the archive are 512 bytes. The blocks directly follow one another, they are not separated by End of Record or CR/LF characters.

The archive files are available from both ftp and http downloads.

        ftp: ftp://ftp.amsat.org/amsat/telemetry/ao40
        http: http://www.amsat.org/amsat/ftp/telemetry/ao40

If using a browser to retrieve them I suggest the HTTP location, if doing a direct ftp, then use the ftp site. The files are organized in directories by year and by month, then by filenames that specify the satellite, date and orbit.

Figure R. Sample Archive http: data listing for July 2001
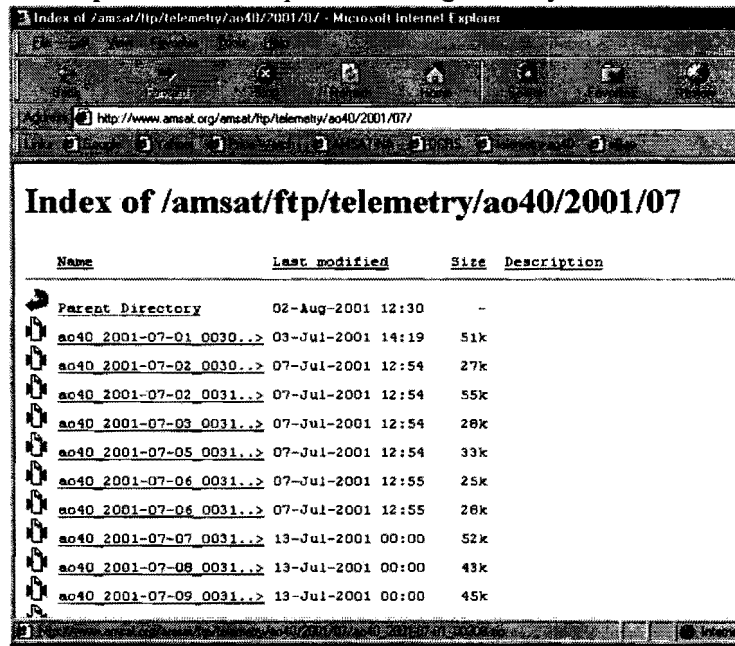
Even though the orbit number is not visible, placing your cursor over the filename will display the complete filename at the bottom of the browser. Clicking on the underlined filename should start the download into your machine.

Sample archive file name: ao40_2001-08-19_00370.zip

The file name tells us that this is AO-40 telemetry from 19 Aug 2001, orbit 370

IV.2.3 The Archiving Process

Paul does two main merge runs per day, at 6:30am and 5:30pm (more if requested). Each merge process takes about 25 - 40 minutes per session, depending upon the amount of data to process.

IV.2.3.1 Paul's Merge process:

1) Unzip the files into a \to be processed directory
2) Manually inspect the submissions and delete junk - like text messages and data that is in non-archive format
3) Rename raw files into the standard format -

TYYMMDDA-NNN@*callsign*.RAW

T - mixed block
YYMMDD - date
A,B,C,... - multiple files from the same callsign for the same orbit
NNN - orbit number
callsign - callsign of submitting station, unique name if SWL or GSFC
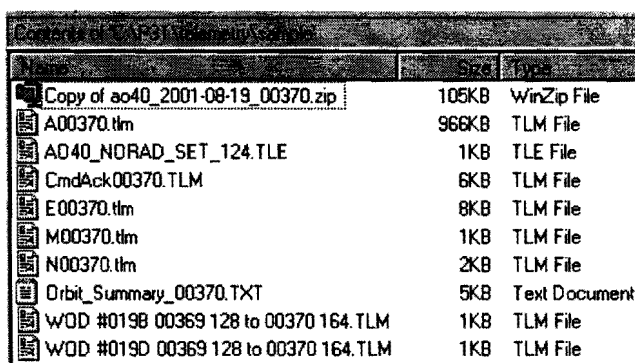   if received from the Goddard feed

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4) Run a merge program which Paul wrote to:
   a) Reads all files to be processed,
   b) Filters all CRCC OK A blocks by orbit number and stores them in a separate directory by orbit number
   c) Read all files from the \to be merged directory
   d) Remove duplicate blocks, each block type has its own file, these are checked and sorted to remove duplicates
   > A blocks separated and ordered by UHR date/time
   > D blocks separated by internal CRCC, no order
   > K, L, M, N, CmdAcks, Q, Y and E blocks by re-calculated CRCC

5) After all files have been processed, Paul extracts the most up to date WOD entries from the K and L blocks and stores them in a unique file named by Channel ID and start/stop orbit/MA. This has proved to be very helpful for the command stations.

6) If there are D blocks, Paul feeds the original raw data into another utility that displays the number of D blocks downloaded and whether there are any missing blocks in the sequence. If any are missing he manually, bit merges the bad CRCCblocks to build good blocks (there is an internal checksum). Once the D block sequence is complete, he writes the D blocks to files with the format :   DNNNNN_JA.TLM
   > D - D block data
   > NNNNN - orbit number
   > JA - the D block file ID, one file for each sequence
   D block format and decoding information is found in the telemetry spec. If the D blocks contain data that needs further processing (JPEGs or A blocks from the IHU-2). The IHU-2 can capture 2 days worth of A blocks from IHU-1 and download them on request. Paul says this was used quite a bit during the ATOS firings. The JPEGs are extracted using his D block utility, zipped and put into the orbit directory.

7) Paul sorts the best keps for the orbit either from NORAD/OIG or from the ranging keps and places them in the orbit directory.

8) A utility is run that reads the A block files and produces the orbit summary text file (look at one of the summary text files with a text editor or import it into a spreadsheet program, see Figure C). He then combines all of the files for that orbit and produces the zip file for the archive.

The zip file for each orbit contain some or all of these components:
> A, E, D, WOD, CmdAck, Q, Y blocks
> Zip file with JPEGs
> Summary Text file
> Latest Keps (for historical analysis)

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Figure S. Representative files in one AO-40 orbital zip from the archives

Name	Size	Type
Copy of ao40_2001-08-19_00370.zip	105KB	WinZip File
A00370.tlm	966KB	TLM File
AO40_NORAD_SET_124.TLE	1KB	TLE File
CmdAck00370.TLM	6KB	TLM File
E00370.tlm	8KB	TLM File
M00370.tlm	1KB	TLM File
N00370.tlm	2KB	TLM File
Orbit_Summary_00370.TXT	5KB	Text Document
WOD #019B 00369 128 to 00370 164.TLM	1KB	TLM File
WOD #019D 00369 128 to 00370 164.TLM	1KB	TLM File

9) Finally, Paul emails the zipped archive file to the command stations, the
   telemetry group and to the ftp site. Paul, KB5MU manually places the
   files into the ftp site for everyone to download.

10) In addition to these regular tasks, Paul also does multiple orbit extracts for the
   command stations as needed. This is how James Miller, G3RUH
   determined that he could use the spacecraft temperature as a sun sensor.
   See James Miller's Executive Summary 24 Apr 2001 at
   http://www.amsat-dl.org/journal/adlj-p3d-01-3.htm

IV.3 Decoding the Telemetry

The data sent in the 512 byte blocks is RAW data. These are hexadecimal values that
relate to specific data points and status by their position in the block. Each raw analog
data value must be converted by its own translation equation to the actual value that it
represents. Although a number of temperature sensors are exactly the same part number,
each records the same temperature as a slightly different value. The same is true for the
current and voltage sensors. During the construction of the satellite and with a final
tweaking in Kourou, Stacey Mills, W4SM determined the values that would normalize
these sensor readings and has converted them into a translation equation for each analog
channel.

IV.3.1 Decoding the Analog channels

Looking at the sample RAW telemetry block in Figure T. The first byte is #41, this is the
ASCII character A, followed by a #20 the ASCII space character. This is an A block.
Read the data from the hex value on the left for each row, then add the value at the top of
the column to the row value to locate a specific byte. We know from the telemetry
specification that the V Tx temperature is location #15E. Using Figure T., go to row
#150, over to column #0E where the value is #9F. This corresponds to a decimal value of
159, this is not a temperature of 159°C. The raw value must be converted to the actual
temperature value we seek.

To find these translation equations go to the telemetry specification, analog section, down to channel #15E. The V Tx temperature is Temp 31 and the translation equation is:

```
T = 0.659 * X -69.7
T = 0.659 * 159 -69.7  (order of operations, * first)
T = 104.781  - 69.7
T = 35.08°C is the current temperature for the V Tx.
```

As some of my favorite professors used to say, "I will leave the rest of the calculations for you to do as an exercise." Of the remaining 127 analog values, 15 are not assigned and 8 more were rendered invalid by the December incident. It is a nice exercise for you to do a few of these to satisfy yourself that you understand the concept and more importantly you can demonstrate it.

Figure T. Sample Raw A block data from the P3T program Monitor selection

```
Byte Dump                        P3T

    | 00  01  02  03  04  05  06  07  08  09  0A  0B  0C  0D  0E  0F
--------------------------------------------------------------------
000| 41  20  20  48  49  2C  20  54  48  49  53  20  49  53  20  41
010| 4D  53  41  54  20  4F  53  43  41  52  2D  34  30  20  20  20
020| 20  20  20  20  32  30  30  30  2D  31  31  2D  31  38  20  20
030| 31  33  3A  32  35  3A  35  30  20  20  23  30  30  33  46  20
040| 28  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D
050| 2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D
060| 2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D
070| 2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  28
080| 7C  20  28  20  41  4F  20  34  30  20  69  73  20  61  6C  69
090| 76  65  20  61  6E  64  20  77  65  6C  6C  21  21  20  20  20
0A0| 20  20  37  33  20  66  72  6F  6D  20  74  68  65  20  41  4D
0B0| 53  41  54  20  50  33  44  20  54  65  61  6D  20  20  20  7C
0C0| 2B  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D
0D0| 2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D
0E0| 2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D
0F0| 2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2D  2B
100| 84  07  07  0B  15  07  84  0E  24  19  4B  BB  B8  BA  AC  9E
110| AC  A4  AB  07  07  07  07  07  24  23  0B  07  07  07  0B  43
120| 43  BC  07  7E  81  07  07  59  6A  AE  62  29  24  07  07  07
130| 07  07  07  07  07  07  07  07  07  07  09  0B  14  1E  2A  2F
140| 78  8B  7C  83  07  8E  85  82  8E  89  8B  86  6A  7F  8B  7F
150| 7F  6B  7D  8A  8B  1C  7F  8B  82  8B  87  86  86  1C  9F  84
160| 1C  74  A3  82  7E  7F  86  87  8A  83  86  8C  8A  7F  83  8F
170| 3F  07  57  8B  07  2A  0E  99  1E  07  07  07  07  8B  8B  8B
180| 0B  00  00  00  0B  FF  00  00  C0  86  40  B5  0D  13  0B  0B
190| FF  0E  03  83  20  07  85  05  11  B5  00  8B  0B  18  01  01
1A0| 01  7F  0C  16  01  11  05  0B  18  32  19  8D  A5  20  01  00
1B0| 0B  00  01  00  B0  00  01  00  00  0B  01  00  00  00  00  00
1C0| FE  5F  FE  5F  FE  5F  50  00  00  03  00  0B  00  78  00  00
1D0| 00  00  00  00  00  00  00  3F  00  82  03  00  00  7C  08  00
1E0| 3F  00  00  00  05  00  00  20  00  00  00  00  00  00  00  00
1F0| 00  00  00  10  00  20  00  30  00  40  00  50  40  60  00  70
```

Of course, you can check your answers in the P3T program. Select some interesting analog channels from the telemetry specification, get an archive file, unzip it, replay an A block, bring up the temperature window (or any of your choice), select the Monitor function, click on the Data Window box and a window like the one in Figure T. pops up for the corresponding A block. Follow the same process as I did in the example.

IV.3.2 Decoding the digital channels

The digital channels, bytes #180 to #1FF are a fairly straight forward bit decoding operation - if you are familiar with binary operation.

If you are not familiar with the binary conversion from hex, I will leave this as an exercise also. Anyone that is interested and cannot find out how to do this, send me an email and I will gladly send you an explanation and work with you. I feel that I can probably handle this additional traffic from both of you.

The IF Matrix settings reside in the digital area, so let's use one of these as an example.

Bytes #1F0 - #1FF are used for IF Matrix settings, these are not part of the IPS kernal software, but maintained by the flight software. This concept is new with AO-40 and not part of the original IPS system design. Looking at Figure T. again, we see that byte #1FC has a value of #40. This converts to a binary pattern of (bit 7)MSB 0100 0000 LSB(bit 0). The bits that are set or equal to 1 are active. Bit 6 is set in this example. From the telemetry specification we get channel #1FC:

```
#1FC IF matrix column 6   bit    significance
                          ------------------
                          0 LSB  L2 Rx to V Tx
                          1      L2 Rx to U Tx
                          2      L2 Rx to S1 Tx
                          3      L2 Rx to 3 cm Tx
                          4      L2 Rx to K/S2 Tx
                          5      L2 Rx to Leila#2
                          6      MB to V Tx
                          7      MB to U Tx
```

we see that bit 6 corresponds to MB to V Tx. This data was from an A block on orbit 5 when the V or 2m transmitter was operational. The Middle Beacon was transmitting at the time on the V transmitter.

Another digital example this time using byte #188, Experiment control. From Figure T. byte #188 has a value of #C0, the binary value for this is (bit 7)MSB 1100 0000 LSB(bit 0).

```
#188   Experiment          2MUX[8]
       control              bit    significance
                           ------------------
                           0 LSB ARU ON       (Array Release Unit)
                           1     Rudak ON
                           2     GPS ON
                           3     Mon Rx ON
                           4     A CAM ON
                           5     B CAM ON
                           6     Cedex control ON
                           7 MSB Cedex power ON
```

Bits 7 and 6 are set which says that the Cedex experiment must be on. Since this is an IHU-2 experiment, IHU-2 must also be on. We check channel #1C9. It has a value of #03 which converts to binary (bit 15)MSB 0000 0011 LSB(bit 8).

```
#1C9 Transmitter         8      IHU-2  ON
     control -hi          9      V  Tx  ON  )  Only one may be
                          10     U  Tx  ON  )  on at a time
                          11     S1 Tx  ON
                          12     ---
                          13     X TWTA ON
                          14     Ku Tx  ON
                          15 MSB ---
```

Bits 8 and 9 are set, so this confirms that IHU-2 is on and that it is using the V Tx which we already know to be active. Voila!

This is how the analog and digital telemetry is decoded manually. It is common to get 2300 A blocks per orbit and with the additional message and event blocks these can easily combine for more than 3400 blocks per orbit. It would be a full time job to manually convert and analyze this much data, Stacey Mills has once again provided us with an outstanding tool – P3T (Phase 3 Telemetry) software. This program automatically decodes the 512 data bytes and neatly organizes them into logical groups in separate windows. Input demodulated, raw AO-40 telemetry data and the P3T software elegantly displays the data groups in realtime, as well as logging this data to a standard archive format file. Let's explore these and many other features that P3T has to offer.

V. Telemetry data display, recording and analysis

V.1 P3T telemetry display software

The current version of the P3T software in August 2001 is v1.4c. This is found in the P3T Main window, Help, About. This software can be downloaded from the author's site listed in the **Useful AO-40 telemetry information sites** section. After unzipping, installing and setting up P3T, you are ready to decode some telemetry. Instructions on accomplishing these first three feats are found in the P3T documentation and in both the AMSAT Digital and Analog Satellite Guides. The first window that pops up upon running P3T is the Main P3T window,

Figure U1. P3T Main window

The Main window allows access to all of the major features of P3T:

Input – shows the live receiving status of blocks and CRCC
    status either Good or Fail
Setup – change the initial Setup choices
DSP Load – load an external file for 400 bps PSK telemetry
    into a DSP modem
Logging – change the logging status of the telemetry
Monitor – select specific data changes to monitor
Replay – archive or logged files from the telemetry directory
Filter – choose file filtering characteristics for replay
TCP/IP – connect to receive or send telemetry data
Help – operational documentation and descriptions
Text selections- pick specific message blocks or all message
    blocks
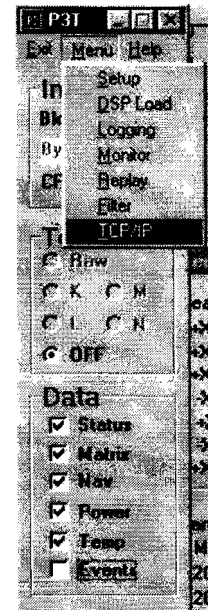
V.1.1 P3T data windows

    Telemetry
    Status
    Matrix
    Navigation
    Power
    Temperature
    Events

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V.1.1.1 P3T Telemetry window

Once live data or Replay data is available to P3T the Telemety window opens and displays the received blocks. The Text setting determines which blocks are displayed. The Text selection should be Raw to display all of the message blocks that arrive via live, TCP/IP data or Replay of saved or archive data. If the block is bad, the block type should be in inverse character mode.

Figure U2. Telemetry window with A block data
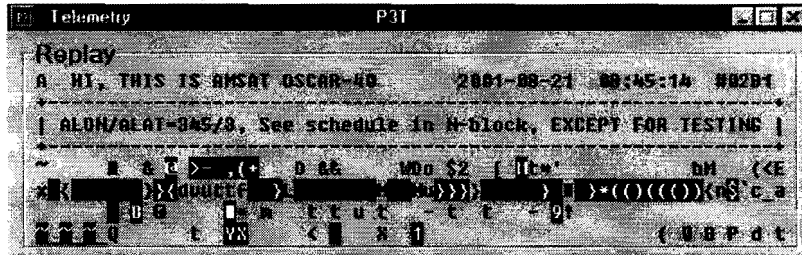
The P3T data windows display the decoded telemetry items grouped by the major categories list.

V.1.1.2 P3T Status window

The Status window is the general purpose window that displays the basic information about the satellite such as the date and time the last A block was received, current satellite MA and orbit. There are eight additional areas that appear in the Status window.

Figure U3. Sample P3T Status window
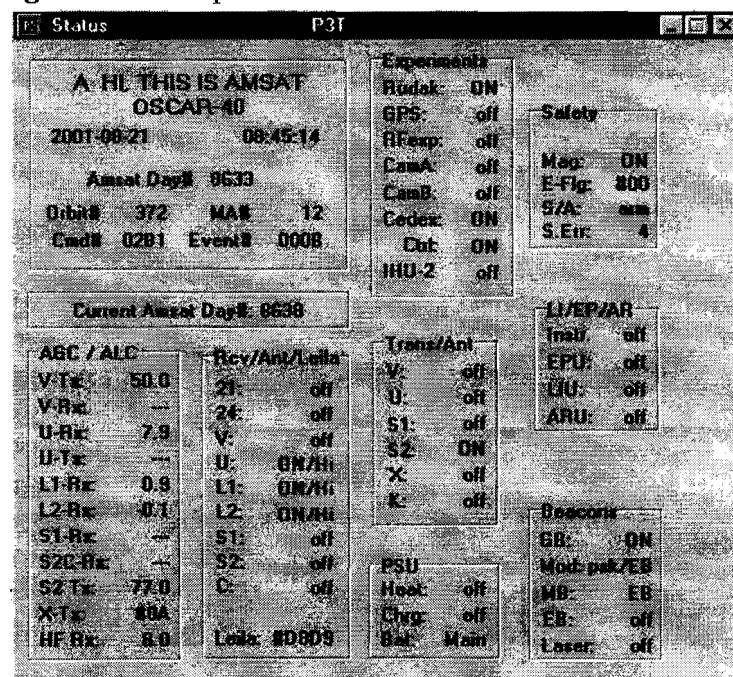
The abbreviations used in the telemetry windows can be found in the Glossary at the end of the telemetry specification. This Glossary is a must have at your fingertips item if you are interested in AO-40 and its telemetry.

The 8 major sub-items in the Status window are the :

AGC/ALC values for the receivers and transmitters;

Rcv/Ant/Leila - receiver, receive antenna and Leila status;

Trans/Ant - transmitter selection and transmit antenna;

Experiment – onboard experiment status;

PSU (Power Supply Unit) status;

Safety – magnatorquer, emergency flags, safe/arm plug for
the 400 N motor, soft memory errors;

Li/EP/AR - 400N motor ignition, power and electronics for ATOS,
solar panel release; and

Beacons - current Beacon status.

V.1.1.3 P3T IF Matrix window

The IF Matrix window displays the current receive, Leila and transmit selections for the spacecraft. These are read as inputs from the left to outputs on the bottom. Receivers connected to Leila on the bottom then become corresponding inputs on the left which lead to their selected transmitter. See Figure U4. Here the U (70cm) receiver is connected to Leila 2 as an input, so follow Leila 2 from the left side to the S2 transmitter as the output. The L1 receiver is tied directly to the S2 transmitter without going through Leila. The MB is also connected to the S2 transmitter. Referring back to Figure U3, notice that the U, L1 and L2 receivers are all on, that is why they are red in this display.

Figure U4. P3T IF Matrix window and Temperature window
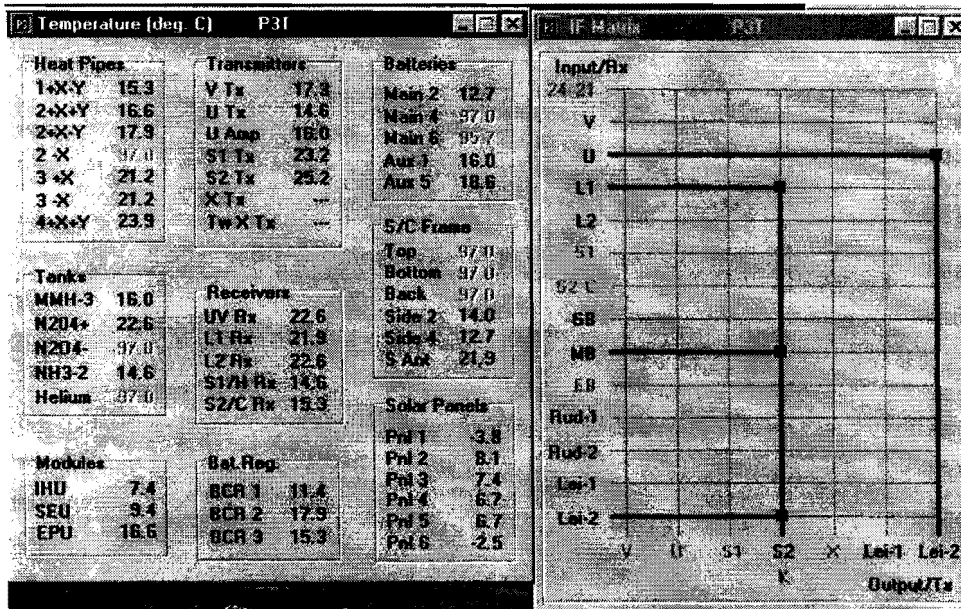
V.1.1.4 P3 T Temperature window

The Temperature window has the 9 areas grouped for temperature display. There are 37 active temperature sensors in the spacecraft. Refer to the analog sensor location drawings in the Appendix to get a graphical idea of where the temperature sensors are located and how these temperatures are physically related. The eight temperature values that are gray,

are no longer valid; they are victims of the December event. The temperature groups are the:

Heat Pipes – pipes that transfer heat between the six sections of the spacecraft;
Tanks – the fuel Tanks;
Modules – the IHU computer, the SEU (sun and earth sensor unit) and the
      EPU(power supply and electronics for the ATOS motor);
Transmitters – the various transmitters;
Receivers – the spacecraft receivers;
Bat. Reg – the battery regulator units;
Batteries – the Main and Aux batteries (numbers are the spacecraft sections
      That identify where the batteries are mounted);
S/C Frame – spacecraft frame;
Solar Panels – the solar panel temperatures.

V.1.1.5 P3T Power window

The Power window displays the items associated with the power system. These are mainly concerned with voltage and current values. There are 56 active voltage measurement on AO-40 and only 3 active current measurements. The December event eliminated 9 of the 12 current measurements. The analog sensor location drawings in the Appendix are also useful in finding the voltage and current sensor locations. The Power window is divided into 6 basic areas, 3 of these are the battery charge regulators(BCR) units. Although many of the systems are critical, the BCR and the IHU determine whether there is an operational satellite or not.

Figure U5. The P3T Power and Navigation windows
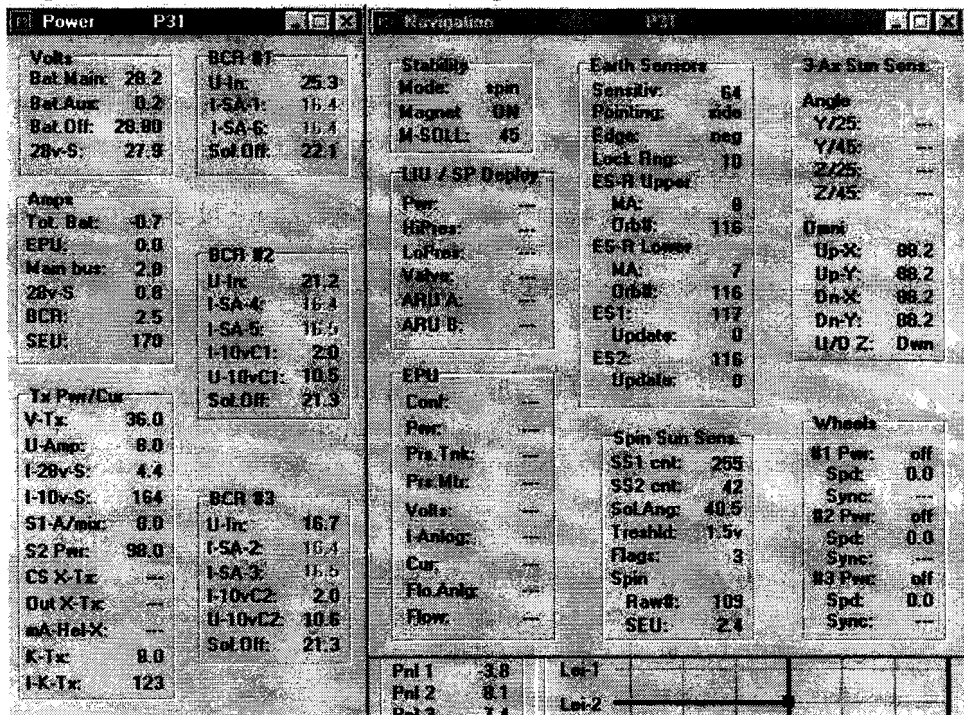
The six Power groups shown in the P3T display are:

> Volts – Main and Aux batteries, Battery offset (a digital selection) and the 28 volt bus voltage

> Amps – all done with voltage measurements, for the total battery current, the ATOS motor power supply and electronics, the main bus current, BCR current and the sun and earth sensor unit(marked invalid in the telemetry spec);

> Tx Pwr/Cur – transmitter power and current usage for the various transmitters on the spacecraft;

> BCR #1 – U-In is voltage in to the BCR from the solar panels 6 & 1 and the array voltage offsets determined by digital values;

> BCR #2 – voltage in from solar panels 4 & 5, the 10v power supplies and the array voltage offsets determined by digital values;

> BCR #3 – voltage in from solar panels 2 & 3, the 10v power supplies and the array voltage offsets determined by digital values

V.1.1.6 P3T Navigation window

The Navigation screen is mainly concerned with the spacecraft attitude, magnetorquing, spacecraft stabilization, spin rate, operation of the momentum wheels and operation of the ATOS motor. See Figure U5. There are seven areas grouped on the navigation screen, they are:

> Stability – Mode of spin stabilized or 3-axis stabilized, Magnetorquer On or OFF, M-soll is magnet vector desired angle to the de-spun sun;

> LIU/SP Deploy – Liquid Ignition Unit electronics that control the 400N motor, Solar Panel deployment for array A and B (panels 2 & 3 and panel 4 & 5);

> EPU – Electric Propulsion Unit are power supply and electronics for the ATOS thruster;

> Earth Sensors – the earth sensors work in conjunction with the Sun sensors;

> Spin Sun Sensors – work in conjunction with the Earth sensors to determine the spacecraft attitude and magnetorquing;

> 3-axis Sun Sensors – these sensors work when the 3-axis stabilization system is in place, the magnetic reaction wheels;

> Wheels – the three magnetic reaction wheels, used for 2-axis stabilization.

V.1.1.7 P3T Event window

The Event selection cause all displayed windows to switch to the latest event state and display the values during that event. Turning this off returns the windows to the last A block display. Once an event block has been received the Events selection turns blue.

V.2 Data Recording

As mentioned before both AO40RCV and P3T offer data logging features. The P3T program will select auto logging with one click during setup. AO40RCV allows you to enable this feature with only a few clicks and your callsign entry.

V.3 Data Analysis

Telemetry analysis is the most challenging area of telemetering. The command team must make major decisions using only limited data. They must be experienced, very creative and thoroughly knowledgeable about the entire spacecraft system. The key concept here is system. No part of the spacecraft acts independently; they all depend upon other pieces of the system to be able to accomplish their function – just as the human body does. A change to any piece of the system will ultimately effect other pieces of the system. These interactions provide the interesting and challenging aspects of satellite command.

The ground control stations have only the A and E block data generated by the spacecraft every 13 seconds to diagnose and try to correct any problems. The AO-40 command team has demonstrated numerous times their creativity in diagnosing problems and finding alternative ways to gains information about the spacecraft. Just as in life, work and family it is the unexpected that presents the greatest challenge to the command team. They have assembled numerous contingency plans and thought through many scenarios, but there are always surprises. It is up to command team to determine the cause, weight the consequences of different responses and ultimately make the best decision at the time. Sometimes this must be done in a short period of time.

To be able to make informed decisions the command team has devoted countless volunteer hours to understanding the different spacecraft systems and their interactions. It is necessary to have long term knowledge of how the spacecraft performs under many different conditions, i.e. different attitudes, different sun angle, different power generation and usage situations.

So, the point of this is for those beginning to analyze telemetry not to take a particular reading or series of reading during one orbit and come up with a conclusion. It is important to have some long term knowledge about that particular data point and its interaction with and dependencies upon the other systems aboard the spacecraft. Learn as much as you can about as many spacecraft systems as possible. This means read about the hardware design and operation, the particular requirements for that part of the system and how other parts of the system effect it and it effects other parts of the system.

V.3.1 Telemetry analysis using P3T

Stacey has provided an excellent analysis tool in the P3T software in addition to the decoding, display, logging, serving, filtering and

Basics in using P3T for analysis

1) Hold the mouse cursor over any telemetry title and the hex/decimal address of that data channel will appear after a couple of seconds. The example below show the addresses for the V-Tx channel.


Telem. addr = #124/292
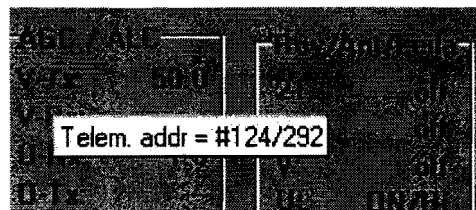
2) Double clicking on a channel name will bring up the Graphic Data Byte box that allows a quick graph of the selected data channel. This box does not remind you which channel you selected, but simply clicking OK will bring up the labeled graph of the data channel. The Start and Stop Blk # 's allow you to choose the scale of the graph. The X axis is the number of MA units recorded in the selected number of blocks. Raw and Translated determines whether you graph the data as Raw values read directly from the telemetry data or translated into the actual units (volts, temperature, current).
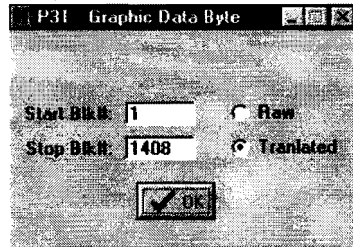
3) Clicking OK on the **Graphic Data Byte** box brings up a graph of the selected data channel in a new window. Figure V. show the graph of the Temperature of Heat Pipe # 1 in the +X-Y area of the spacecraft. See the Telemetry Sensor location drawings in the Appendix to give you a better idea of the location of this temperature sensor.
The selected range is the same as the Graphic Data Byte box above from Blk #1 to Blk #1408, Translated data. Additional functionality is provided by moving your mouse cursor over the graph. As you move horizontally the current location BLK # will change in the top right and as you move vertically the actual vertical value of the cursor (not the data in the graph) will change in the Value display in the upper right. The Block and Value displayed in Figure V. had the cursor point at the top of the fluctuations in the center of the graph. Clicking anywhere on the graph will bring up the Graphic Data Byte box. Here you can change the scale of the graph to examine a specific area more closely or see what happens over a longer period of time.

Figure V. Sample Data Graph from the P3T program
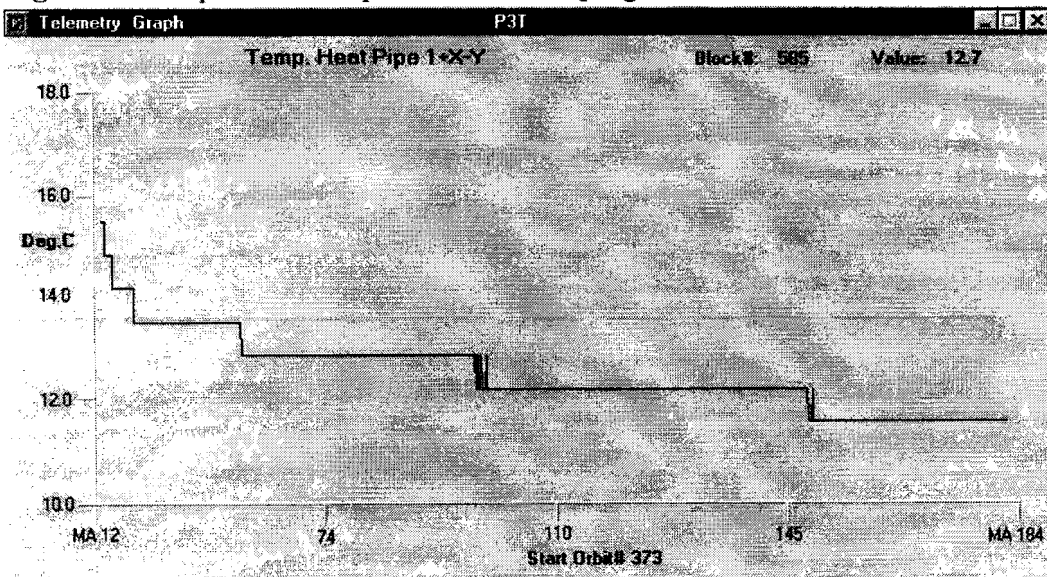
3) P3T Monitor function

This useful and powerful feature allows the user to select up to 10 specific channels to monitor the raw values for each incoming block or in Replay mode. The channel selection can be entered in hex or decimal manually or by simply clicking on a location in the Data Window (see Figure T). Only data in 'A' and 'E' blocks will appear in the Monitor window. Data can be displayed a either decimal, hex or binary and in byte or word format. The Data Window will open and close as you click the Data Window checkbox at the bottom of the Monitor window.
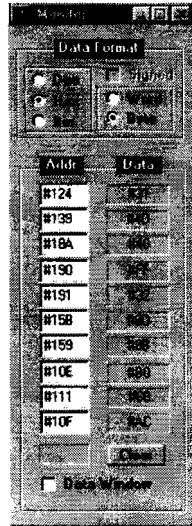
4) Exporting telemetry data

Windows allows you to capture a screen graph , save it into a paint program, capture another graph add it to the save file and compare these graphically. Although possible this is not practical. It often necessary to have data from several data channels during the same orbit to look at for patterns or interactions. To do this it is necessary to Export the telemetry data to a spread sheet. Here you can look for traits in specific data channels over several orbits, compare and graph these. P3T provides this feature as part of the Replay function. You can use archive data or data that you logged. This feature will take up to 8 data channels and export them as ASCII, comma delimited data. Simply enter the desired channels and any appropriate bit masks(if you are interested in digital channel data) and click the Export button. An ASCII file named 'export.txt' is created in the Telemetry subdirectory. Once you import this data into the spreadsheet you are ready to export more data. The next export operation will overwrite the last 'export.txt' data, so save it as another filename if you need to save the data.

Figure V2. Sample export.txt data

```
Blk#, Amsat Day, Telem. addr. = #124, #139, #18A, #191, #190, #10E, #111, #10F
-------------------------------------------------------------------------
1, 8634.16015, 50.0, 77.0, 64.0, 50.0, 255.0, 128.0, 162.0, 169.0
2, 8634.16046, 50.0, 77.0, 64.0, 50.0, 255.0, 125.0, 148.0, 170.0
3, 8634.16109, 50.0, 77.0, 64.0, 50.0, 255.0, 175.0, 138.0, 170.0
4, 8634.16139, 50.0, 77.0, 64.0, 50.0, 255.0, 176.0, 132.0, 171.0
5, 8634.16201, 50.0, 77.0, 64.0, 50.0, 255.0, 176.0, 172.0, 135.0
6, 8634.16264, 50.0, 77.0, 64.0, 50.0, 255.0, 176.0, 171.0, 135.0
7, 8634.16544, 49.0, 77.0, 64.0, 50.0, 255.0, 176.0, 134.0, 170.
```

V.4 Recommendations for aspiring telemetry analysts

Select a specific area of interest in the operation of the spacecraft. Learn as much about that area as you can. Ask questions, read material and develop a understanding about how those systems work. Study the telemetry for the data channels related to that area over a long period of time. Examine the telemetry and make observations, then test those observations. You very likely will come upon some unknown or not completely understood operational characteristic of the spacecraft.

V.5 Additional system information useful for telemetry analysis

Batteries – Main battery is NiCad, Aux battery is nickel metal hydride(NiMH). August 2001 sees the Aux battery offline and off trickle charge to .prolong its life.

Heat pipes – will not function correctly and transfer heat if the spacecraft is spinning too fast. 10 RPM or less is acceptable for heat pipe operation. The S2 Tx temperature went from 36° C to 20° once the spacecraft slowed down.

Hibernation – a period when the Sun sensors cannot see the Sun, the Sun angle to the spacecraft Sun sensors is >45°. This deprives the controllers of attitude control via magnetorquing. The magnetorquing software requires Sun sensor data to prevent continual magnetorquing to put the spacecraft in a bad attitude
Hibernation #1 Jan/Feb 2001 orbits 89-149
Hibernation #2 Apr 2001   orbits 202-228

MA in the telemetry – Keplerian elements are uploaded to the spacecraft to compute its location and MA. The MA sent in the telemetry may be a little different than what you see on your tracking program.

Magnetorquing – takes place around perigee. The magnets are pulsed for a few seconds at a time, causing the 28V bus voltage to lower for a short period, causing a shift in the beacon audio.

PSU (Power Supply Unit) – has four states
    1) Main & Aux batteries connected to the 28V bus and the BCRs
    2) Main only batteries connected to the 28V bus and the BCRs
    3) Aux batteries connected to the 28V bus and the BCRs
    4) Charge On, the un-connected battery can be trickle charged or not.

Nyquist rate – is the minimum sampling rate to fully describe a signal or event. It is necessary to sample an object at greater that twice the rate of any expected/detected problems. This factor makes it very difficult to determine almost any problems with AO-40 since systems are being sampled about every 26 seconds. For instance, to determine a spin rate of 7 RPM, a sample must be taken at a minimum of 14 times a minutes, 21 times a minute is preferable (this is every 2.8 seconds). Alternative methods must be employed to determine periodic events aboard AO-40.

S1 vs S2 antenna – the S1 antenna is highly directional and not very useful at squint angle > 35-40°. The helical S2 antenna has less gain, but a wider beamwidth.

SEU on Navigation screen – this is the spacecraft calculated spinrate in RPM.

Solar panel temperature/voltage – panels 1 and 6 are permanently attached to the spacecraft. They have half the solar cells of the other panels and have reflective tape to aid in thermal balancing. The fact that they have fewer cells, different backing and reflective tape means that the voltage will be different and their temperature will be different compared to the deployable panels 2, 3, 4 and 5.

Solar panel temperature profile – from work by James Miller, he has found that the average solar panel temperature for panels 2,3,4 and 5 can be used to predict the spacecraft attitude when the Sun sensors are at an angle of >45°.

Sun Angle – The angle between the Sun's direction and the spacecraft's spin equator. A Sun angle of 0° means maximum illumination on the solar panels. A Sun angle of 90° means the Sun shines directly on the top or bottom of the spacecraft,

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providing no direct illumination of the solar panels. The goal is to keep the Sun angle between +/- 45°.

The temperature of the entire spacecraft decreases as the Sun angle decreases. As more of the top or bottom of the spacecraft is exposed to the Sun, the higher the spacecraft temperature.

Time in the telemetry – this is computed by the spacecraft and may differ from UTC at times. Called UHR in the telemetry (German for time)

X-band Tx temperature – this value is only valid if the X-band Tx is turned on.

Useful AO-40 telemetry information sites:

General AMSAT AO-40 telemetry information and resources
http://amsat.org/amsat/sats/ao40/ao40-tlm.html
Paul Willmot's telemetry capture notes for the archives
http://amsat.org/amsat/sats/ao40/capture_notes.txt
AO-40 Telemetry Specification
http://www.amsat-dl.org/p3d/tlmspec.txt
RUDAK Telemetry Specification
http://www.amsat.org/amsat/sats/ao40/rudak/telemetry/
Robert Rice's Getting Started with AO-40 (general AO-40 telemetry resources)
http://ao40.homestead.com/index~ns4.html
Robert Rice's AO-40 Telemetry FAQ
http://ao40.homestead.com/TelemFAQ.html (AO-40
AMSAT DL site with a great deal of AO-40 information in English
http://www.amsat-dl.org/
AMSAT UK site with additional AO-40 information
http://www.uk.amsat.org/phase3d.htm
JAMSAT SCOPE camera information site
http://www.jamsat.or.jp/scope/index_e.html
Telemetry Archive HTTP   http://www.amsat.org/amsat/ftp/telemetry/ao40/
Telemetry Archive FTP   ftp://ftp.amsat.org/amsat/telemetry/ao40/
D block JPEG format   http://www.amsat.org/amsat/sats/ao40/d-block-jpeg.html
P3T software download site http://www.cstone.net/~w4sm2/software2/P3t_AP.zip
RUDAK link   http://www.coloradosatellite.com/P3D/RUDAKIntro.html
Mini-Glossary   http://www.amsat-dl.org/journal/adlj40ge.htm

Appendix

Telemetry sensor location drawings

TEMP 11
TEMP 21
+Z
TEMP 40
TEMP 44
TEMP 39
TEMP 6
07   HEAT PIPE
TEMP 10
TEMP 41
TEMP 9
-X
18   REACTION WHEELS
TEMP 42   TEMP 20   TEMP 43
TEMP 7
20   EARTH SENSOR #1
TEMP 8
TEMP45   17   NUTATION DAMPER
TEMP 12   DIVIDER PANEL 02
EQUIPMENT PANEL 02   04   SIDE PANEL
-Y   STRINGER   +Y
MODULE BOX 05
TEMP13
06 SOLAR PANEL
TEMP16 TEMP17
TEMP18   TEMP14   TEMP15
+X   Omni
Sun Sensor
Volts 46-56
15 GPS ANTENNAS (4x)
03
06 ARCJET ENGINE
14   SEP.-INTERFACE
(UMBILICAL)   -Z

Temp 03
Volts 15
~~Curr 02~~
~~Curr 03~~

Volts 09
Volts 11
Volts 14

Volts 33
Temp 27

Temp 01
~~Curr 01~~

| GPS | ASSP | CMDA LRX 1 | LIU | PFA | |
| BCR #1 | RUDAK | IHU IO Modul | CEDEX | SEU | BCR #3 |

Temp 34

Temp 04
Volts 16
Volts 17
~~Curr 04~~
~~Curr 05~~
~~Curr 06~~

Curr 10

Volts 27

Temp 38?

Volts 26
Volts 45

| K XMT 1 K XMT 2 | K XMT OSC | PSU | X Band Antennas TWTA Power | R Laser Exp | GPS Exp 1 GPS PSU |
| ARM CAN Temp 2 | LEILA IF Matrix | EPU | | X Band XMT Exciter | BCR #2 |

Volts 59
Volts 60

Temp 02

Volts 24

Volts 25
Volts 44

Temp 05
Volts 18
Volts 19
~~Curr 07~~
~~Curr 08~~
~~Curr 09~~

Temp 29
Volts 57
Volts 58
Curr 11?
Curr 12?

Temp 46

Temp 28
Volts 10
Volts 35

Temp 26
Volts 31
Volts 32

| SCOPE | YACE IHU #2 | S2 HPA Helaps Exciter Wandler | S1 HPA Helaps Exciter Wandler | U + V RCV | RFRU |
| L Band RCV 2 | HF RCV | C Band REC 2 | U Band Exciter CAN Temp 1 | U Band XMT Mod | V Band XMT |

Temp 19
Volts 23

Temp 24
Volts 29

Temp 23
Volts 28
Volts 30?

Temp 25

Temp 32
Volts 38
Volts 39

Temp 31
Volts 36
Volts 37

VII. References

AMSAT Journal, P3D Special Edition, November 2000
AO-40 Telemetry reference - http://www.amsat.org/amsat/sats/ao-40-tlm.html
Beckmann, Paul, "P3G to P3D", AMSAT 1997
Bloom, Al, Sun Sensor information, http://amsat.org/amsat/sats/phase3d/sun_sensor.html
Chin, Phil, "AO-40's 'Christmas Miracle' Recovery", CQ magazine, March 2001
Current AO-40 information - http://www.amsat-dl.org/journal/adlj-p3d.htm
http://garc.gsfc.nasa.gov/www/
Meinzer, Karl, "IPS High Level Programming of Small Systems", AMSAT-UK, 1978
Mills, Stacey, "P3Tsoftware",http://www.cstone.net/~w4sm2/software2/P3t_AP.zip
Mills, Stacey, W4SM, specific answers to numerous questions & satellite drawings
Oxford English Dictionary Online edition, http://dictionary.oed.com
Smith, Gould, "Decoding Telemetry from the Amateur Satellites", AMSAT-UK, 1991
Willmott, Paul, VP9MU the telemetry archives and answers to many questions
YACE pictures - http://amsat.org/amsat/features/yace00292/index.html

The PCsat Mission

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Abstract

There are growing opportunities for Universities to gain educational access to Space. As a spin-off of our PCsat project, we have investigated several off-the-shelf solutions to the Telemetry, Command and control portion of small satellites that can greatly simplify small satellite and CubeSat designs. This permits students to concentrate on the various payloads and other aspects of the project without starting from scratch with a comm. system.

This simple comm System based on AX.25 packet radio is being flown this summer in the Naval Academy's Personal Communications Satellite (PCsat) which will demonstrate downlinks receivable on Hand Held Transceivers (HT's) with only a whip antenna. Further these simple downlinks can be easily fed into the Internet for live worldwide distribution of data. We hope to share our common downlink of 145.825 with any and all other low-duty-cycle downlink digipeaters that support this common mission objective. Thus greatly simplifying operations for both the users and the internet SatGates.

These designs are all based on the amateur radio standard on-air AX.25 packet network protocol that is implemented in a number of off-the-shelf modems (called Terminal Node Controllers or TNC's). The following paragraphs describe three such hardware devices and the remainder of this paper describes how TNC's and the AX.25 protocol were used on PCsat.

OFF-THE-SHELF AX.25 HARDWARE

One advantage of using the AX.25 protocol is that any node in the system can be used for relaying data between any other nodes. Thus, the TNC can not only provide the dedicated up and downlinks and command/control channels, but also serve as a generic relay for other applications on a secondary basis. Examples of TNC's on orbit are SAREX, SPRE, MIR, ISS, SUNSAT, OPAL and soon to be PCsat, SAPPHIRE and maybe future STARSHINE's. Here are our choices for AX.25 hardware:

The MIM Module

The simplest Telemetry module is the one cubic inch MIM module which provides for multiple periodic AX.25 packets at 1200 baud AFSK containing up to 5 analog channels and 8 on/off bits. Different rates can be set for the BEACON, Telemetry, GPS position and CW Identification. The module has no command and control capability, but that is easily added with CTCSS or DTMF receivers/decoders.
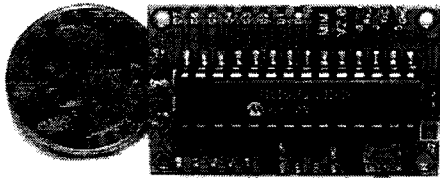
Photo 1. The MIM module. See http://www.toad.net/~wclement/bru ninga/mic-lite.html

1200 Baud KPC-3+

The second and more capable telemetry is the use of a Kantronics KPC-3PLUS TNC which has the advantage of an AX.25 receiver and thus the ability to do command and control. It can even be carved down to fit within the four inch cube. The board will fit diagonally in a Cubesat if the connectors are removed and the power supply portion of the board is relocated
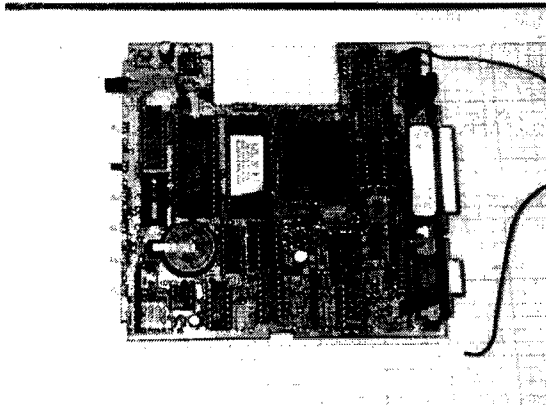
This gives the same Telemetry, Beacon, GPS and CW ID capability as with the MIM module, but includes a full TNC DIGIPEATER and 4 channel COMMAND/CONTROL channel as well. With the full TNC, a complete digital communications transponder mission, such as used on PCsat, can be supported.

9600 Baud KPC-9612+

The 9612+ TNC adds a second comm. Port to the TNC offering one port at 1200 and the other at 9600 baud. The 9612+ offers the same 5 analog telemetry channels of the MIM module and serial port communications of other TNCs, but also gains a total of 8 configurable command or I/O bits, four ON/OFF command bits and one input bit. Because of the added 9600 baud comm. Port, the KPC-9612+ TNC was designed into the final PCsat design. PCsat is just one of a possible constellation of student built satellites supporting the ASTARS Mission all based on using AX.25 TNC's in orbit.

THE ASTARS MISSION

The ASTARS Mission is a generic mission (supported by any TNC in orbit) to provide real-time message, position, and status relay via satellite to a worldwide Internet linked amateur radio tracking system. Any amateur or university payload can support this mission by simply enabling the DIGIPEAT-ON function in any AX.25 compatible transponder (TNC). The users of such a relay system can be for Boats at Sea, remote environmental sensors, cross country travelers, expeditions, school projects, or any other travelers which are far from any existing APRS terrestrial tracking infrastructure.

The satellite downlink from such travelers or remote sites are fed into the existing worldwide Internet linked ground system by a few permanent ground stations. These APRS satellites would join our own PCsat, and other University built small satellites to provide connectivity to everyone involved in this mission providing connectivity to their birds while not locally in view. AND all on 145.825 downlink.

The Space segment of PCsat/ASTARS has been demonstrated a number of times in space via MIR School

tests, the Shuttle SAREX, the SPRE mission, AO-16, UO-22 and more recently via SUNSAT and ISS. The satellite concepts described herein would be operated under the rules of the Amateur Satellite Service and the rules of the FCC. Full details of the Cubesat concepts and the PCsat mission can be found at:

http://web.usna.navy.mil/~bruning
a/cubesat.html
http://web.usna.navy.mil/~bruning
a/astars.html
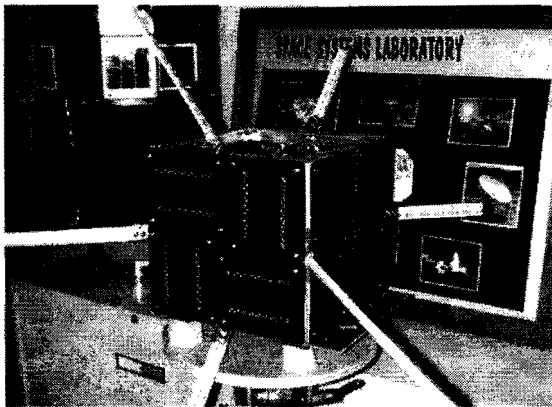
Photo 2. Personal Communications Satellite (PCsat) with Antennas

Photo 3. Personal Communications Satellite, PCsat and Design Team

The PCsat MISSION

The remainder of this paper will describe the design of a low cost easy to build APRS satellite to meet the need for mobile and handheld amateur satellite users. This APRS Satellite Mission is

for worldwide real-time message and position/status data exchange between users and is in contrast to the mission and design of all existing amateur PACSATS that concentrate on message store-and-forward. Further, it incorporates the Internet as part of its design instead of trying to compete with it. Although the Naval Academy has been in dialog with a number of other satellite owners and designers over the last 7 years to accommodate these concepts into their designs as well (SAREX, SPRE, MIR, ASUsat, UO-22, and SUNSAT), PCsat will be the first satellite designed with APRS UI digipeating as the primary mission with these objectives:

1) Handheld/Mobile live digital tracking and communications in footprint
2) Worldwide handheld and mobile position and status reporting (via internet)
3) Handheld and Mobile message uplink to satellite (then to Internet)
4) Handheld and Mobile message downlink/delivery from Internet
5) Nationwide Bulletin delivery
6) Low Power GPS tracking of buoys, telemetry devices, wildlife, etc
7) Other UI digipeating applications
8) Worldwide one-line Emailing
9) School demonstrations and satellite lab activities

All of these mission objectives can be met with just a simple hardware TNC on orbit acting as a UI digipeater. Also, with the sophistication and added I/O of recent TNC's designed for APRS, the TNC itself can be the command and control system. Thus no additional on-orbit CPU's are required. Not only is the satellite hardware simple, but it can be reproduced by other satellite builders to help form a constellation of these relay satellites, all operating on the same frequency to give mobile users extended access beyond what is possible with one satellite alone. This concept of a Builders Channel for similar-mission spacecraft was presented at last years AMSAT Symposium [1].

BACKGROUND TO THE MOBILE
SATELLITE NEED

Modern Technology is on the move. Satellite Wireless is the leading edge of technology. In the amateur satellite program, it should be a major driver for future amateur satellite missions. In just the last year there have been *many* hints at the future of Amateur Mobile and Handheld satellite communications.

1) Growing popularity of UI digipeating via MIR through 1999
2) Continuing high popularity of AO27 for handheld FM voice communications.
3) Activation of UO-14 for FM voice repeater mode in February 2000
4) Experimental UI digipeating via the UO-22 Satellite
5) FM VOICE repeating via SUNSAT SO-35 throughout 1999
6) Recent activation of SUNSAT SO-35 for UI and APRS
7) Recent Introduction of new TNC/Radios (Kenwood & Alinco)
8) Dayton 2000 introduction of the upgraded Kenwood TH-D7 data HT!

The potential of two-way satellite handheld text messaging (national paging) was serendipitously demonstrated at the Dayton Hamvention during a parking lot demo of the SUNSAT downlink. Due to a scheduling error, there was no success at the expected time so the HT was placed in a pants pocket and forgotten. But minutes later, the tale-tale beeping of the TH-D7 alerted me to an incoming APRS message and on inspection, it was a Bulletin from SUNSAT. Thus, amateur satellite message delivery to an un-attended obscured Handheld Transceiver was demonstrated.

Photo 4. Chas Richard, W4HFZ's mobile APRS Satellite capability (including HF). With an APRS Satellite, he can send and receive brief text messages anywhere on the planet a few times a day.

ASTARS

To identify this APRS satellite communications system from its terrestrial counterpart the space segment is called ASTARS for APRS Satellite Tracking and Reporting System which has evolved through a number of existing and previous satellite communications experiments. First was **1200 Baud PSK ASTARS** which was called TRAKNET [2] at the 1998 and 99 AMSAT conferences using AO-16, LO-19 and IO-26. It is a very viable capability for stations with PSK TNC's or using more recent sound-card modem uplink capability[3]. But it never became popular due to the rarity of PSK modems amongst most amateur satellite operators.

Satellite packet experiments using **1200 Baud AFSK ASTARS**, however, which *any* TNC can do, were demonstrated many times during experiments with the Space Station MIR[4] packet system and SAREX[5]. These experiments culminated in the June 1999 week long experiment via MIR which used the new Kenwood TH-D7 with built in 1200 and 9600 baud TNC's to demonstrate two-way self-contained APRS communications via

MIR at 1200 baud. During this test[6], over 55 stations conducted 2 way HT message communications.

Recently, experiments have been conducted with **9600 BAUD ASTARS** using UO-22 and SUNSAT and the new Kenwood 1200/9600 baud APRS data mobile radio, the TM-D700A [7]. This dual band data radio with built-in TNC's and front panel APRS displays made it possible to send and receive the very short APRS style communications via any 9600 Baud PACSAT with digipeat enabled (UO-22). Thus, the TM-D700 radio is an off-the-shelf satellite data terminal ready for ASTARS and it needs NO PC or other accessory. Kenwood also followed suit with 9600 baud upgrades to the TH-D7(G) HT with its internal front panel displays. Alinco also now sells another integrated TNC/Radio called the DR-135 which can also do both 1200 and 9600 baud built-in, though it needs an external Laptop to display the APRS data.

THE INTERNET

Unlike previous Amateur Satellite designs, APRS satellites can capitalize on the connectivity of the Internet instead of trying to compete with it. The Internet makes possible the linking together of multiple disparate downlink sites which allows a tremendous gain in reliability through space and time diversity reception. Instead of each station requiring their own downlink receiver and then only being able to hear packets within his own footprint, the Internet allows a few stations, called SAT-Gates (Satellite IGATES) to combine all packets heard into the existing worldwide APRS infrastructure (APRServe)[8] for delivery to any APRS operator anywhere.

APRS MESSAGES

For satellite operators unfamiliar with APRS messages, it should be understood that an APRS message is a single LINE of text. Most messages stand alone, but are occasionally strung together if it will not fit on one line. Photo 2 is a photo of a very brief 15 byte message received on the TMD700 radio. Messages from mobiles are usually quite brief as they must be entered on the Touch-Tone pad. But longer messages up to 64 bytes are routinely displayed.
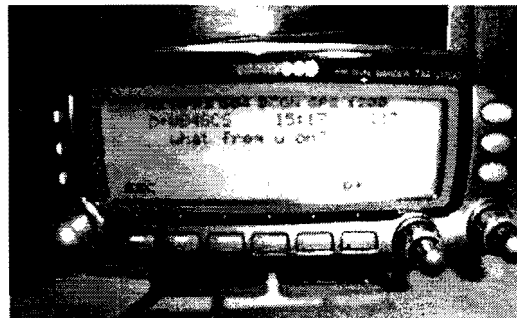
Photo 5. The front panel of the TM-D700 showing an incoming 15 byte message (Messages can be longer up to 64 bytes).

EMAIL

Similarly, APRS can send and receive standard EMAIL messages via the worldwide internet linked APRServe system. This capability is limited, but very useful. The first limitation is that messages are only ONE LINE and the one line *includes* the full email address. This forces BREVITY! Secondly, although EMAIL can be originated under the control of the HAM sending it, EMAIL replies back from the Internet are only allowed via special Igates with operators that have volunteered to screen such traffic for 3rd party legality prior to being returned to RF. Here is an Email transmitted from my D700 mobile en route to work. Here is how it was entered into the D700:

```
EMAIL :wb4apr@amsat testing delivery via pacsat from my van
      en route to work.
```

Yet, here is how it was received by my Email system after being SAT-Gated to APRServe and from there, picked up by the EMAIL Engine at WU2Z's and shipped out as regular Email:

```
Date: Mon, 7 Feb 2000 07:58:09 -0500 (EST)
From: WB4APR-9@unknown.net
To: wb4apr@amsat.org
Subject: APRS Message from WB4APR-9
-----------------------------------------------------------
testing delivery via SUNSAT from my van en route to work.
-----------------------------------------------------------
Message received by MacAPRS IGate station WU2Z
Located in NO BRUNSWICK, NJ
APRS path = WB4APR-9>APK101,SUNSAT*:
```

USER GROUND STATION EQUIPMENT

To design an APRS satellite the link budget and capabilities of the users mobile stations must be well understood. The table below shows the uplink power and receiver antenna gains for all participating stations in the ASTARS system. The column labeled Standby Receive Gain is for the user who is not aware of, nor optimized for satellite reception. For example, someone hiking with a HT in his pocket, or mobile parked under trees.

USER Stations	ERP UHF (W)	ERP VHF (W)	Rcv UHF dBi	Rcv VHF dBi	Rcv STBY dBi	Applications
HANDHELDS	3	5	3	3	-6	Sailboats, Hikers, Wilderness
MOBILES	70	100	5	5	-6	Remote Travelers, Boats
HOME Stations	700	1000	13	13		Not intended for UPLINK

NETWORK Stations						
IGATE Receiver			7	5		Omni Internet receive site
MESSAGE NODE	70	100				Internet to user UPLINK site
COMMAND Station	700	1000	13	13		USNA

Although a wide variety of power and receiver gains are involved, these values are what form the basis of the APRS Satellite design and the architecture of the overall ASTARS System.

REQUIREMENTS/CONSTRAINTS DESIGN DRIVERS

To design a satellite to meet the HT/Mobile communications objective and the internet links as well, there are a number of factors involved in selecting the frequency band, antenna types, and baud rates for each of the mission objectives. First there are a number of boundary conditions or assumptions:

1) Optimum ALOHA channel efficiency is about 20% due to collisions
2) VHF links have a 9 dB advantage over UHF links (omni to omni)
3) 1200 baud AFSK has a 7 dB advantage (measured) over 9600 baud FSK
4) T/R delays render 9600 only twice as fast as 1200 for APRS bursts
5) UHF uplinks require wideband Sat Rcvrs to avoid Doppler (- 4 dB)
6) UHF downlinks require user tuning during pass (not desired)

With these design drivers as a guide, the following are some of the first-order alignments of requirements to hardware. From these, then, the optimum trade-offs were made to arrive at the final PCsat design.

1) MSG delivery to HT in Standby requires best possible downlink (1200 baud VHF). Igate uplink is relatively unconstrained.
2) MSG receipt from HT requires best possible uplink (1200 baud VHF).
3) Downlink to internet is relatively unconstrained.
4) Continent wide Bulletin Delivery requires existing 144.39 over USA and 1200 baud. The same for Europe will require a common European frequency too.
5) HT/Mobile real-time messaging requires same up/downlink & baudrates
6) GPS HT/Mobile tracking is relatively unconstrained.
7) Low power GPS tracking devices require best uplink (1200 baud VHF) and the uplink must not be used by any other satellite uplinks to avoid unintentional interference to other systems.
8) Other UI digipeating applications should be crossband full duplex and should use same up/downlink baud rates
9) Multiple uplink receivers to minimize collisions is desired.
10) Synchronizing of same-band downlink transmissions is desired to maximize the available half-duplex satellite receive time.
11) Redundancy and Backups are desired.
12) Bundling of packets in bursts amortizes individual TXDelays
13) UHF downlinks are of little value due to poor link budget and Doppler.
14) KISS Principle should reign. (Keep it Simple, Stupid)

HARDWARE ALIGNMENT TO REQUIREMENTS

Using the above criteria, PCsat was designed around two KPC-9612+ Dual Port TNC's. These TNC's have all the latest APRS generic digipeating advantages and can even cross route packets between ports. By using standard off-the-shelf TNC hardware and FIMRWARE, on orbit risk was minimized due to the track record of thousands of identical hardware in use all across the country for terrestrial APRS. Thus, the firmware is proven.

Each dual port KPC-9612+ can cross relay from either of its two inputs to its two outputs. With only two transmitters on VHF for best downlink budget, PCsat outputs both the 1200 and 9600 baud channels to the same transmitter, one for each TNC as shown below. PCsat uses a single VHF half-duplex channel in the ITU Satellite Subband for its primary uplink and downlink, and one other unpublished VHF uplink. Similarly there are one published and one unpublished UHF uplink. For the unique APRS paging downlink over North America PCsat uses the dedicated 144.39 assignment to be able to send urgent messages from the satellite to travelers at any time who may only be monitoring the terrestrial APRS channel.

```
          KPC-9612 #1
          +-----------+
VHF-1 --->| 1200 Baud |--*-----> VHF-1
          |   \ /     |  |  |
          |   / \     |  |  |
UHF-1 --->| 9600 Baud |--*
          +-----------+

          KPC-9612 #2
          +-----------+
VHF-2 --->| 1200 Baud |--*-----> 144.39
          |   \ /     |  |  |
          |   / \     |  |  |
UHF-2 --->| 9600 Baud |--*
          +-----------+
```
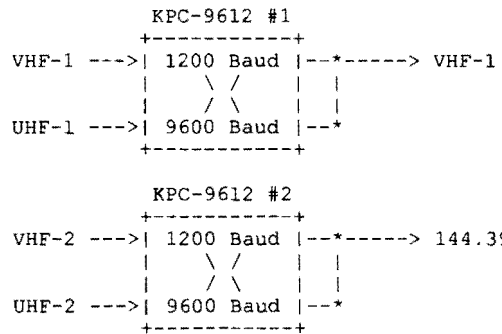
FAILSAFE RESET

To recover from a SEU or other lockup condition in these commercial off-the-shelf TNCs, PCsat uses 3 methods of hardware resets back to launch defaults. First, each TNC has a failsafe RESET circuit that monitors the PTT of each TNC and as long as a transition occurs at least once a minute, then the TNC is assumed to be operating correctly and the TNC remains powered up. If there are no transmissions for over 1 minute, then a one-shot timer removes power from the TNC for 1 second to allow for a complete power up reset of the TNC.

Second, there is a 72 hour fail safe reset circuit that will

reset both TNC's unless the counter is cleared by command from the ground at least once every 3 days. Third, a command bit in each TNC can be commanded to reset the other TNC.

TELEMETRY

Back in 1995 we defined the APRS 5 channel TELEMETRY format that Kantronics subsequently has added to their "plus" TNC's. To make this usable on our satellite, the PCsat team added a 16 channel-to-four hardware multiplexer to allow telemetry to read as many as 16 values transmitted in four consecutive telemetry packets.

LINK BUDGET

The primary driver of this APRS Satellite design was to deliver messages to handhelds and mobiles with only whip antennas. For this, the downlink needed to be at least 12 dB stronger than most existing digital satellites. PCsat accomplishes this by taking advantage of the 9 dB link improvement of 2 meters compared to 70 cm and by using a 3 watt transmitter. Further, PCsat operates at a low transmit duty cycle unlike most existing PACSATS, because the Amateur

Satellite population only covers 10% of the earths surface and with the low duty cycle of the ALOHA style of APRS operations, less than 4% of PCsat's average power budget is required.

Similarly, to conserve power and bandwidth, the 2 meter uplinks are reserved for only the low power handheld stations, or stand-alone tracking devices or data collection buoys or remote WX stations such as the one built by Ronald Ross, KE6JAB in Antarctica [9]. The mobiles and SATgates which have 35 to 50 watt transmitters will be asked to operate only on the UHF uplink frequencies where they can afford the more difficult link budget. The result is the further advantage of having spread out the user base over 4 uplink channels to minimize collisions.

CHANNEL USAGE AND MISSION SCENARIO

The following table maps the mission objectives into the various uplinks and downlinks on the satellite. It matches strengths and weaknesses of each mission area to the available link budgets and hardware:

MISSION ELEMENT:	UPLINK	PATH	DOWNLINK
HT Uplink of MSGS/POSIT to Internet	145.825@12	UIDIGI	145.825@12
Live HT-to-HT Footprint QSO's	145.825@12	UIDIGI	145.825@12
Live HT-to-Mobile crosslinks	145.825@12	XBAUD	145.825@96
Live Mobile-to-HT crosslinks	435.25 @96	XBAUD	145.825@12
Mobile uplink of MSGS/POSIT to Internet	435.25 @96	UIDIGI	145.825@96
Live Mobile-to-mobile Footprint comms	435.25 @96	UIDIGI	145.825@96
Command and Control	ALL	MYRemote	145.825
Other UI Applications	TBD	UIDIGI	145.825
Low power Trackers	VHF2	UIDIGI	144.39 USA
Nationwide Message delivery	UHF2@9600	MYgate	144.39 USA
Nationwide Bulletin delivery	UHF2@9600	Mygate	144.39 USA

Notice the advantage of incorporating the single North American Continent-wide coordinated APRS frequency into the downlink frequency plan. Although this frequency is in use by over 2000 users fulltime including over 600 wide area

digipeaters, it is a well
established universal frequency
where ALL APRS operators can be
found whether they are aware of a
satellite pass or not. Actually,
although 90% of the USA ham
population is within range of
this terrestrial infrastructure,
70% of the land mass is not so
travelers are often out of range
of the terrestrial links.

Due to the shared use of 144.39
with the thousands of existing
users, this downlink on 144.39
will ONLY be used for the special
applications consistent with the
national significance of this
channel. Such applications might
be getting an emergency or
priority message to an existing
APRS mobile no matter where he
is; Infrequent Bulletins of
National interest; Low power but
high profile tracking of special
devices, for example, the Olympic
Torch. Due to the low duty cycle
channel statistics of an ALOHA
TDMA channel like APRS, even
though the channel is in full use
by thousands of users, still more
than 50% of the time, the channel
is "clear" as heard by any mobile
anywhere at any instant.

SAT-GATE OPERATIONS

The Mobile-to-mobile and HT-to-HT
communication missions work
without any special
considerations on the satellite
or on the ground. But the more
useful application is sending and
receiving messages to any other
APRS station worldwide by having
the packets received by the SAT-
Gates that are monitoring the
satellite downlink and feeding
every packet heard into the
APRServe system. These SAT-Gates
perform the following functions:

1) Monitor both downlinks and feed ALL
   packets into the Internet
2) Maintain a track on all Calls heard
   via satellite
3) Monitor the Internet and capture
   MESSAGES for these Calls
4) Deliver these messages at a "fair"
   rate under these conditions:
   a. The satellite is within 1400
      km (above 30 deg) to mobile

   b. It sees "QRZ" in the Mobile's
      STATUS text or CUSTOM-3
   c. Deliver these messages until
      seen in the downlink 3 times

OMNI NO-TRACK SAT-GATES

Setting up a SATgate is trivial
requiring nothing more than a
normal packet station and omni
antenna. Any APRS station can do
it with existing software which
contain the built-in Igate
capabilities. Even if the
station does not have horizon-to-
horizon coverage, they are only
contributing their packets to the
same worldwide stream as all the
other Igate receivers, so any
station can help. Unlike any
previous amateur satellite
activity, PCsat will use the
Internet to combine the outputs
from a dozen such stations
nationwide and the result is over
a 99.96% chance of capturing
every packet over the USA! Even
if only 4 stations at any one
time have the bird in view of
their station and even if they
only have a 60% chance of
decoding each packet, their
combined probability is 98%. But
if the original packet is
replicated TWICE, then this
probability becomes 99.96%! A
Certainty!

BASE STATION OPERATIONS

Since the APRS Satellites are
shared assets with limited
bandwidth, this message system
should only be used by mobiles
who have no other means to
communicate from distant
locations. For this reason, base
station operations are not
encouraged other than SAT-Gates
or for direct contact with a
mobile if needed. A Mic-E style
packet from the D700 is only 9
bytes long, compared to a typical
WinAPRS 80 byte position report.
Thus, base station transmissions
are discouraged.

SATELLITE TRACKING AND PASS PREDICTIONS

To help with satellite tracking for the casual and mobile user, Satellite tracking has been added to APRSdos in the form of APRStk.exe. When run within an existing APRSdos file structure (so you get all the maps and other built-in-data), it presents the satellite predictions on the APRS map and will auto-tune the Kenwood radios including Doppler. It is available zipped up as a complete system for download from:

ftp://tapr.org/aprssig/dosstuff/APRSdos/aprstk.zip
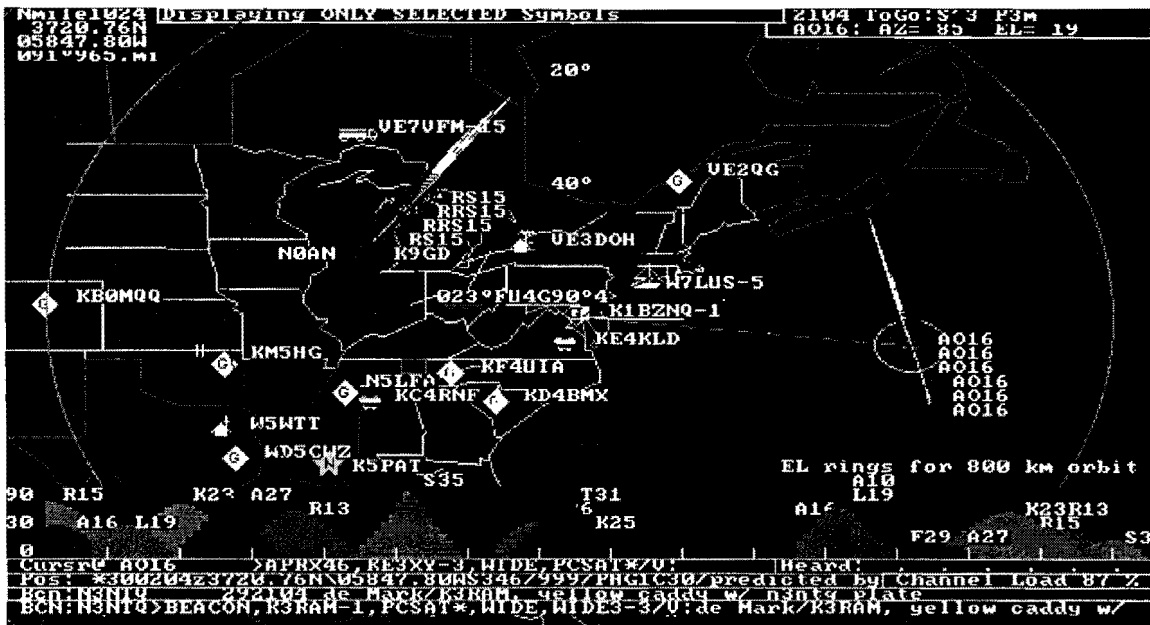
All satellites are shown on the map as moving objects. Across the bottom of the screen the next 2.5 hours of satellite passes are shown in a graphic showing the maximum elevation of the pass.

DISTRIBUTING LIVE SAT TRACKING DATA TO MOBILES

Another version of the same APRSdos derivative is called APRSdata.exe and it has the unique feature that it can distribute via the terrestrial network sufficient pass information for display on the front panel of the Kenwood radios so that other travelers are aware of pass times long before they drive out into the wilderness.

Not only does this put this special Satellite Pass Info directly on the mobiles' radio, it also posts the Satellites in view as objects to the local 144.39 network so that all mobiles can see the range and azimuth to the satellite as well as the up and downlink frequencies. Thus, our mobile satellite users can get the PASS info they need without lugging along a laptop.
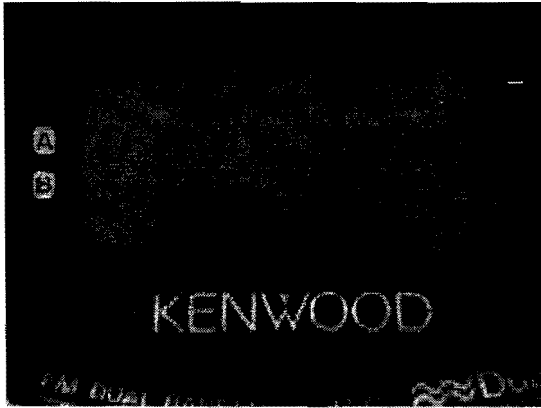
Photo 7. Screen shot of the TH-D7 showing the next 80 minute satellite schedule.
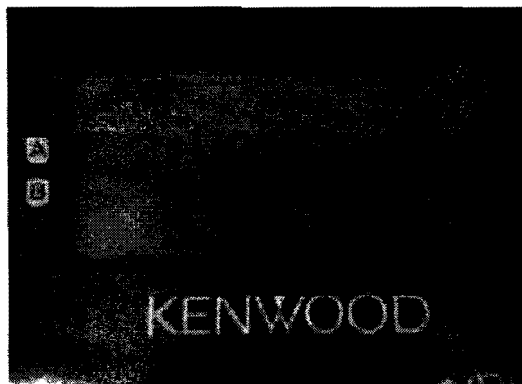
Photo 8. Showing the range and downlink frequency of UO-14.
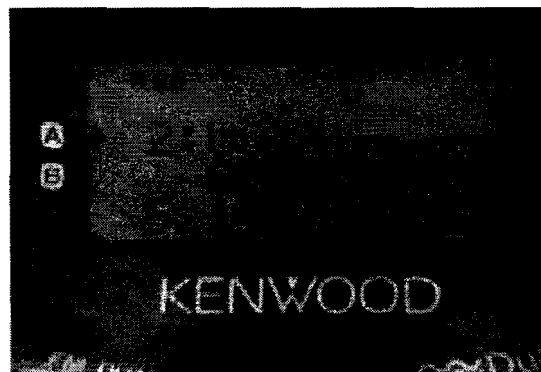
Photo 9. Showing the direction and distance to the Satellite.

The screen shots show what the TH-D7 HT will capture and display about the satellites while monitoring the terrestrial network if an APRSdata.EXE station is in range. First is the DX-SPOT list showing that there are three satellites UO22, AO27 and UO14 coming up in the next 80 minutes and when.

The next two screens show up when the satellite is in view. They show the Range, Azimuth Frequency, Doppler and distance to the satellite. Just perfect for aiming your handheld antenna. For more details on this resource for non-PC distribution of satellite info, see the WEB site:

http://web.usna.navy.mil/~bruning a/satinfo.html

The power of this on-line, real-time delivery of current satellite pass data to mobiles and handheld users without the need for a laptop is in itself a brand new opportunity for the Amateur Satellite Service. Already it has been expanded to hundreds of other data screens that can be pushed to these radio displays. We call them Tiny Web Pages [10]. Although this application is beyond the scope of this paper, the ability to deliver these Tiny Web Pages to any HT/Mobile anywhere on the planet with the combined resources of the existing APRS infrastructure and the ASTARS Amateur Satellites.

CONCLUSION

The time is ripe for extending Amateur Satellite digital communications services to mobile and handheld users. Since packet was first introduced on the Space Shuttle mission STS-35, there have been numerous experiments to test and validate the capability for using UI packet digipeating for real-time digital communications between users. This combined with the recent maturity of the Internet as a global resource for exchanging data worldwide suggests that there is a unique opportunity to join the advantages of the Internet and Amateur Satellites as a means of tying together

SatGates throughout the world where the infrastructure exists to extend worldwide amateur communications to mobiles in areas where it doesn't exist. And, rather than starting such a global system from scratch, the APRS protocol and worldwide internet infrastructure provides a means of packaging and delivering and displaying this type of real time traffic to users both on the satellite downlink and worldwide via the Internet.

The introduction of the Kenwood and Alinco integrated TNC/Radio combinations and the Kantronics TNC's give us off-the-shelf solutions for providing mobile and handheld Satellite Communications Terminals to all users. By encouraging UI digipeating as auxiliary payloads on most small satellites the Amateur Satellite Service can bring all of these pieces together into the most powerful and far reaching Amateur Satellite project to date.

REFERENCES:

1. Satellite Builders Channels, 17th Annual AMSAT Symposium, pp191-5

2. http://web.usna.navy.mil/~bruninga/ traknet.html

3. http://members.aol.com/dquagliana/upw/index.html

4. http://web.usna.navy.mil/~bruninga/mirex.html

5. http://web.usna.navy.mil/~bruninga/sarex.html

6. http://web.usna.navy.mil/~bruninga/mir-ht.txt

7. http://web.usna.navy.mil/~bruninga/TM-D700A.gif

8. http://web.usna.navy.mil/~bruninga/www.aprs.net

9. Antarctic Expedition, AMSAT Journal, Winter 2000

10. Tiny Web Pages, ARRL/TAPR Digital Communications Conf, 2000

A Helix Feed For Surplus MMDS Antennas

Gerald R. Brown, K5OE

Many of the commonly available surplus dish antennas are remnants of the MMDS (Multipoint Microwave Distribution System) industry. These "dishes" are typically grid-style paraboloids in a rectangular shape. Many come with integral dipole feeds, while others may have no feed at all. Many of these antennae have already found new homes atop the towers of amateur satellite enthusiasts, as AO-40 S-band downlink antennas. Some examples are depicted below in Figure 1.
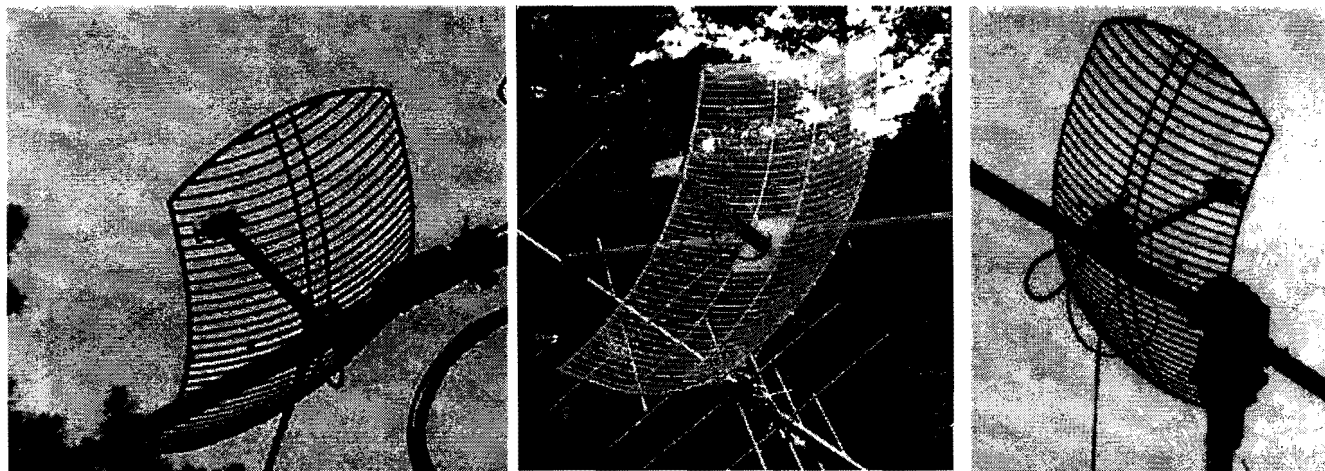
Figure 1: MMDS Antennas Installed For AO-40 Downlink At N1JEZ, KE4AZN, & KK5DO

While these antennae are optimized for their intended application, they can be improved for amateur satellite S-band downlink. My recent experimentation with helical antennae led me to believe a helix feed may be an excellent choice for the home brewer.[1] In pursuing this, I combined several design concepts, each adding incrementally to the antenna's efficiency. This fortunate synergy provided an easy-to-replicate design ideal for AO-40 S-band reception.

Detailed below are some basic parabolic dish design guidelines, some extrapolations of various ideas as they apply to parabolic antennae, and some specific construction details for one of the commonly available grid-style dish antennas. Much of the following discussion also may be applied to surplus offset dishes from the fast-changing DDS (Direct Digital Satellite) industry.[2]

Understanding What You Have:
Figure 2, below, depicts the asymmetrical E-plane and H-plane patterns for a resonant dipole-plus-parabolic-reflector array (using 3 reflectors) at 2401.500 MHz in free space.[3] Note how the –3 dB beamwidth pattern for the H-plane is about twice as "broad" as the E-plane: 120 degrees compared to 70 degrees. Considering these patterns for a feed, it is obvious the rectangular shape of the MMDS reflector is by design. The MMDS antenna manufacturers have taken advantage of this inherent dipole characteristic in designing their antennae broader in the H-plane—perpendicular to the dipole's orientation. It appears an optimized design for the dipole feed, providing higher potential gain and lower G/T (Gain / antenna noise temperature), but invariably requires a low f/D ratio in the range of 0.3 to 0.4 in order to capture as much of the low-gain, wide-beamwidth pattern of the dipole array as possible. For a MMDS dish, measuring 38" (97 cm) x 26" (66 cm), the theoretical gain is:

49

$G = 10 * \text{Log}_{10}[\eta(4\pi/\lambda^2)*A]$, where η=efficiency, A=aperture of the dish, λ=wavelength

$G = 10 * \text{Log}_{10}[0.50(4\pi/24.5)*(38*26)]$ (for A, I substituted (length*width) for πr^2)

$G = 10 * \text{Log}_{10}[0.2564*988]$

$G = 24$ dBi

An (optimistic) efficiency of 50 percent is assumed in the foregoing calculation. The *focus* is where the parabolic shape of the dish concentrates the reflected signal and is determined by:

$f = D^2 / 16d$, where D=diameter of the dish and d=depth of the dish

$f = 38^2 / 16*5.75$ and $f = 26^2 / 16*2.75$ (inches)

$f = 15.695$ and 15.365 (perpendicular to the dipole and in-plane with the dipole)

$f \approx 15.50$ in. (39.4 cm)

Thus, the focus/Diameter (f/D) ratio of this "typical" MMDS antenna is approximately 0.6 in the in-plane dimension and 0.4 in the perpendicular dimension, referenced to the dipole array feed.
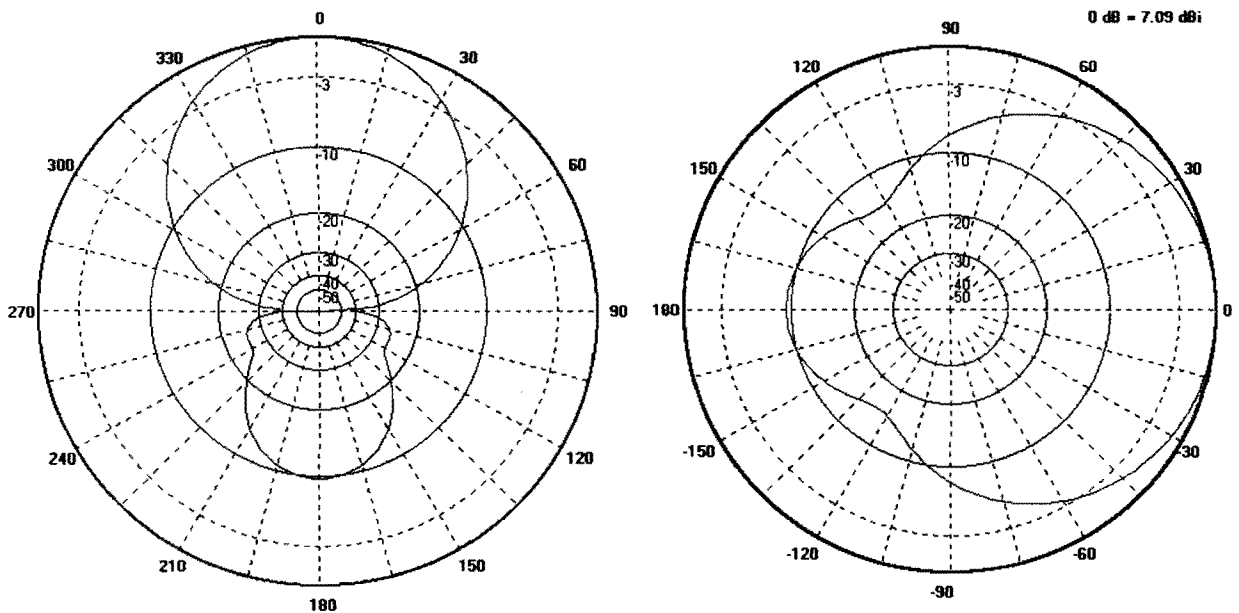
Figure 2: Azimuth (E-plane) and Elevation (H-plane) Patterns For Dipole Array

Wade, in his authoritative on-line text, states the general feed design goal succinctly: "in order to have a very efficient dish illumination we need to increase energy near the edge of the dish and have the energy drop off very quickly beyond the edge."[4] The oft-quoted feed efficiency rule of thumb is illumination power equal to −10 dB at the dish edge, with perhaps −13 or −15 dB for slightly less efficiency but better G/T ratio.[5] A little trigonometry shows the E-plane edge-of-the-dish-cutoff (σ^E) is at 46 degrees and the H-plane cutoff (σ^H) is at 63 degrees for the author's surplus dish:

$\sigma^E = \arctan[13 / (15.5-2.75)]$

$\sigma^E = 46$ degrees

$\sigma^H = \arctan[19 / (15.5-5.75)]$

$\sigma^H = 63$ degrees

50

Note the dipole patterns above, at the calculated cutoff angles, are closer to –5 dB and –4 dB, leading to significant *spillover loss*--thus efficiency is low for this dish, especially in the H-plane dimension. The standard dipole array feed simply does not have enough gain to meet the –10 dB design goal. Given this, the *de facto* 50 percent efficiency (η) used above appears optimistic and was shown to be just that at a recent microwave conference in Texas. A few iterations of these formulae will indicate a *f*/D greater than 0.5 helps achieve the desirable characteristic by compensating for the antenna's beamwidth pattern; *i.e.,* the *prime focus* is closer to the edge than the center. For comparison, an *f*/D of 0.4 requires about 1.4 dB stronger signal at the edge (inverse square law) than at the center of the dish for constant illumination, while an *f*/D of 0.6 requires only 0.7 dB at the edge.[6] These values are derived from applying the classic power equation to the dish geometry:

$$P = 10 \, Log_{10} \, [\text{opposite} \, / \, \text{hypotenuse}], \text{ where P is in dB}$$

Less is More:
Common surplus MMDS antennas are designed for linearly polarized terrestrial signals—hence the dipole feed is a natural choice. The signals of most interest to amateur satellite enthusiasts, however, are predominantly circularly polarized; *e.g.,* the S-band signals from AO-40. Using a linear antenna to receive a circularly polarized signal nets a 3 dB penalty for the antenna above, resulting in a phase-corrected expectation of 21 dBi actual gain from this antenna.[7] Simply substituting an appropriately circular feed would seem to regain the lost 3 dB: just replace the dipole with a helix feed inside a cup feedhorn.[8] If, however, maximizing the antenna gain is also desired, two feed efficiency design issues need be addressed: 1) phase alignment and 2) losses due to feed geometry.

Phase alignment is simply assurance the polarity characteristics of the desired signal are mirrored in the reflector+feed so as to minimize losses. Unfortunately, the linear grid pattern of the subject surplus antennas will not effectively reflect a circularly polarized signal. The simplest solution is to cover the reflector surface with a reflective grid. I found aluminum screen wire (mesh) inexpensive and easy to fashion and support on the grid using small conductor wire interlaced in the grid.

Losses due to feed geometry include under-illumination, spillover, and feed blockage. Under-illumination and spillover are addressed by selecting an efficient circularly polarized feed matched to the *f*/D of the reflector. Feed blockage can be minimized with a coaxial support through the center of the helical feed. Since a helical feed element has symmetrical E- and H-plane patterns, there is no need for the dish's rectangular shape. I cut the grid reflector down to 26" (66 cm) square, which also lowers the wind loading, the visible profile, and the weight of the antenna—all good things. Since I now had a uniform 0.6 *f*/D and planned to improve the illumination efficiency considerably, I felt justified in modestly increasing the efficiency (η) factor to 55 percent in the gain calculation:

$$G = 10 * Log_{10}[0.55(4\pi/24.5)*(26*26)] \quad (\text{for } A, \text{ I substituted (length*width) for } \pi r^2)$$
$$G = 10 * Log_{10}[0.2821*676]$$
$$G = 22.80 \text{ dBic (minus } 1.0 - 1.5 \text{ dB for real-world edge diffraction losses)}$$

This smaller antenna with a circular feed actually has more net gain than the (larger) original one. If a circular feed horn is used, it may be appropriate to ignore the "corners" of the now-square dish and treat it as a circular paraboloid, using the traditional πr^2 area factor instead of the substituted length*width. A "dish equivalent" gain of 21.75 dBic results—still marginally better than the larger original dish.
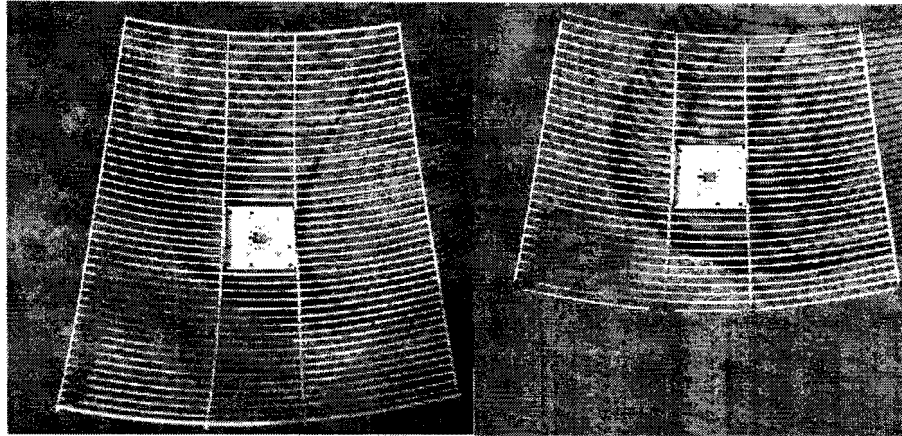
51

Figure 3: Before (38" x 26") and After (26"x 26")

Helix Feed Design:

With the reflector portion of the antenna now defined, attention is turned to the feed. I integrated several antenna design concepts, each incrementally contributing to an overall efficient design: 1) an end-fire monofilar helices to achieve circular polarization; 2) a cupped reflector to improve forward gain while simultaneously reducing the side lobes to maximize reflector illumination; and 3) design of the cupped feed reflector as a feedhorn to limit/eliminate spillover losses beyond the dish's edge.

A critical component of the antenna's overall performance is determined by the accuracy of the placement of the feed's *phase center* at the *prime focus* of the dish.[9] I tested a number of helices from 4-turns to 10-turns, using local MMDS video signals as my test source, and found the signal peaked from about the 180 degrees to 450 degrees (1/2-turn to 1-1/4 turn) points of the helix. The drop in signal is slight in moving the feed so the focus is located all the way towards the back of the cup, but is quite pronounced when moving the cup so the focus is located beyond the 450 degree point (towards the dish). Installing a cupped reflector had no measurable impact on this phenomenon. This is in general agreement with other references specifying a range of $\lambda/6$ to $\lambda/8$; a range of 0.6 – 0.85" (15-22 mm) for a nominal 2.401 MHz helix.[10]

Kraus describes a *cupped ground plane* as having "supergain" properties, but does not quantify this benefit.[11] K&W modeled such a construct and report a consistent 2 dB gain.[12,13] My own empirical testing confirms a notable gain, as much as 1 dB, for even a short helix. Kraus defines the parameters as: Diameter $\approx 0.75\lambda$ and depth = Dia/2.[14] These parameters produce a nominal S-band cup with 3.75 - 4" (10 cm) diameter and 1.75" (4.8 cm) deep.

But, I wanted to also use this cup as a feedhorn, and specifically to construct it so as to limit the spillover from the dish's edge. My idea was to place the helix phase center at the prime focus and then use the previously calculated edge-of-dish-cutoff (σ^E) of approximately 45 degrees as the (convenient) geometric limit for the depth of the cup; in effect, a helical feedhorn. Figure 4 depicts this geometry. Note how the 45 degree angle goes through the helix's first turn--the phase center-- and intersects the edge of the dish.

52
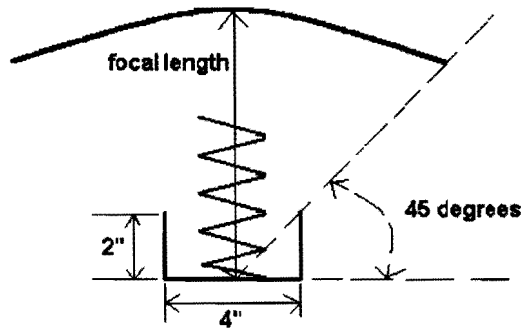
Figure 4: Dish Geometry

Design of helix feed itself was the last "paper" task in this antenna design exercise. As noted above, gain greater than a dipole array was required, but not so high as to concentrate too much energy at the center of the dish. The *ideal* helical pattern would be 90 degrees at –10 dB, with as wide a –3 dB (half power beamwidth) as possible. I built some simple computer models of this *ideal* helix and the –10 dB point for a 3-turn helix appears greater than 120 degrees, progressing to 90 degrees for a 4-1/2 to 5-turn helix.
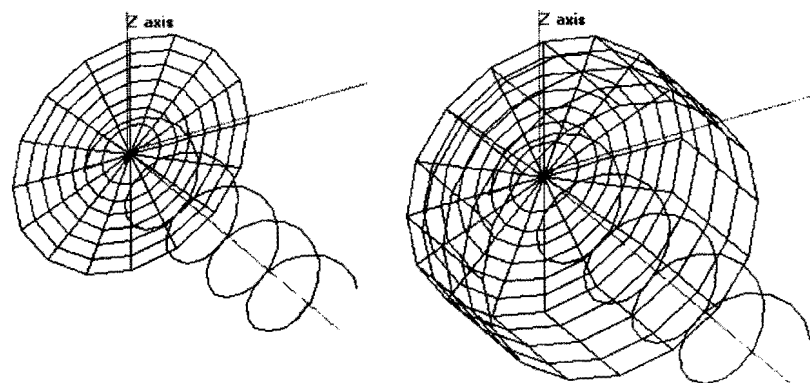
Figure 5: End-Fire Monofilar Helices Without and With A Cupped Ground Plane

Several more complex models were built—both with and without a cup—to analyze the *free space* behavior of the helices. These are depicted above in Figure 5, with the model on the right constituting more than 450 *wires* and more than 3,000 *pulses*. This exercise was started with a 1.5λ (6-turn) helix. Much of the literature is in dispute regarding the gain of longer helices, but the preponderance of the data converges on 1.5λ (roughly 6-turns) with 11.5 dBi maximum gain. [15]
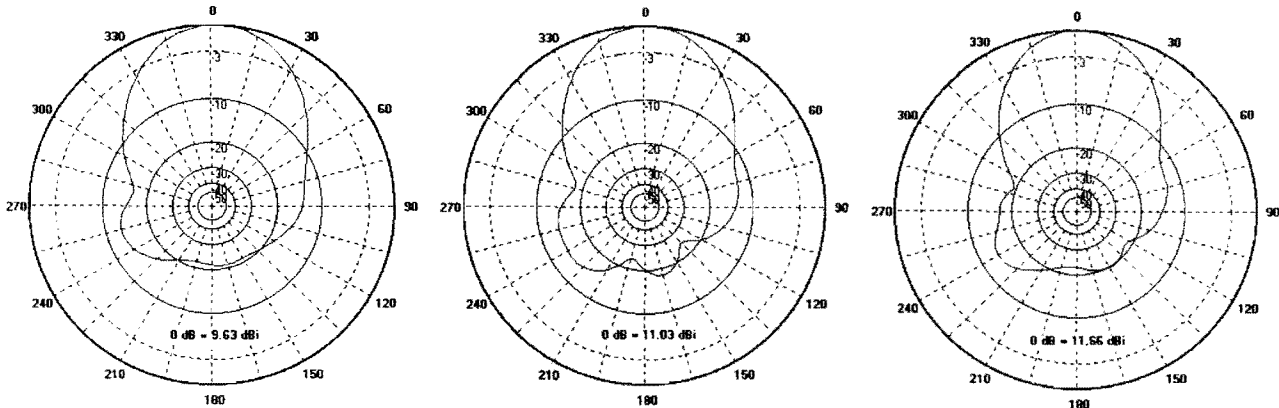
Figure 6: Free Space NEC Patterns for Helices of 4, 5, and 6-turns Inside A Cup

I modeled helices from 3-turns through 7-turns. Several are depicted above in Figure 6. Note the small, progressive changes in the gain and -3 dB and –10 dB points for each successively longer helix. The –3 dB points align well with the idealized patterns, but the –10 dB points, particularly noted in the sidelobes, are quite different. These patterns indicate a longer-than-ideal helix is needed to achieve the specified –10 to –13 dB cutoff. It appears from these patterns the 6-turn, or possibly even a 7-turn, helix is a better choice. I found this development surprising and disappointing, because I could not determine which data were correct. Review of the literature was unsatisfactory, as little is documented on helices this short. Since I could not resolve this discrepancy through research, I decided to do my own field testing. I hoped to either validate the NEC models or discard them as inaccurate. The test was conducted using a 2.4 GHz signal source (inside a coffee can), a test fixture to rotate the subject helix in 5 degree increments, and a semi-calibrated receiver--via a converted MMDS downconverter. [16] I tested helices with a 0.8 lambda diameter reflector from 3-turns to 7-turns and then repeated the tests with a 0.4 lambda deep cup.
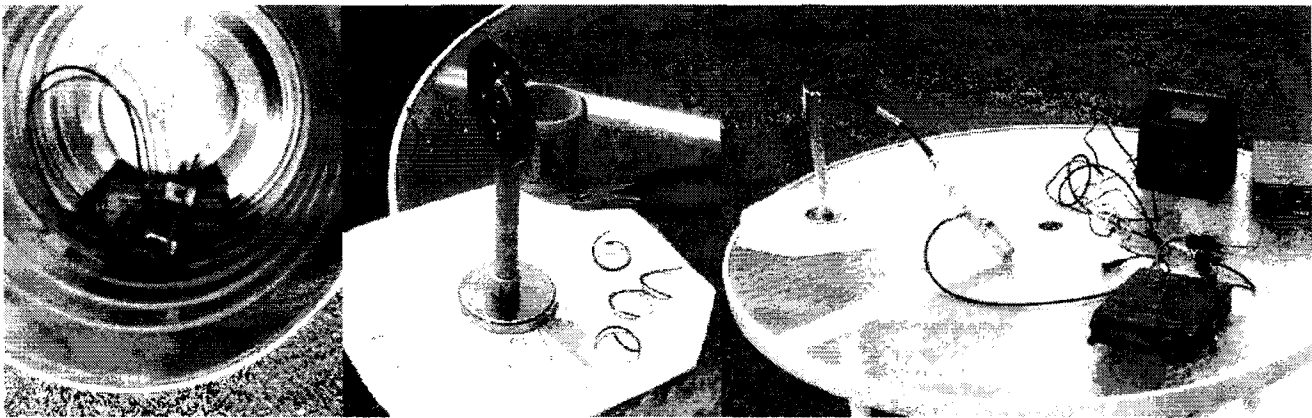
Figure 7: The Signal Source, The Test Fixture, and The Receiving Gear

Things kept getting worse. These empirical data indicate the helix patterns from the tests are generally representative of, but the half-power-beamwidth and rear lobes of the actual antennae are much worse than, the NEC models predicted. In consultation with Paul Wade, W1GHZ, it became apparent I had considerable reflections in my "test range" (also known as my patio). I then moved the test apparatus out to a vacant field and repeated the tests—braving the hot Houston sun and fire ants in August!

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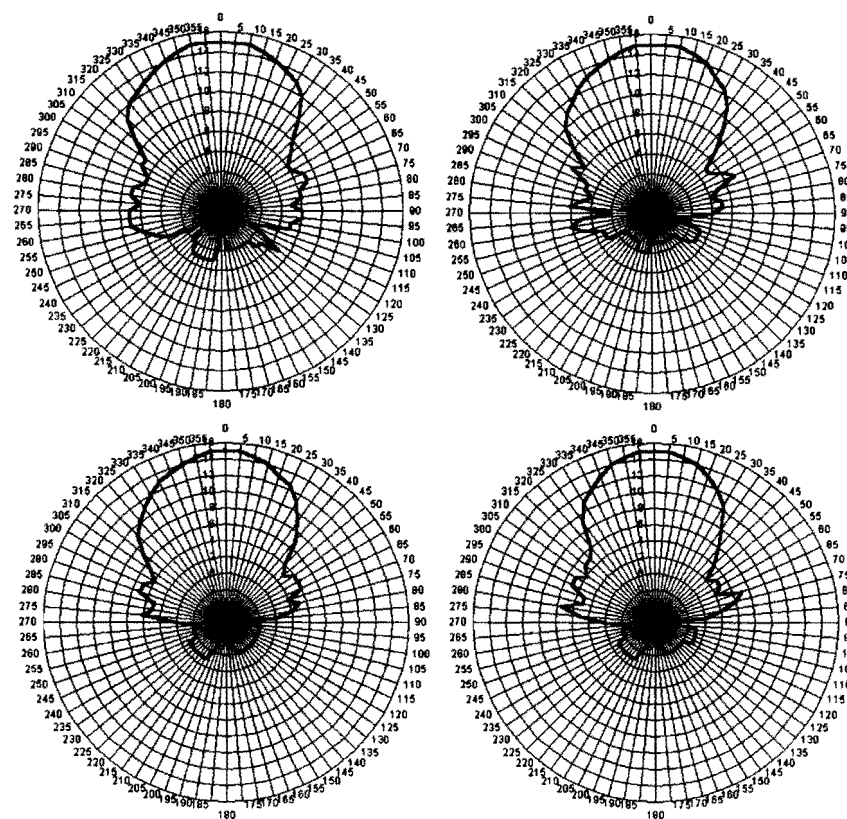
Figure 8: The Test Patterns Collected For 4, 5, 6, & 7-turn Helices With Cup

This subsequent testing produced more believable results, although still considerably below the performance predicted by the NEC models. I took all three data sets and ran the W1GHZ feed pattern program against them and produced an illumination/spillover analysis/graph for each case. [17] The results are summarized below. I now had three disparate "optimum" helix sizes: a 4-turn based on an "ideal" helix; a 7-turn based on NEC modeling; and a 6-turn based on my testing. Which one was correct? I needed to build it to find out.
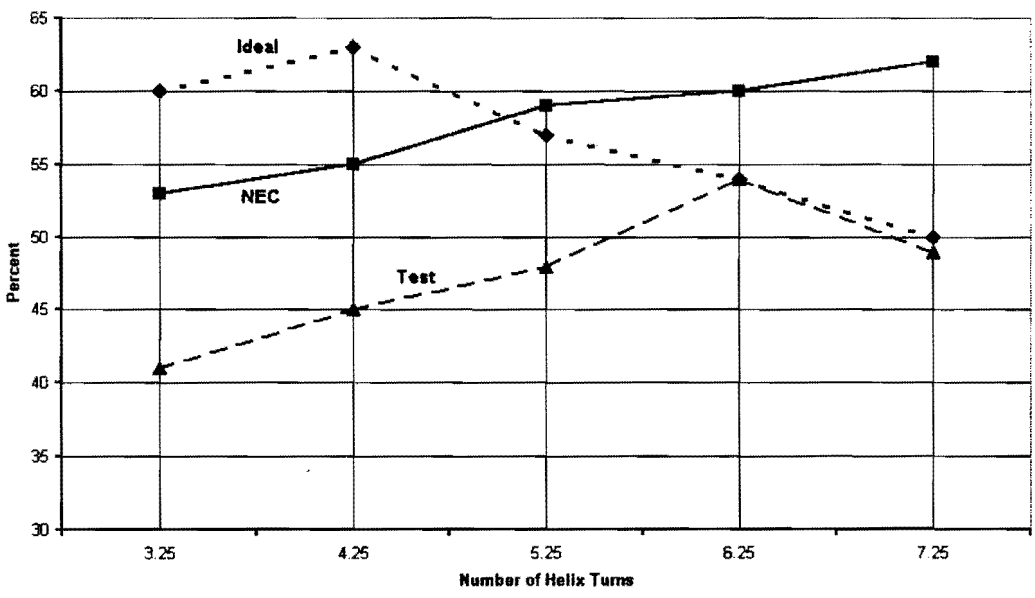
Figure 9: Maximum Possible Efficiency Per W1GHZ Feed Pattern Program

Construction:

Now the design was complete—except for the number of helix turns-- and building it was a matter of finding materials conforming to the design requirements. The helix itself was crafted from common copper house wiring—repeating a prior successful design.[18] This design utilizes a smaller-than-optimum diameter and close spacing of the first turn to effect a close match to 50 Ohms.
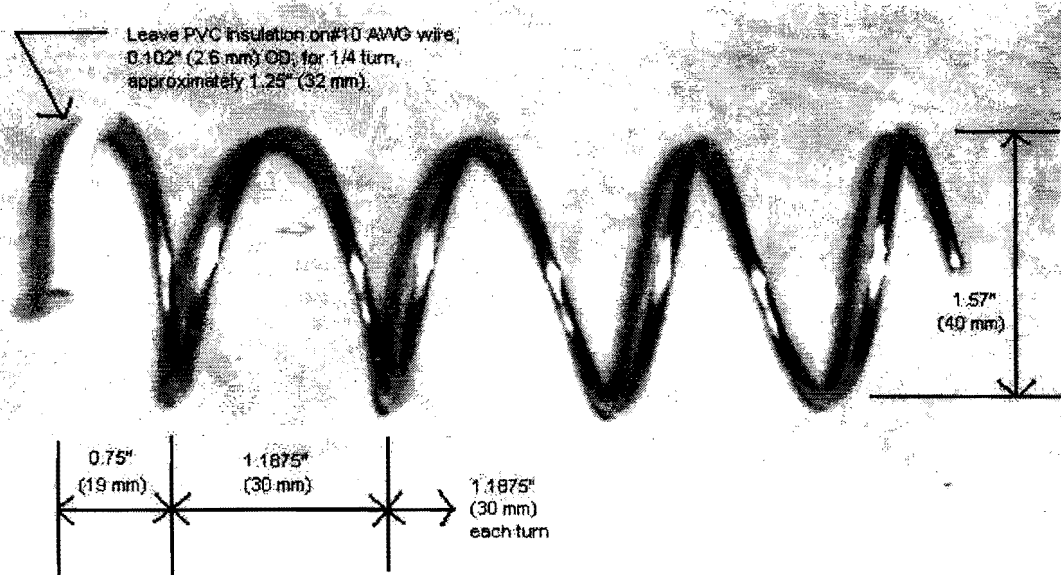
Figure 10: Helix Construction Details

Next, I searched for a suitable feedhorn. My previous use of a coffee can feed was convenient, but my ability to keep them from rusting was in serious doubt. I spotted an old MDS antenna in my junk pile that had a near-perfect 4" (10 cm) diameter aluminum feedhorn. I cut it down to a 2" depth and started the search for a coaxial support mechanism. I discovered ½" EMT fittings with a threaded connection on one end and a compression fitting on the other end. A pair of these and a short section of ½" EMT conduit is all that is required for support. This hardware is common and inexpensive, and provides both support for the feed and a cable route without creating additional aperture blockage.
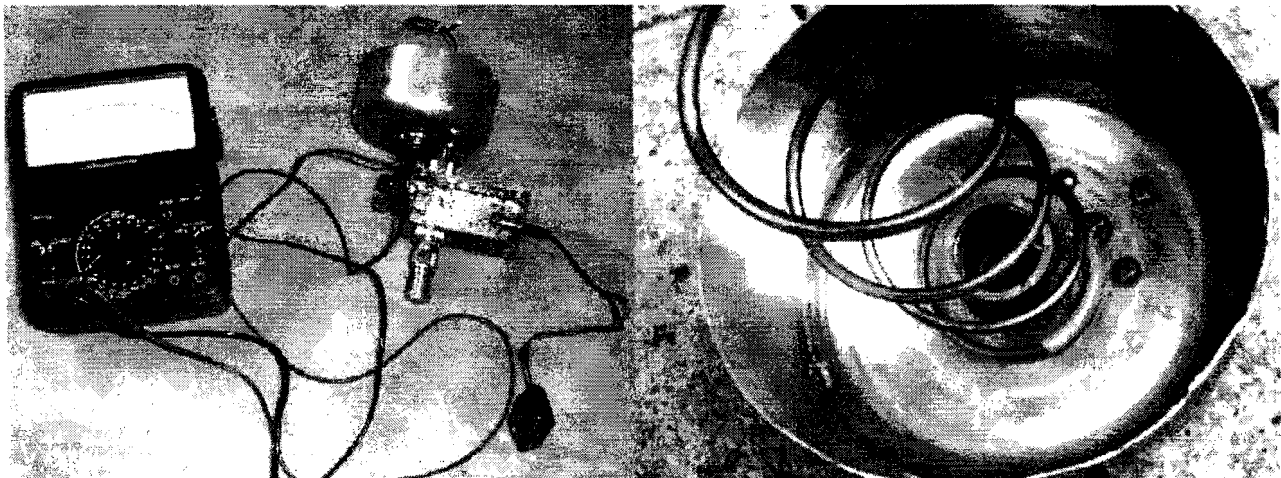
Figure 11: Tuning Using W4MVB's Bridge and the Helix Feed Connection

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I used a borrowed impedance bridge to adjust the feedpoint impedance match of the helix inside the cup.[19] Note the insulation was left on the #10 AWG wire for the first ¼ turn. By pushing the helix coil's insulated first ¼-turn against the back of the cup, a perfect 50 Ohm match was obtained. Figures 11 and 12 depict construction details. As mentioned above, the cut-down reflector was covered with aluminum screening cloth and secured with a weaving of small conductor wire.
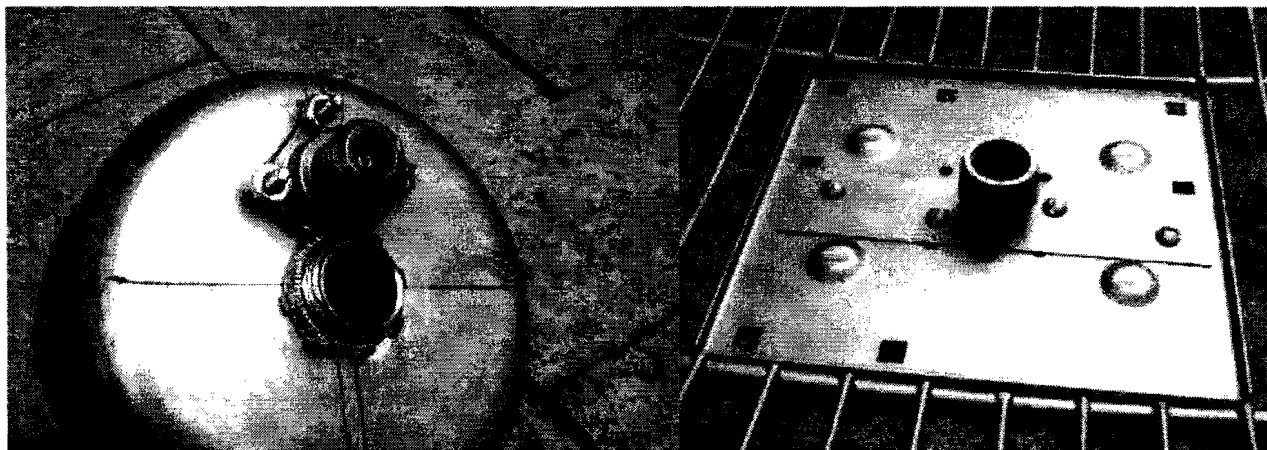
Figure 12: N-Connector / EMT Fittings and Reflector Plate Modification for EMT Fitting

The completed prototype was installed and immediately tested on UO-11, which provides an excellent, repeatable test signal.[20] Later tests on AO-40's S2 telemetry beacon provided very positive feedback on the antenna's performance: at 30,000 km the signal was 9 S-units above the noise on the author's system and telemetry was still solid at apogee (62,000 km) with signals at 5-7 S-units above the noise. You can see the completed prototype below. Note the preamp connects directly to the feed and the preamp's output cable is routed through the ½" EMT conduit.
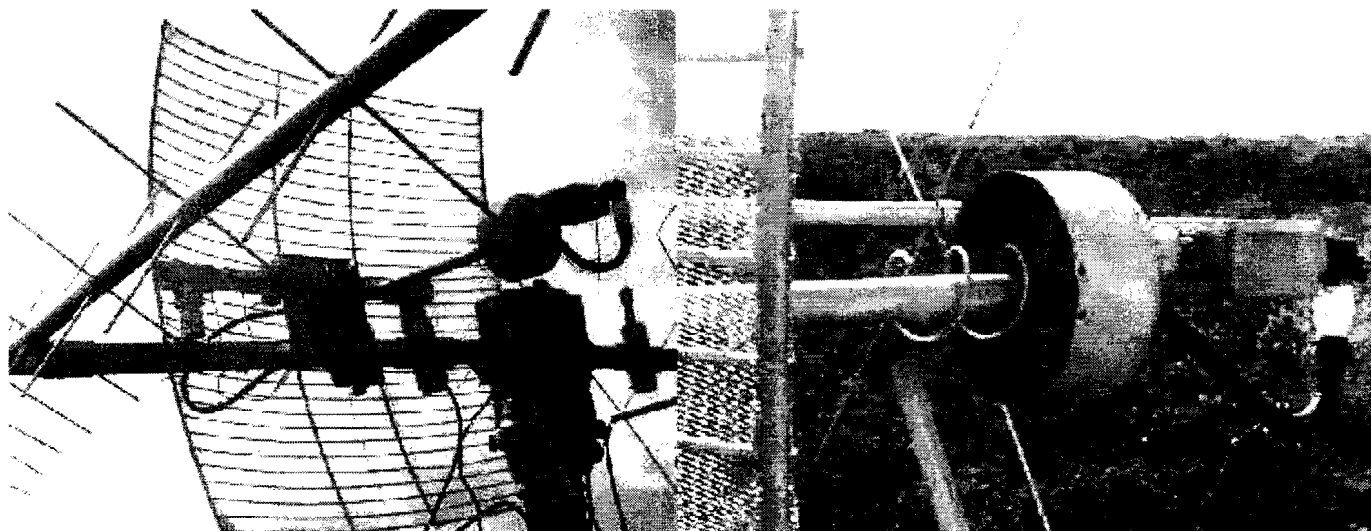
Figure 13: The Prototype Installed (barely) Between the Rotor and 70 cm Yagi

Final Testing:

I still needed to determine the optimum number of turns for the helix feed. I did another round of tests with the completed antenna separated 100 meters from the signal source; this time using a G0MRF 2.4

GHz oscillator kit in a coffee can.[21] The results of this final testing compared favorably with the NEC models, but show no discernable performance difference between 5-1/4 turns and 6-1/4 turns. A 6-1/4-turn helix, with approximately 11.5 dBi gain and -10 dB beamwidth of a little over 90 degrees, was chosen for the final design. The 7-turn helix has additional gain and would be a good choice for a shallower dish with an *f*/D of 0.75, or if a better G/T was desired at the sacrifice of a little efficiency.
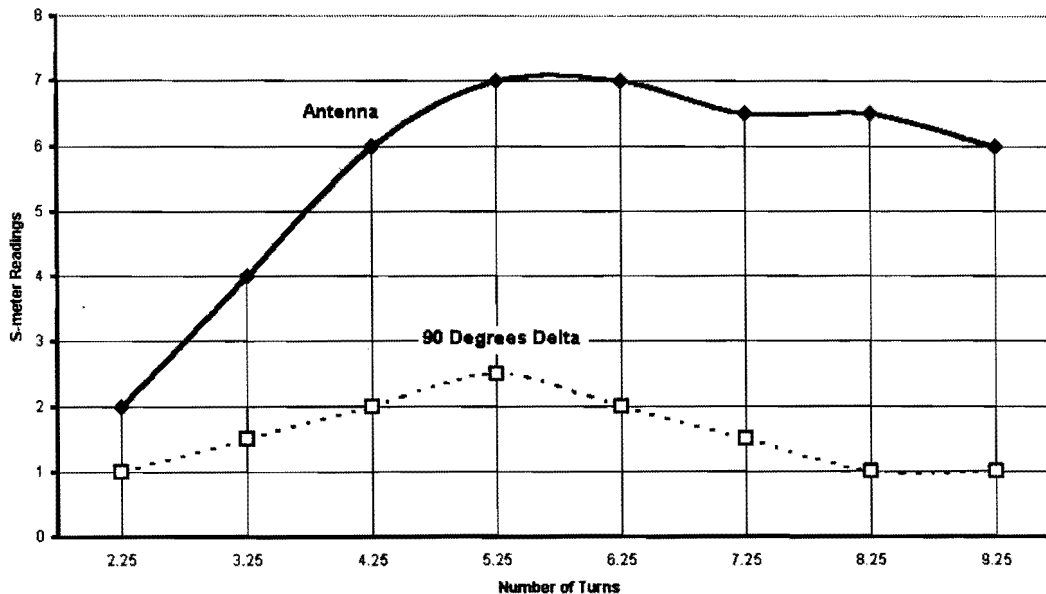
Figure 14: Results of Final Antenna Testing

The results of the final testing shown above also include a rough measurement of circularity. All of the primary readings were taken with the antenna in the horizontal plane (original grid) and the antenna was manually rotated to vertical and readings taken again. These circularity readings are relative delta values (from the horizontal reading) and were quite limited by the resolution and range of the S-meter on my test radio. Still, a strong positive correlation to number of turns is indicated.
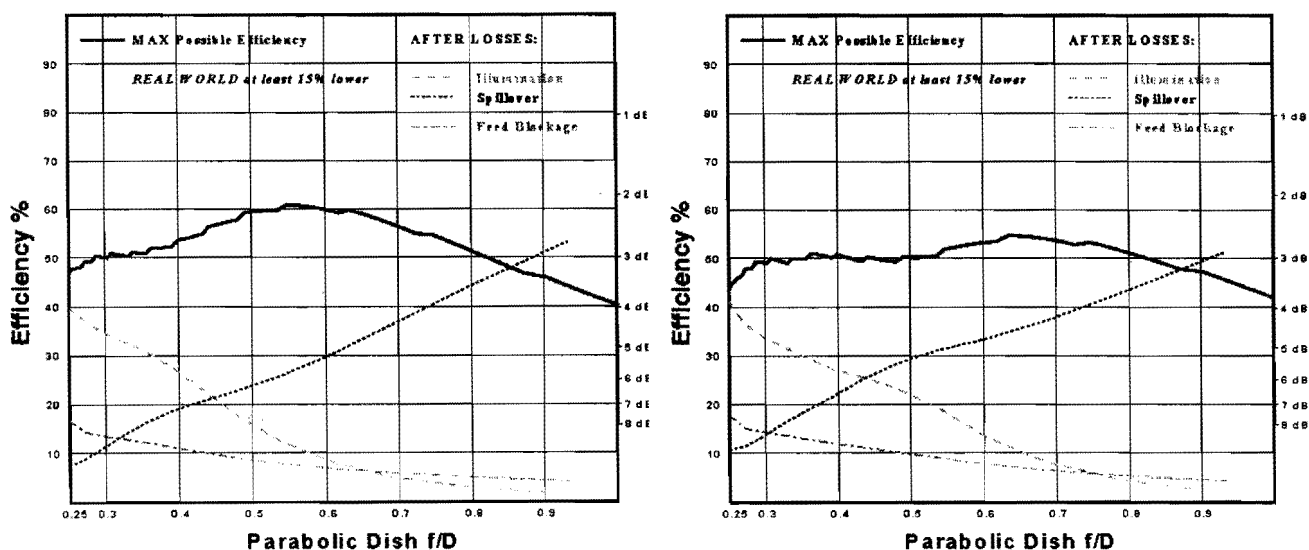
Figure 15: FEEDPATT.exe Comparison of 6-1/4-Turn Helix With Cup: NEC Model v. Tested

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As can be seen in Figure 15, achieving a 55 percent efficiency in "the real world" seems unlikely. The author's dish, with an *f*/D of 0.6, has the edges 85 percent of the distance to the center. An *f*/D greater than 0.5 compensates somewhat for the decreasing illumination at the dish's edge, called *taper*.[22, 23] Table 1 offers guidelines for helix+cup lengths based on dish geometry. If a conventional reflector plate is used in lieu of the cupped reflector, add 1/2 turn to these recommendations. I followed K9EK's recommendation to add ¼-turn to all helices to improve the return-loss figure.[24]

F/D Ratio	No. Turns
0.75	7.25
0.7	6.75
0.6	6.25
0.55	5.75
0.5	5.25
0.4	4.25
0.3	3.25

Table 1: Helix Turns

Conclusions:

The author's first home-brew dish antenna was built without much analysis, but proved successful enough to warrant further thought. This subsequent effort focused on analysis first and construction second. Careful consideration was given to designing an antenna easy to replicate with common hardware materials. The integration of several ideas--a circularly polarized feed, a smaller size reflector suited to that feed, a feedhorn matched in geometry to the reflector, and a helix matched in gain to the dish's geometry--all contributed incrementally to producing a high performance, low profile antenna system. All indications are this antenna system performs well, even if not to the "paper" design specifications. The transponder noise floor is detectable at 40,000+ km. Success!

Potential improvements lie in the area of reducing the feed's aperture blockage—perhaps by reducing the size of the cup or using a back-fire helix with no cup.[25] In the end, the author concludes the helix is an easy-to-build and effective, if unimpressive, feed for an S-band dish. Much more work, with better test equipment and methodology, is required to develop this concept further. The helix feed's strongest point of recommendation is ease of construction, not its performance attributes.
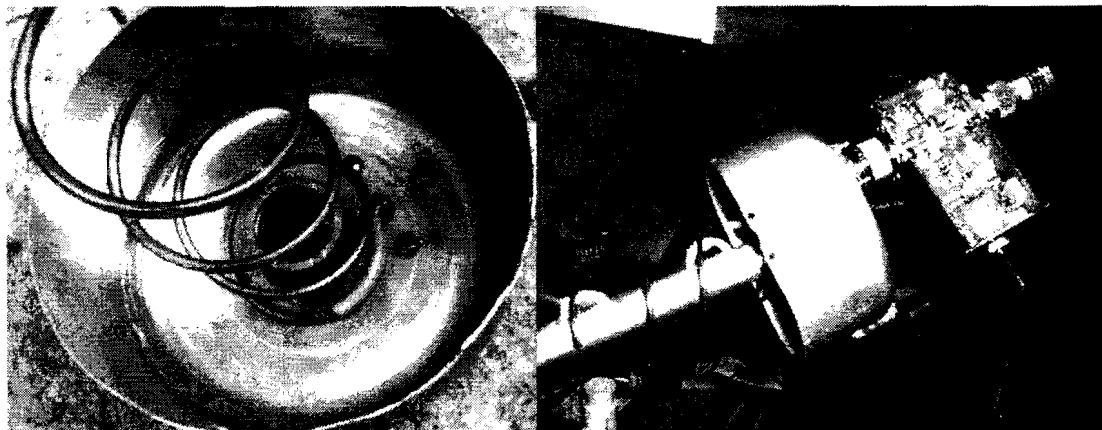

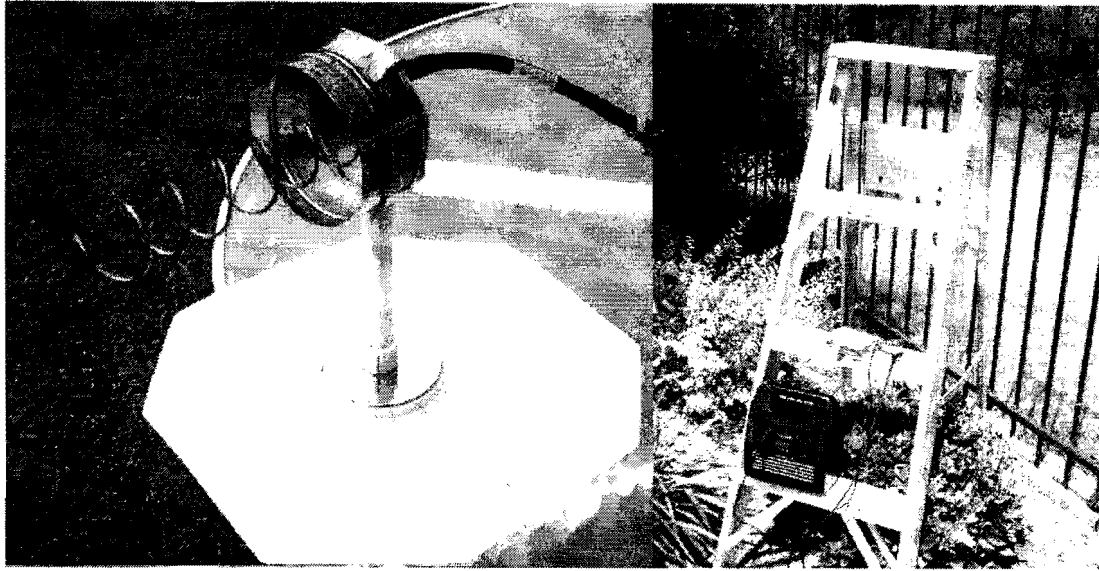Figure 16: Helix Connection Inside Cup and Bench Testing With Bridge

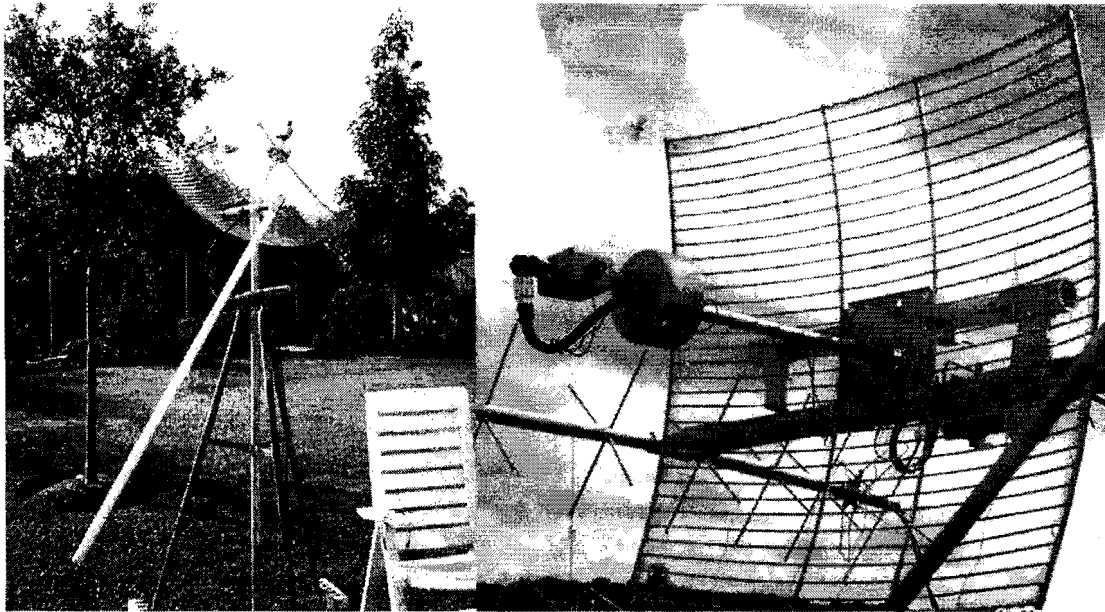Figure 17: Test Helix On 5 Degree Stand and Remote "Duckling" Signal Source

Figure 18: Portable Setup On Tripod In Back Yard and Installed on Antenna Boom

References:

1. Brown, Gerald R., "YAHE (Yet Another Helix Experiment)," *Proceedings of the AMSAT-UK Colloquium 2001*, July 2001, pp. 89-94.
2. Long, Howard, "Modify an Analogue Sky TV Dish for AO-40 S-Band," http://www.g6lvb.com/60cm.htm; and "Entry Level AO-40 Capable Satellite Station," *Proceedings of the AMSAT-UK Colloquium 2001*, July 2001, pp. 67-80; "Build an Entire AO-40 Ground Station for Under $500," http://www.g6lvb.com/el/index.htm.
3. A model was built with a resonant dipole and three equidistant reflectors using NEC4Win95: http://www.orionmicro.com/n4w95/n95page.html.
4. Wade, Paul, N1BWT (W1GHZ), *Online Microwave Antenna Book*, Chapter 4, "Parabolic Dish Antennas": http://www.qsl.net/n1bwt/contents.htm.

5. *Ibid*, Chapter 11, "Parabolic Dish Feed—Performance Analysis."

6. *Ibid*, Chapter 4, "Parabolic Dish Antennas, Practical Dish Antennas, Feed Patterns."

7. Davidoff, Martin, *The Radio Amateur's Satellite Handbook*, ARRL, 1998, pp. 9-4 – 9-7.

8. Brown, *Ibid*.

9. Wade, Chapter 6.0.3 Antenna Efficiency.

10. Martin, Sven, "Antenna Diagram Shaping for Pseudolite Transmitter Antennas..." Institute of Flight Guidance and Control, Technical University of Braunschweig, Germany. Also see the author's additional *phase center* testing with a local noise source at: http://groups.yahoo.com/group/AmsatTech/files/phase_center_09.JPG.

11. Kraus, John D., *Antennas*, 1988, Figure 7-16c, p. 281.

12. King & Wong, "Characteristics of 1 to 8 Wavelength Uniform Helix Antennas," *IEEE Transactions*, AP-28, No. 2, March 1980, pp. 291-296.

13. Trueman, Kubina, & Slater, "Modelling Helix Antennas with NEC4," *IEEE Transactions*, 1997, pp. 1584-1587.

14. Kraus, *Ibid*.

15. Emerson, Darrel, "The Gain Of An Axial-Mode Helix Antenna," *Antenna Compendium Volume 4 (ARRL)*, 1995, pp. 64-68; also: http://ourworld.compuserve.com/homepages/demerson/helix.htm.

16. ICM Manufacturing, 5 MHz crystal oscillator: http://www.icmfg.com/osc.html.

17. Wade, Paul, W1GHZ, feed pattern program, FEEDPATT.exe, available for download at: http://www.qsl.net/n1bwt/contents.htm.

18. Brown, Gerald R., "16-Turn Helix Antenna," http://members.aol.com/k5oe.

19. Koehler, Jim VE5FP, & Rawson, Eric KN6KC, "Putting Together a L/S Band Antenna System for the Phase 3D Satellite," *The AMSAT Journal*, Sep/Oct 2000, pp. 13-19.

20. Wallis, Clive. G3CWV, OSCAR-11 Satellite, http://www.users.zetnet.co.uk/clivew/index.htm.

21. Bowman, David, G0MRF, http://www.g0mrf.freeserve.co.uk/source2.htm.

22. Nelson, Robert A., Antennas, "The Interface with Space," *Via Satellite*, Sept. 1999, pp. 6-7, also: http://www.aticourses.com/antennas_tutorial.htm.

23. *EW & Radar Systems Engineering Handbook*, see: http://www.ewa-australia.com/handbook/ANTENNA%20INTRODUCTION%20-%20BASICS.htm.

24. Krome, Ed, K9EK, *Mode-S, The Book*, pp. 114-121; also "Dish Feeds For Mode S Reception," *The AMSAT Journal*, Sept/Oct. 1994.

25. Nakano, Yamauchi, & Mimaki, "Backfire Radiation from a Monofilar Helix with a Small Ground Plane," *IEEE Transactions on Antennas and Propagation*," Oct. 1988, pp. 1359-1364.

Satellite Awards

Bruce Paige, KK5DO
AMSAT & ARRL Awards Manager

Operating on a satellite is a lot of fun. Not only do you get to speak with people all over the world but you also collect a lot of interesting QSL cards. With those confirmed QSL cards, you can collect a few pieces of wallpaper. Actually, you can collect a lot of wallpaper. Awards come in many different flavors. There are some sponsored by AMSAT, some sponsored by the ARRL and others sponsored by other countries.

If you are looking for a very easy award to earn, there is nothing easier than **AMSAT's Satellite Communicators Club Award** (*Figure 1*). In fact the only thing you have to do to earn this certificate is to make your first satellite contact. This is the only award that does not require a confirmed QSL card. Send the info about your contact to:

> AMSAT Headquarters
> Attention AMSAT SCC Manager
> 850 Sligo Ave.
> Silver Spring, MD 20910

The cost is $1 for members and $2 for non-members.

Another award from AMSAT is the **Oscar Satellite Communications Achievement Award** (*Figure 2*). This award is for 20 confirmed contacts with a station in another state, DXCC country or Canadian call area. If you work six VE3's then you can only submit one of them towards this award. These contacts can be on any satellite and any mode. To submit for this award, you need to send copies of the front and backs of your confirmed QSL cards to:

> AMSAT Awards Manager
> Bruce Paige, KK5DO
> PO Box 310
> Alief, TX 77411

The cost is $3.50 for members and $5 for non-members. Also send two units of postage for your return certificate.

Along the same line as the Oscar Satellite Communications Achievement Award are the Oscar Sexagesimal Award and the Oscar Century Award. The **Sexagesimal Award** (*Figure 3*) requires the previous 20 confirmed contacts plus another 40 for a total of 60. The **Oscar Century Award** (*Figure 4*) is for 100 confirmed contacts, which includes the 60 from the Sexagesimal Award. Both of these awards are submitted to the AMSAT Awards Manager.

South Africa sponsors the **South Africa AMSAT Satellite Communication Achievement Award** (*Figure 5*). This award is for 25 confirmed satellite contacts on any Phase 2 satellites. These satellites are Fuji-Oscar 20/29, AO-21 (no longer operational), AO-27 and RS-10/12/15. The costs for this award are the same as the previous AMSAT Awards and are also sent to the AMSAT Awards Manager.

The next AMSAT award is the **W4AMI Satellite Operator Achievement Award**. This award requires no confirmed QSL cards but does take a bit of record keeping. You get credit for each 1,000 satellite QSO's up to 5,000. Please submit your log (computer generated or handwritten) to W4AMI Awards Manager at AMSAT headquarters. The cost is the same as the previous awards.

The ARRL sponsors several awards. They are the **Worked All States** (WAS) Award with Satellite endorsement, the **VHF/UHF Century Club** (VUCC) Award, the **DX Century Club** (DXCC) Award and **Worked All Continents** (WAC) Award.

For Worked All States, you must work someone in each of the 50 states through any amateur satellite in any mode. For the VHF/UHF Century Club Award, you must work someone in 100 different grid squares. Endorsements are available for every 25 grid squares after the first 100. The final award, DXCC, requires you to make a satellite QSO with 100 different DXCC countries. For **Worked All Continents** (WAC), you work someone on each of the 8 continents. More information on these awards can be found on the ARRL's website. http://www.arrl.org, then click on Operating Awards.

Finally, I would like to introduce the newest AMSAT Award. It starts with contacts on or after November 1, 2001. The award is the **AMSAT Elmer Award**. The complete rules for this award are as follows.

This award has 3 levels, Beginner, Intermediate and Expert. The Certificate for this award is being designed and not available for this publication.

Beginner Level
Work 1 School Club Station
Work 4 YL Ops
Work 4 Young Ops (16 and younger)
Work 10 Ops that have had their license for less than 2 years at the time of contact

Intermediate Level (includes contacts from Beginner Level)
Work 2 School Club Stations
Work 8 YL Ops
Work 8 Young Ops (16 and younger)
Work 15 Ops that have had their license for less than 2 years at the time of contact
Work 2 Ops as their '1st Satellite Contact' (ever, not just on a particular satellite)

Expert Level (includes contacts from Intermediate Levels)
Work 3 School Club Stations
Work 12 YL Ops
Work 15 Young Ops (16 and younger)
Work 25 Ops that have had their license for less than 2 years at the time of contact
Work 4 Ops as their '1st Satellite Contact' (ever, not just on a particular satellite)

Any satellite may be used for these contacts but contacts must be made by Voice or CW. No packet contacts allowed. Contacts with the ISS, Shuttle or any other manned spacecraft are not to be used for this award.

Contacts must be made on or after November 1, 2001.

Call signs may be used only once. Therefore, if a call sign fits multiple categories, it is your choice as to which category you claim it for (i.e., Mahana, W5BTS, could be claimed for YL op, Young Op and Op licensed less than 2 years). School Club call signs count only towards the School Club category.

No QSL cards are required, however, random checks with the operators listed will be performed.

To submit for the award send a list in date/time order with the following information:
Call Sign/Date of Contact/Time of Contact/Satellite/Category to the AMSAT Awards Manager, KK5DO.

For category please use:
YL for YL ops contact
Teen for Young ops
First for 1st Contact
New for ops less than 2 years
School for School Club Station

Sample

Call Sign	Date	UTC	Satellite	Category
ZZ2ZZ	05 Nov 2001	0300z	UO-14	YL
ZZ1ZZ	06 Nov 2001	0415z	UO-14	YL
ZZ1ZY	06 Nov 2001	0425z	AO-10	Teen
ZZ1ZX	07 Nov 2001	0530z	AO-10	First
ZZ3ZX	07 Nov 2001	0530z	AO-10	New
ZZ4AA	08 Nov 2001	0400z	UO-14	School

A certificate is available for $3.50 for AMSAT members and $5 for non-AMSAT members. Two units of postage are required for return of your certificate.

Various magazines, countries and ham groups have other awards. There is even one from Russia, the Cosmos Award. So you may have to check around to find them. Should you have any questions about any of the AMSAT or ARRL Awards, I would be happy to answer them. Please send them to me via snail mail or the preferred method, email kk5do@amsat.org

Please keep in mind that although you might like to collect awards and need another Ops QSL card, it is for your benefit. It would be wise to send your card along with a SASE or if overseas, with SAE (including an IRC or green stamp). Also, be courteous on the satellites, especially the FM birds. If you collect grid squares and someone does not give his on the air, don't keep asking 'What is your grid square?' You use up valuable transponder time doing that and it is very easy to look the grid up using an electronic database or website. You should also listen. The Op probably gave his grid square on the last QSO or will give it again on the next.

73 and good luck on chasing your favorite award
Bruce, KK5DO

Figure 1
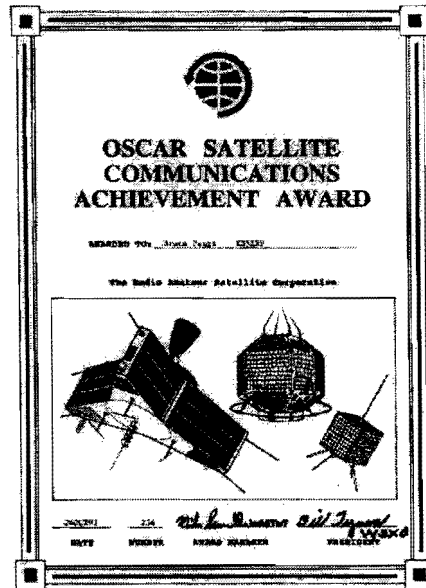
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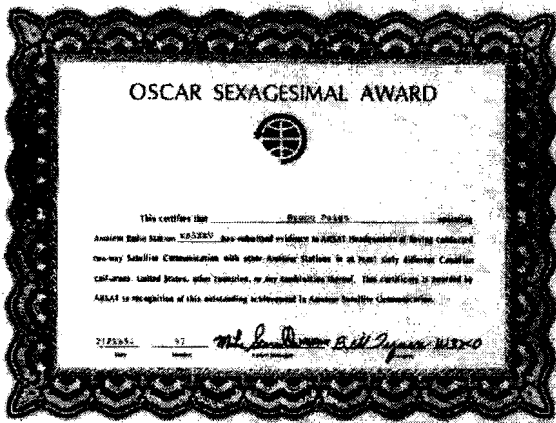
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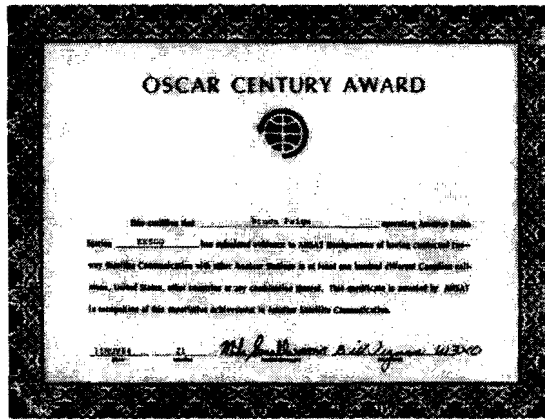
Figure 4

Figure 5

2001: A Moonbounce Odyssey

Executive Director, The SETI League, Inc.

Abstract

On numerous occasions during the past four decades, several of the world's largest radio telescopes have been used to reflect interesting microwave signals off the Lunar surface, introducing hundreds of the world's amateur radio operators to the exotic world of EME (Earth-Moon-Earth) communications, or moonbounce. Operating under club callsign W2ETI, radio amateurs at the nonprofit, grassroots SETI League recently had an opportunity to return the favor, by providing astronomers at the Arecibo Observatory with a highly stable, precisely calibrated moonbounce signal with which to test their equipment. In the design, construction, and operation of their *Lunar Reflective Calibration Beacon for Radio Astronomy and SETI* (funded in part by a NASA small equipment grant administered by the American Astronomical Society), these radio hams have demonstrated that the difference between amateur and professional involves neither scientific rigor nor technological prowess, but rather the size of the paycheck.

Introduction: 23 cm EME

Radio amateurs have been exploiting the Earth-Moon-Earth (EME, or moonbounce) communications path for forty years, utilizing the lunar surface as a passive reflector to extend the range of VHF, UHF, and microwave signal propagation. As a communications satellite (affectionately known as OSCAR 0), our Moon represents a low-gain transponder with only about 6 percent surface reflectivity. Its distance from the Earth is about ten times greater than that of satellites in the Clarke goesynchronous orbital belt. The resulting high free-space isotropic path loss, coupled with various fading mechanisms, makes EME communications a challenge for the advanced amateur. Nevertheless, the ease of visually tracking this satellite makes the Moon a popular target.

The very first successful amateur EME communications occured in the 23 cm ham band, at a frequency of 1296 MHz, and this remains a popular frequency for contemporary moonbounce activity. A significant portion of both amateur and professional radio astronomical research is conducted in the adjacent 21 cm spectrum, at the 1420.40575 MHz emission frequency of neutral interstellar hydrogen. The typical hydrogen-line radio telescope (Figure 1) strongly resembles the low-power, low-cost (i.e., receive) half of a 23 cm EME station. Thus, many radio astronomers are in a position to receive amateur 23 cm EME emissions by merely tuning their receivers slightly lower in frequency (see Figure 2). In fact, members of the nonprofit, membership-supported SETI League (who have collectively put 105 small radio telescopes on the air worldwide) frequently use weak amateur moonbounce signals to verify the proper operation of their equipment.
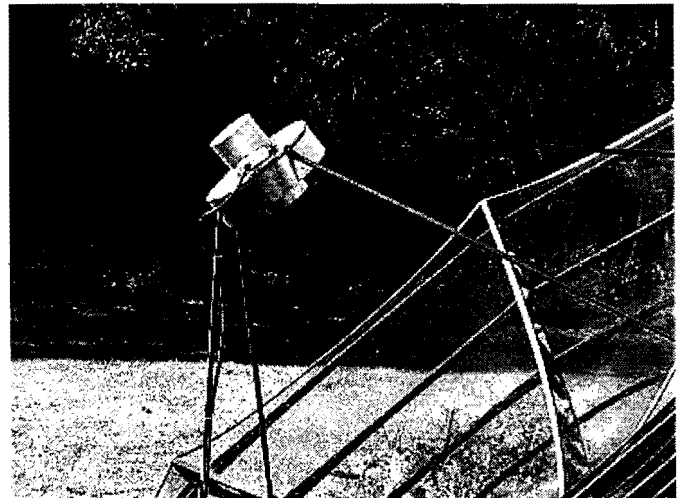

Figure 1
Typical Hydrogen-line radio telescope

Searching for a Pioneer

Professional radio astronomers also require stable, weak extra-terrestrial signals to calibrate

their much more sensitive receiving systems. For the past quarter century, a popular calibration source has been the weak microwave telemetry beacon aboard NASA's Pioneer 10 interplanetary space probe (Figure 3). Even over distances exceeding the radius of our solar system, this weak beacon has been detectable in waterfall spectrograph displays (Figure 4) using sensitive receivers on the world's great radio telescopes, such as the famed Arecibo observatory in Puerto Rico (Figure 5).

Figure 2
Amateur 1296 MHz EME signals received on an amateur 1420 MHz radio telescope, after digital signal processing

Figure 3
NASA Pioneer 10 interplanetary probe (JPL image)

In March of 2000, SETI League president Richard Factor, WA2IKL (Figure 6) chanced to be visiting colleagues at Arecibo, as they were conducting observations in the SETI Institute's Project Phoneix targeted search for intelligently generated signals of extraterrestrial origin. For the

first time, those radio astronomers found themselves unable to receive the trusty old Pioneer 10 beacon. The spacecraft was now at a distance of about 7 billion km from Earth. Link analysis (Table 1) revealed the Pioneer 10 downlink signal to be about one dB weaker than the detection threshold of the Project Phoenix digital signal processors.

Figure 4
Pioneer 10 beacon as received at Arecibo, displayed on the Project Phoenix spectrograph (SETI Institute image)

Figure 5
Arecibo Radio Observatory (NAIC photo)

Xmtr Output =	8 W = +39 dBm
Xmtr Freq =	2320 MHz
Ant Gain =	+33 dBi
EIRP =	+72 dBm
Path Loss =	301 dB
Incident Pwr =	-229 dBm

Table 1
Link Analysis, Pioneer 10 beacon (ca. March 2001)

Figure 6
SETI League president Richard Factor visiting the
Arecibo Radio Observatory (SETI League photo)

frequency accuracy and stability is required. This is accomplished by locking all frequency-determining stages to a Thunderbolt GPS-disciplined reference oscillator (Figure 8) generously provided by Trimble Navigation, through the good offices of member Art Lange, W6RXQ. This drives a Hewlett-Packard synthesized signal generator with its own frequency counter for cross-verification (Figure 9), both obtained at pennies on the dollar through the *eBay* internet auction site. A cascade of linear solid state amplifier stages from N2CEI at Down East Microwave (seen in Figure 10, atop a DC power supply also obtained through eBay) bring the transmit level up to 20 watts, after feedline losses half of which reaches the antenna.
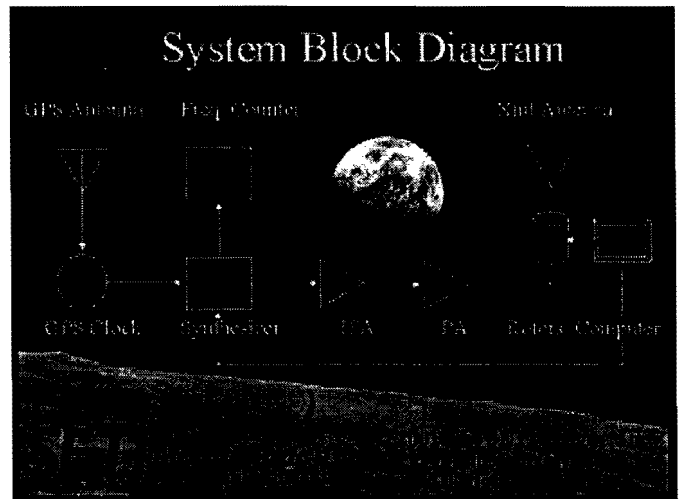

Figure 7
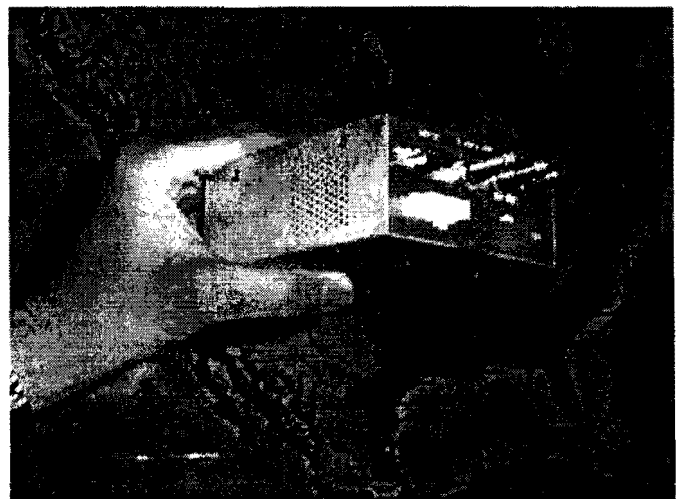W2ETI 1296 MHz EME Beacon block diagram

Remembering the numerous occasions on which Arecibo and other giant radio telescopes had been activated for EME DXpeditions over the years, Factor suggested that radio amateurs might be in a position to return the favor, by developing an amateur EME beacon to provide a weak, stable calibration signal for the use of amateur and professional radio astronomers alike. The resulting system received modest NASA funding through the American Astronomical Society's small equipment grant program, and went on the year just one year later. With the exception of minor outages for maintenance and redesign, the beacon has been on the air ever since, illuminating the Moon at 1296.000 MHz any time it is above the horizon from Factor's New Jersey QTH.

Beacon Basic Blocks
A block diagram of the W2ETI 23 cm EME beacon appears as Figure 7. To prove useful as a calibrator for radio telescopes, the utmost in

Figure 8
Trimble Thunderbolt GPS-disciplined clock

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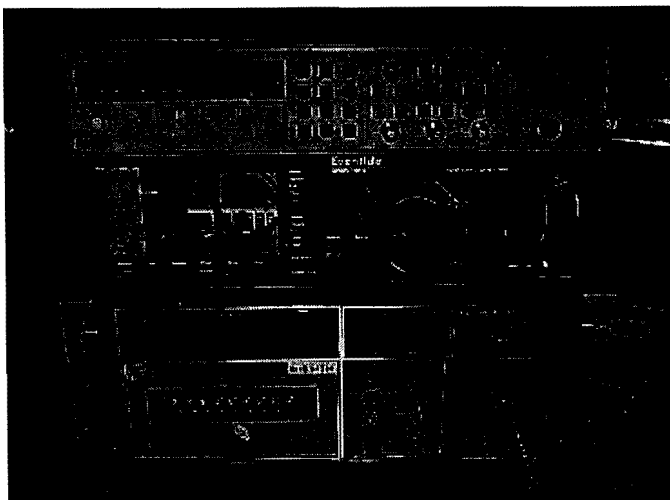
Figure 9
EME beacon exciter (see text)
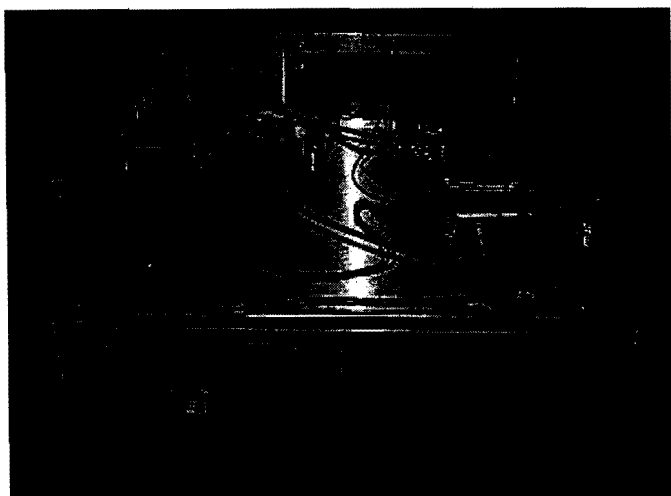
Figure 10
EME beacon intermediate power amplifiers (see text)

using an LL Grace Kansas City Tracker board obtained through AMSAT. The Nova software suite contributed by Mike Owen, W2IP, locates the moon and does much more, as shall be seen below. Figure 12 shows the station computers, yet another eBay acquisition.
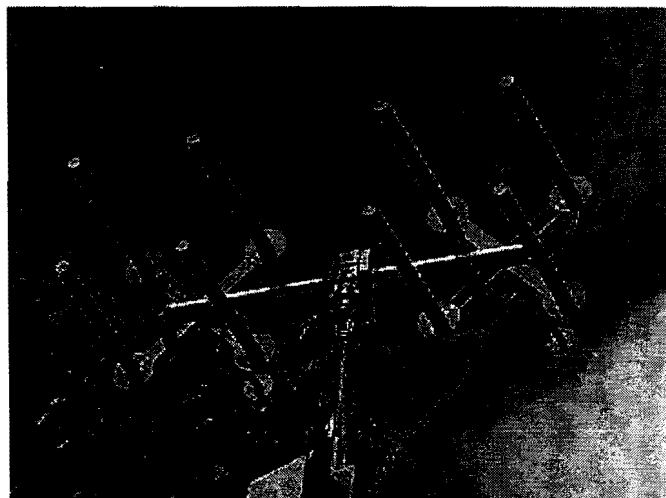

Figure 11
EME beacon antennas; four RHCP and four LHCP helices

Figure 12
W2ETI station computers (see text)

The antenna (Figure 11) consists of an array of four 15-turn RHCP helices for transmit, courtesy of SETI League member David Clingerman, W6OAL, of Olde Antenna Labs. A second quad helix array, this one LHCP, allows reception of the mirror-reversed EME echoes. Each quad array produces +24 dBic of gain. A parabolic reflector of even modest size would produce higher gain, hence stronger echoes. However, this would require precise lunar tracking, because of the resulting narrow beamwidth. By using more modest antennas, tracking precision is reduced, an important consideration for the continuous, unattended operation which this beacon requires.

The antennas do in fact track the Moon in real time, rotated in azimuth and elevation by a set of Yaesu G5600B rotors, under comuputer control,

Note the power amplifier indicated in Figure 7, a stage not implemented in the EME beacon's initial configuration (but to be discussed later). Without it, the SETI League 23 cm EME beacon achieves an effective isotropic radiated power of +64 dBm, and its echoes illuminate the Earth at an isotropic power level of -207 dBm, as indicated in Table 2. Comparing to the Pioneer 10 beacon specifications in Table 1, you will note that this is a

signal about 22 dB stronger than the calibrator previously used at Arecibo.

Xmtr Output	**= 10 W**	**= +40 dBm**
Xmtr Freq	**= 1296 MHz**	
Ant Gain	**= +24 dBi**	
EIRP	**= +64 dBm**	
Path Loss	**= 271 dB**	
Incident Pwr	**= -207 dBm**	

Table 2
Link Analysis, W2ETI EME beacon (ca. March 2001)

First Light

Project Phoenix, which purchases dish time at Arecibo, had scheduled a four-week long observing run to begin in early March of 2001. Because the EME propagation path varies widely over time, it was desired to schedule First Light (initial testing of the EME beacon) for a date and time which would maximize our success potential. Fortunately, the Nova software package facilitated such optimization, as indicated in Figures 13 through 18.
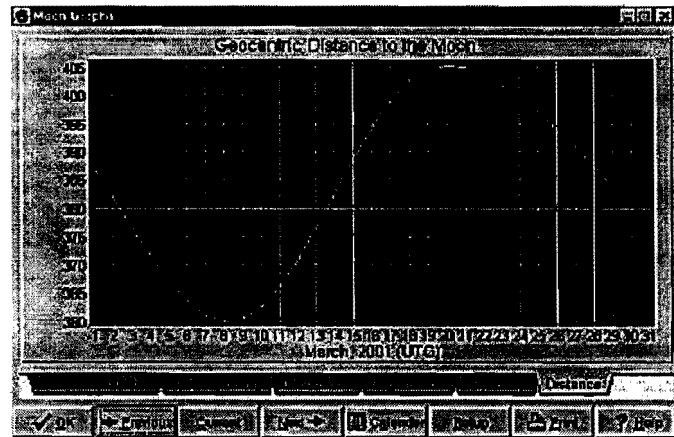

Figure 13
Earth-Moon distance for March 2001 (Nova plot)

Because the Moon's orbit is elliptical, its distance from Earth varies over the course of a moonth -- er, month. Figure 13 is a Nova plot of how this distance varied during March, 2001. It indicated lunar Perigee (closest approach to Earth) for 8 to 9 March, and Apogee (greatest distance) for the 20th. Since greater distance translates into increased free-space isotropic path loss, an operating period perhaps one week into the month appeared optimum.

The 23 degree inclination of the Lunar orbit also influences EME scheduling. Since the 305 meter diameter cylindrical reflector at the Arecibo observatory is fixed, and looks straight up, the antenna's steering is limited, and Lunar passes directly overhead are favored. This suggests operating when the Moon is near maximum Northern declination, which Figure 14 suggests was to occurr on 5 March. Only occasionally do perigee and maximum lunar declination coincide; this time, we seem to have gotten lucky.
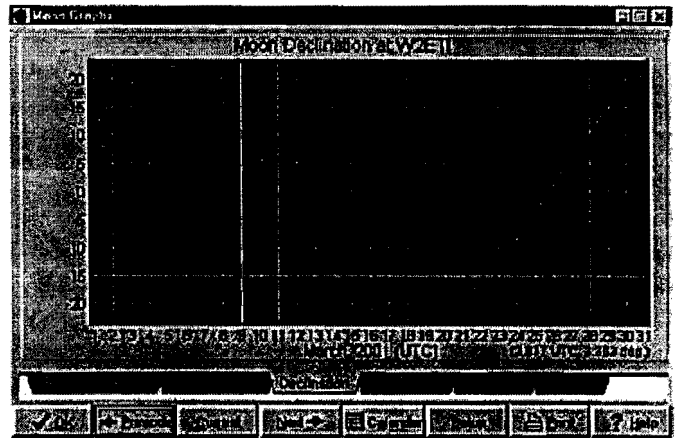

Figure 14
Lunar declination for March 2001 (Nova plot)

Figure 15 shows the combined effects of declination and Earth-Moon distance. It allowed us to select March 8 as the optimum date for running EME tests with Arecibo. In fact, we did not achieve success until March 9, as the 8th saw the US Northeast gripped firmly in the arms of a blizzard, and the helix antennas encased in ice. There are some things that the Nova software cannot predict!
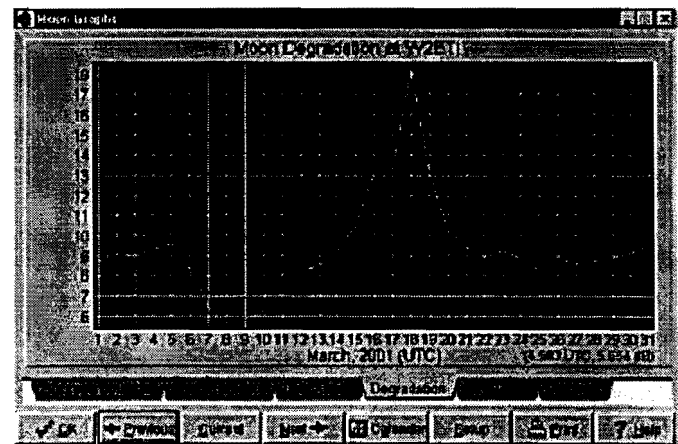

Figure 15
Moon path degradation for March 2001 (Nova plot)

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Because striking the lunar surface with a grazing blow causes polarization scattering of the reflected signal, EME success is maximized when both stations view the Moon straight-on. That would occur at lunar zenith, if both transmitting and receiving stations were situated on the same meridian of longitude. Such is not the case for Arecibo and New Jersey. Fortunately, the Nova package calculates polarization scattering loss over time (Figure 16). Adding together all of these temporal considerations (Figure 17) we see that for 9 March, success potential was maximum at 0400 UTC, and that's when we set up our EME sked.
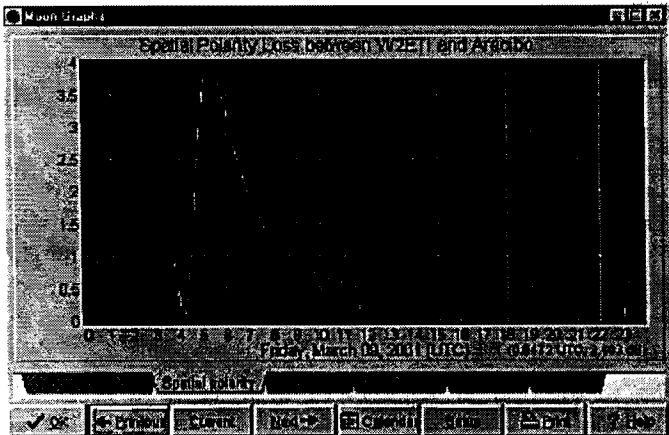

Figure 16
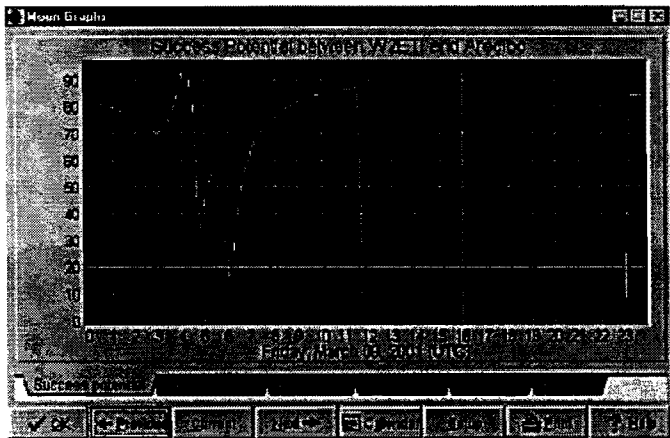**Spatial polarity loss for 9 March 2001 (Nova plot)**

Figure 17
EME success potential for 9 March 2001 (Nova plot)

The blizzard conditions prevailing in the US Northeast nearly scuttled the tests. For days WA2IKL was snowed in at work, and I was snowed in at my Northern PA home. Neither of us was able to reach the location of the W2ETI beacon. Fortunately, all of the beacon equipment was wired

for IEEE-488 bus control, and Richard was able to operate the beacon remotely, via the Internet. I was able to coordinate the experiment from home, monitoring the position of the Moon at both locations (Figure 18) in real time, and using a webcam (Figure 19) to follow Arecibo's progress.
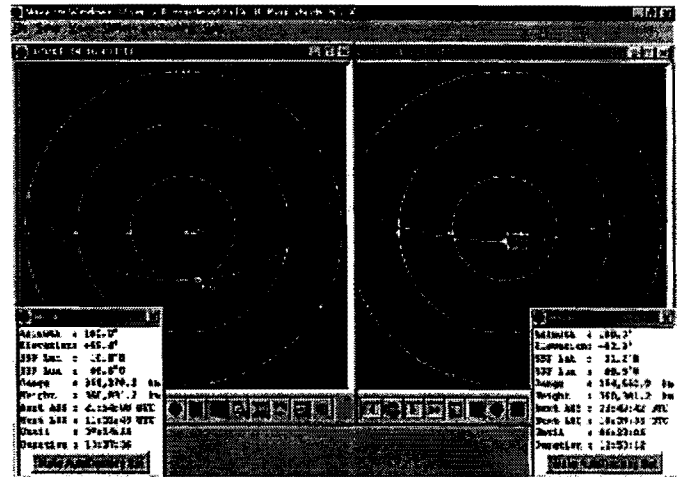

Figure 18
Lunar position during first detection of beacon (Nova plot)

Figure 19
Webcam image of the action at Arecibo. Left to right: Dr. Seth Shostak N6UDK (at edge of frame), software scientists Gerry Harp and Rob Ackermann, astronomer Dr. Jill Tarter, and Congressman Lamar Smith (just off camera with only his leg visible). SETI Institute photo

At 0400 UTC on 9 March 2001, precisely as predicted in software, a slowly Doppler-shifted carrier representing the weak W2ETI beacon appeared on Arecibo's spectrographic display (see Figure 20). First detection was achieved by astronomer Seth Shostak, N6UDK. Two weeks later at the California Academy of Sciences, I

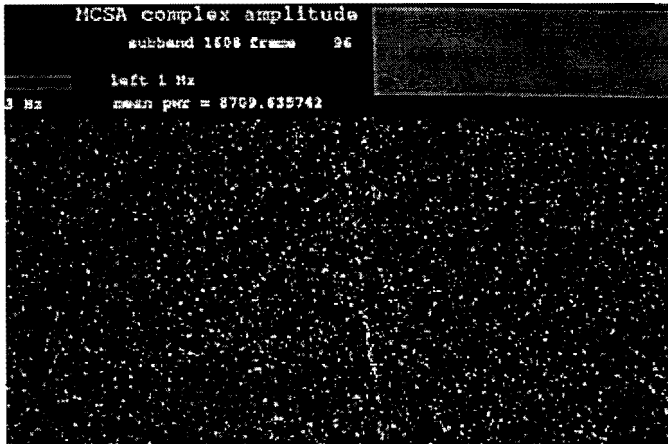presented Seth with the very first W2ETI EME beacon QSL Card (Figure 21).

Figure 20
EME beacon first light at Arecibo (N6UDK image)

Figure 21
The author presents Dr. Seth Shostak, N6UDK with the very first W2ETI EME Beacon QSL card.

Under-Illumination Loss

Only, the signal depicted in Figure 20 was scarcely discernible, and hardly stronger than the former Pioneer 10 beacon signals seen in Figure 4. How could this be, considering that Tables 1 and 2 predicted for our beacon a nearly four s-unit advantage?

It turns out that Arecibo's greatest advantage -- its huge size and impressive gain -- worked to our detriment. Like jam on a soda cracker, our broad uplink beamwidth spread the W2ETI signal smoothly across the 1/2 degree lunar disk. But Arecibo, with its 0.05 degree beamwidth, was only able to lick up about one percent of that jam (see

Table 3). The rest of the jam ended up missing Arecibo completely, merely sticking to the tablecloth. Now if we factor in Arecibo's 20 dB of under-illumination loss, we see in Table 4 that our beacon signal, as available to Arecibo, was only two dB stronger than Pioneer 10. Since that transmitter was estimated at one dB below Arecibo's threshold, it's no wonder that our EME echo was received a scant three dB above mental telepathy!

Moon subtends:	0.5 deg
Arecibo's beamwidth	$\simeq$ 0.05 deg
Loss = $10 * \log_{10} (\theta 1/\theta 2)^2$	$\simeq$ 20 dB

Table 3
Under-illumination loss

Pioneer 10	=	-229 dBm
W2ETI Beacon	=	-227 dBm

Table 4
Comparison of effective isotropic incident power for Pioneer 10 vs. W2ETI EME beacon, as received at Arecibo

Well, we had promised Arecibo a *weak* calibration signal, and that's what we delivered. The 250-foot diameter Lovell Telescope at Jodrell Bank in the UK received us somewhat better; at four times the beamwidth of Arecibo, it actually had about a 12 dB advantage. And Jay Leibman, K5JL, with his 30-foot homebrew dish, fared better than either of these monster radio telescopes. His beamwidth being slightly wider than the lunar disk, he recovered the lion's share of our feeble roar.

Going QRO

Still, not everyone has access to a 30-foot dish. If our objective was to provide a calibration signal which could be received by the average amateur radio astronomer, we were going to have to go QRO. Harry Price, K3AX, came to the rescue with the 225-watt, all solid state linear amplifier seen in Figure 22 (one standard brick driving four bricks driving eight) with which he had made dozens of initial 1296 EME contacts. Back to eBay, and WA2IKL acquired an 80-amp, 14 VDC programmable power supply, to feed this amplifier's voracious appetite.

After nearly five months of continuous operation, the W2ETI beacon was taken off the air in late July of 2001, for total refurbishment. (At this writing it is still off the air). With the K3AX

power amplifier derated to a modest 100 watts for continuous operation, we anticipate continuously illuminating the moon at +74 dBm of EIRP, for an isotropic power on Earth of better than -200 dBm. This should put reception of The SETI League's EME Beacon well within the grasp of our members.
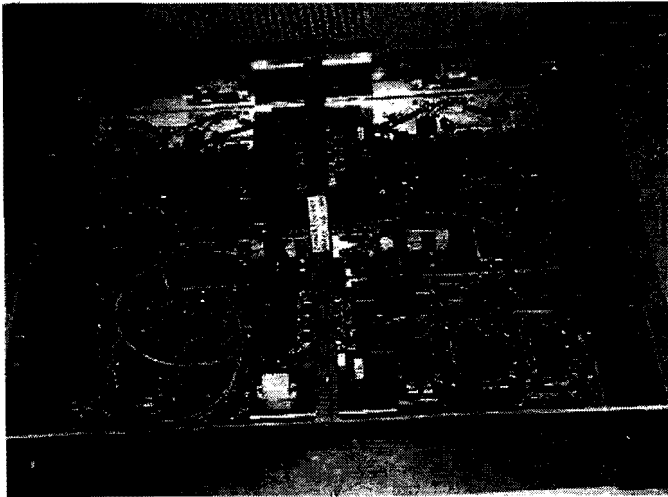

Figure 22
K3AX 225 watt solid state power amplifier (see text)

Conclusion

At 17:27:30 UTC on Saturday, 28 April 2001 (seven weeks subsequent to the Arecibo tests described here), the signal from Pioneer 10 was received at NASA Deep Space Tracking Station 63 in Madrid, the first contact with the spacecraft in nearly a year. It appears that Pioneer 10 has life, albeit in another mode - i.e., only in a two-way coherent mode. Both NASA and Project Phoenix had been listening for the Pioneer 10 signal in a one way downlink non-coherent transmission mode with no success. We conclude that in order for Pioneer 10 to talk to Earth, Earth needs to talk to it. Pioneer may well have outlived its usefulness. Thus, the W2ETI EME beacon will continue to serve as an invaluable calibration aid for the world's radio observatories, proving the dedication and professionalism for which radio amateurs have long been noted.

References

1.   MacCleur, Chuck, W8MQW, *A Pathloss Primer*, Symposium 99 Proceedings, Syracuse EME Symposium, August 1999.

2.   Shuch, H. Paul, N6TX, *SETI sensitivity: calibrating on a Wow! signal*. Proceedings of the AMSAT-NA Fourteenth Space Symposium: 130-141, American Radio Relay League, November 1996.

About the Author

Dr. Shuch, who serves as Executive Director of the nonprofit SETI League, is a retired engineering professor credited with designing the first commercial home satellite TV receiver. A Fellow of the British Interplanetary Society, he is the author of nearly 300 publications, has received numerous honors and awards, and (as N6TX) has operated in all 20 ham bands between 1.8 MHz and 24 GHz. Paul served as Director, Technical Director and Chairman of the Board of Project Oscar Inc., predecessors to AMSAT. He lives on a radio-quiet hilltop in northern Pennsylvania with his biologist wife, five of their seven recombinant DNA experiments, ten networked computers, three motorcycles, two radio telescopes, and an antique MG-TD.

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2001: an Amateur Radio Space Odyssey on the International Space Station

Frank H. Bauer, KA3HDO, Lou McFadin, W5DID, Will Marchant, KC6ROL, and
Carolynn Conley, KD5SJO

Introduction

In 1996, after the first International Partners meeting of the newly formed Amateur Radio on the International Space Station (ARISS) team, we all walked away "cautiously optimistic" that we would be able to develop, deploy and operate a ham radio station on the ISS. This optimistic dream from a handful of internationally-based amateur radio operators has now turned into reality. The year 2001 will go down in history as the year that the ARISS amateur radio station became fully operational.

It was a good thing that those involved in the hardware development and deployment had no idea of the significant challenges that faced them. Otherwise they would have all quit prematurely. The challenges that this international team endured were immense. We were the first "payload" to fly on ISS and no one—USA's NASA or the Russian Space Agency—really knew how we should be qualified. We repeated several flight qualification tests 2 and 3 times to satisfy all the different organizations requirements—the Shuttle, the USA ISS team and the Russian ISS team. We also had to overcome the cultural difference hurdles that result from working as a fully integrated international team. A couple of weeks prior to the launch of the initial ISS Ham radio hardware, we were still hanging on the edge of a precipice. The issue this time was that we had not satisfied the Russian EMI requirements. But we persevered, we made it happen.

This paper will provide an overview of the equipment currently on-board the ISS, the hardware currently in the queue for deployment over the next 12 months, and our long-term vision for the future.

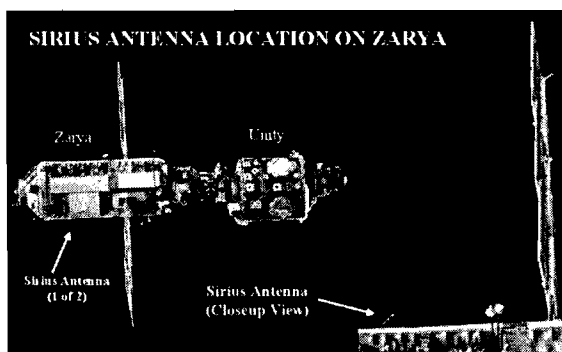## Human Spaceflight and Amateur Radio—a perfect pair

The Amateur Radio on the International Space Station (ARISS) represents a melding of the teams that have pioneered the development and use of amateur radio equipment on human spaceflight vehicles. The Shuttle/Space Amateur Radio Experiment (SAREX) team enabled Owen Garriott, W5LFL, to become the first astronaut ham to use amateur radio from space. Calling "W5LFL from the Space Shuttle Columbia" Owen made hundreds of QSOs on the STS-9 space shuttle mission in 1983. Since then, amateur radio teams in the U.S. (SAREX), Germany, (SAFEX), and Russia (Mirex) have led the development and operation of amateur radio equipment on board NASA's Space Shuttle and the Russian MIR space station. The ARISS team, a delegation of 10 countries, was formed in 1996 to develop, fly, and operate ham radio equipment on the International Space Station.

Through ARISS, the ham radio community can talk to the astronauts and cosmonauts on-board ISS. The primary goals of ARISS operations are fourfold: 1) educational outreach through crew contacts with schools, 2) random contacts with the Amateur Radio public, 3) scheduled contacts with the astronauts' friends and families and 4) ISS-

based communications experimentation. A few schools are selected from around the world for scheduled contacts with the orbiting ISS crew. Ten or more students at each school ask the astronauts questions, and the nature of these contacts embodies the primary goal of the ARISS program, -- to excite student's interest in science, technology and amateur radio. More than 200 schools have participated in a scheduled contact since the first amateur radio equipment was flown on the Space Shuttle.
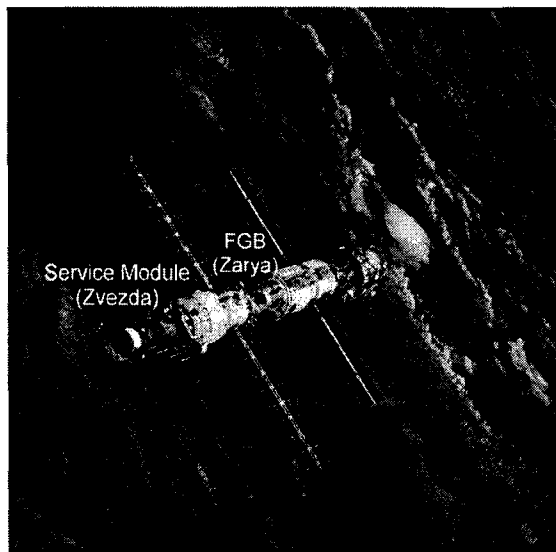
Ham Shack Location

The ISS Ham equipment will reside in two locations. 2 meter operations will primarily be conducted in the Russian Functional Cargo Block (FGB), named Zarya, using Russian antennas used to dock the FGB. These antennas, designed for use near the 2-meter band, (see figure 1) are no longer used by the Russians and can be used by the ISS Ham team permanently. This is the current location of the ISS ham radio station.

Service Module and FGB
Figure 2

at location 426 in the SM, right next to the dining table. See figure 3. Simultaneous multi-band operation can be conducted with these two ham shack locations.
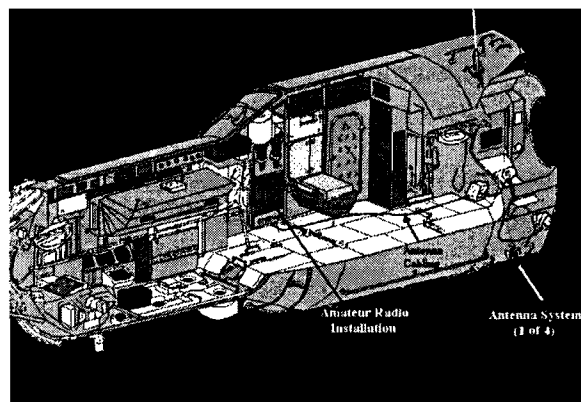

FGB 2 Meter Antenna Locations
Figure 1

In late 2000, a set of 4 antenna systems developed by the ISS Ham team are expected to be deployed. Once these antennas are deployed and checked out, the primary location of the ham shack will reside in the Russian Service Module (SM) named Zvezda. See figure 2. The ham station will be installed
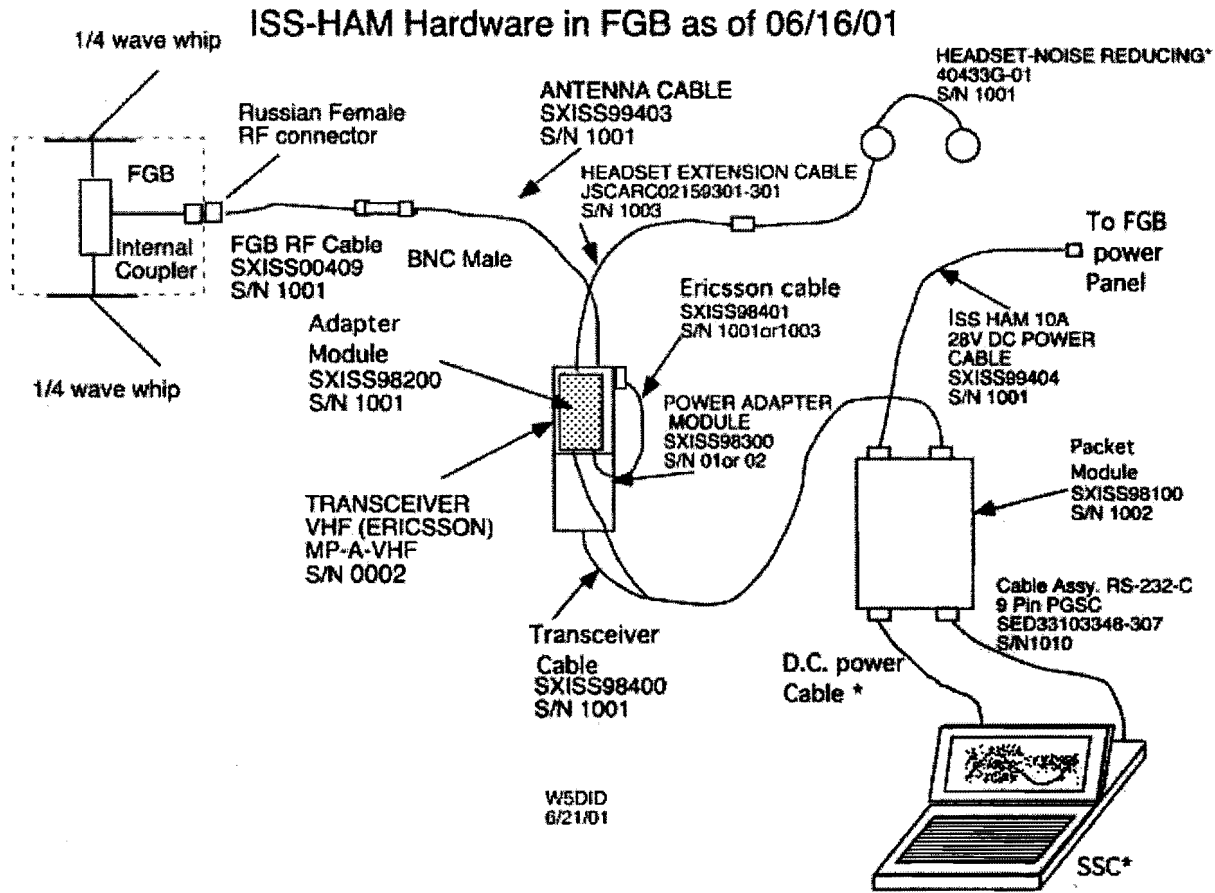

ISS Ham Hardware Location in
Service Module
Figure 3

Hardware Overview

The initial ISS Ham radio system was launched on-board the STS-106 Space Shuttle Atlantis on September 8, 2000. The initial ISS Ham radio hardware consists of two hand-held Ericsson transceivers, a power adapter,

an adapter module, an antenna system, a packet module, a headset assembly, and the required cable assemblies (see figures 4 and 5). The ham radio station is capable of

Amateur Band, and a UHF radio that receives and transmits FM voice or packet radio signals in the 70 centimeter (435-438

ISS-HAM Hardware in FGB as of 06/16/01

ISS Ham Hardware Configuration
Figure 4

operating in either the voice or data (packet) mode with amateur stations within line-of-sight of the ISS. This configuration can be operated in the attended mode for voice communications and either the attended or automatic mode for packet communications. The function of each of the components that comprise the ISS Ham radio is summarized below:

a. **Hand-held Ericsson (M-PA Series) Transceivers** – There are two transceivers on board: A VHF radio that receives and transmits FM voice or packet radio signals in the two meter (144 to 146 MHz)

Photo of Flight Hardware
Figure 5

MHz) Amateur Band. Both radios are

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Ericsson (M-PA) series commercial grade radios. These radios look identical in size and features, but are specially tuned to support the different bands. Each radio is programmed with 4 banks of 16 frequency pairs (for a total of 64 discrete frequency pairs. To date, only the 2 meter radio has been used. The radio transceiver receives 7.5 VDC from the ISS through a DC/DC power converter located in the power adapter. Buttons on the top of the housing are used to control the transceiver, with information being displayed on an eight-digit display on the front of the radio. Up to 5 Watts of output power is available on any one of the possible channels. The radio is built within a cast aluminum housing. The basic radio measures 2.7x1.5x4.6 inches (69x38x117 mm). See figure 6.
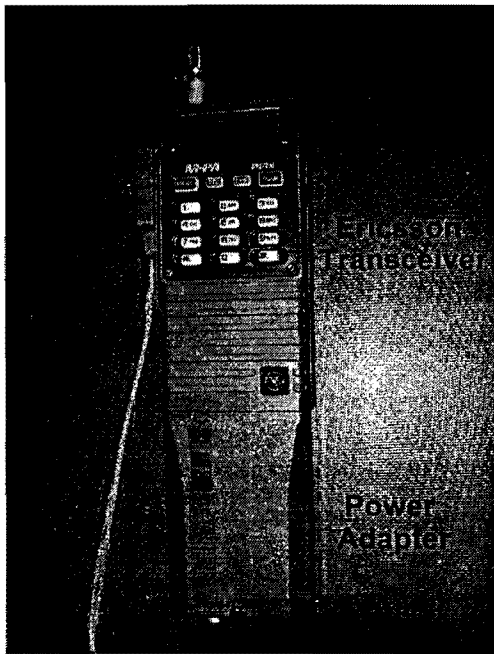
Transceiver & Power Adapter
Figure 6

b. **Power Adapter** – The Power Adapter consists of a specially developed 12 V to

7.5 V DC/DC power converter that converts the 12 VDC received from the power supply in the packet module to 7.5 VDC that powers the transceiver. A 12.0-to-7.5 Switching Mode Voltage Regulator is built into a standard, polymeric Ericsson Battery casing. The power adapter snaps onto the base of the transceiver in place of the battery pack interface (see figure 6).
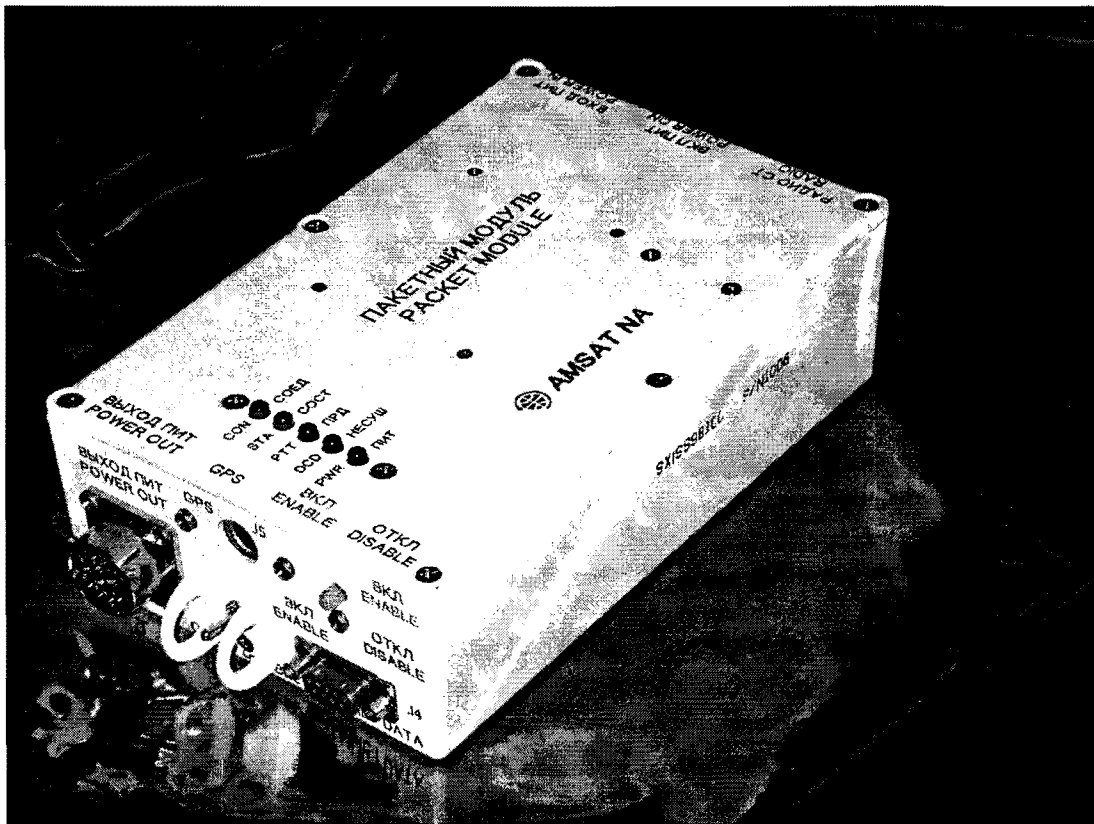
c. **Adapter Module** - Provides a means of interconnecting the ISS Ham transceiver with the supplied headset assembly, as well as, a standard crew personal tape recorder (see figure 7). It also provides the audio interface to the packet module and will become the primary interface with the SSTV hardware.
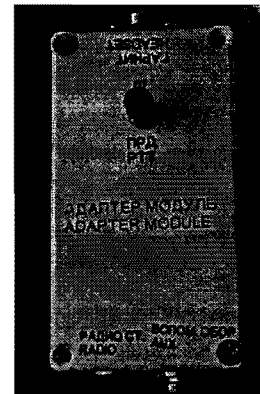
Adapter Module
Figure 7

d. **Station Support Computer (SSC)** – This ISS-provided hardware was supposed to serve as a data terminal for packet radio operations. Due to lack of the required number of computers on-board ISS, the ham radio station has not been able to have the use of a computer. The SSC will also serve as the video and software interface for SSTV system that is planned to be deployed in the near future. Negotiations are underway to make sure that a dedicated SSC will be available for ARISS operations.
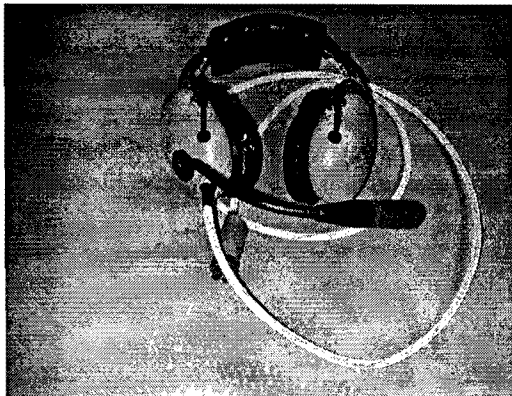
Packet Module
Figure 8

e. **Packet Module** – The packet module contains the primary power supply for the ISS ham radio station. A maximum of 3 amps of current at 28 V can be provided to the various elements that make up the ISS Ham system. Embedded in the packet module is a PacComm Picopacket

Headset Assembly
Figure 9

Terminal Node Controller (TNC). See figure 8.

f. **Headset assembly**: A David Clark aviation-type headset, similar to that used on several shuttle missions, was configured for the ISS ham radio station. See figure 9.

g. **Cable interfaces**: Below is a list of cable interfaces required: See figure 10.

 I. antenna cable – connects radio transceiver to antenna connection on service module or in the FGB.
 II. Ericsson cable – attached to radio transceiver, it connects the radio to the adapter module.

III. transceiver cable – provides power from the packet module to the power adapter, and provides audio link from the packet module to the adapter module.

IV. ISS HAM 10A 28VDC Power Cable – Connects 28 VDC (Russian) to 28VDC (U.S.) using a standard Service Module/FGB 10A outlet.

V. Headset extension cable – connects between the adapter module and the headset assembly. It extends the distance between the headset and the ISS Ham system, allowing the crewmember greater mobility. It has a push-to-talk switch near the crew interface.

VI. RS232 cable – provides a serial link between the packet module and the SSC laptop computer.

VII. SSC DC Power cable –a SSC may be connected to the POWER OUT port of the packet module through the use of this cable.

Future Hardware Deployments

Packet Module Upgrade

To date, the packet system has not been connected to an SSC laptop due to the lack of sufficient laptops on ISS. Also, shortly after the packet system was turned-on for general use, it was discovered that the battery used to backup the RAM had died. Because of these two events, the packet system has been operating in digipeat mode using the ROM defaults (including the Nocall callsign). An upgraded packet module is expected to correct these problems and add new capabilities. The new TNC will include a specially developed ROM with the standard ISS Ham defaults, Russian and USA labels, a new battery, and extended memory (up to 1 meg). Since the packet module serves as the power supply for
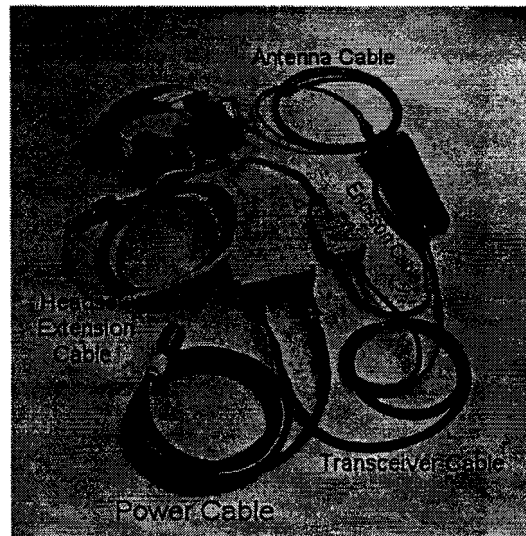
Equipment Cables
Figure 10

the station, the ARISS team has decided to leave both packet modules on-board ISS. The older version will serve primarily as a power supply for one of the stations (FGB or SM). The newer version will provide the packet radio capability. The new packet module was launched on the STS-105 Discovery mission on August 10, 2001.

Antenna Assemblies

The specially designed ISS Ham antenna assemblies will permit operations on HF (20 meters, 15 meters & 10 meters), VHF (2-meters), UHF (70cm), and the microwave bands (L and S band) These dual-use antenna also permit the reception of the Russian Glisser EVA video signals (2.0 GHz). This dual-use capability is the primary reason the ARISS team received access to 4 antenna feedthroughs located on the outside of the Service Module. A total of four antenna systems were developed to get maximum use of the antenna feedthroughs. These will be installed around the periphery of the far end of the Service Module. See figure 11. Three of the antennas (WA1-WA3) will include the VHF/UHF flexible tape antennas. WA4 will

include a 2.5 meter HF antenna. The antenna systems were developed by the U.S., Italian, and Russian ARISS partners.

The antenna assembly consists of a mounting plate, spacer, Russian handrail clamp, VHF/UHF (or HF) metal flexible tape antenna with delrin mounting collar, an L/S band flat spiral antenna with a delrin radome cover, a diplexer and interconnecting RF cables. See figure 12. The antennas will be mechanically mounted on Russian handrails, illustrated in figure 13, using the "clothespin type" handrail clamp. RF connection is accomplished using 4 feedthroughs that have a special EVA connector attached. See figure 14.

The antenna systems are currently scheduled for launch on the UF-1/STS-108 flight. This flight is tentatively scheduled for the end of
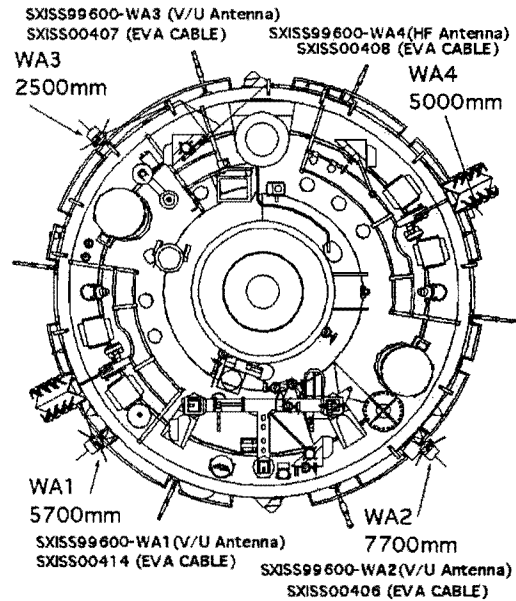
Antenna Location View from End of Service Module
Figure 11
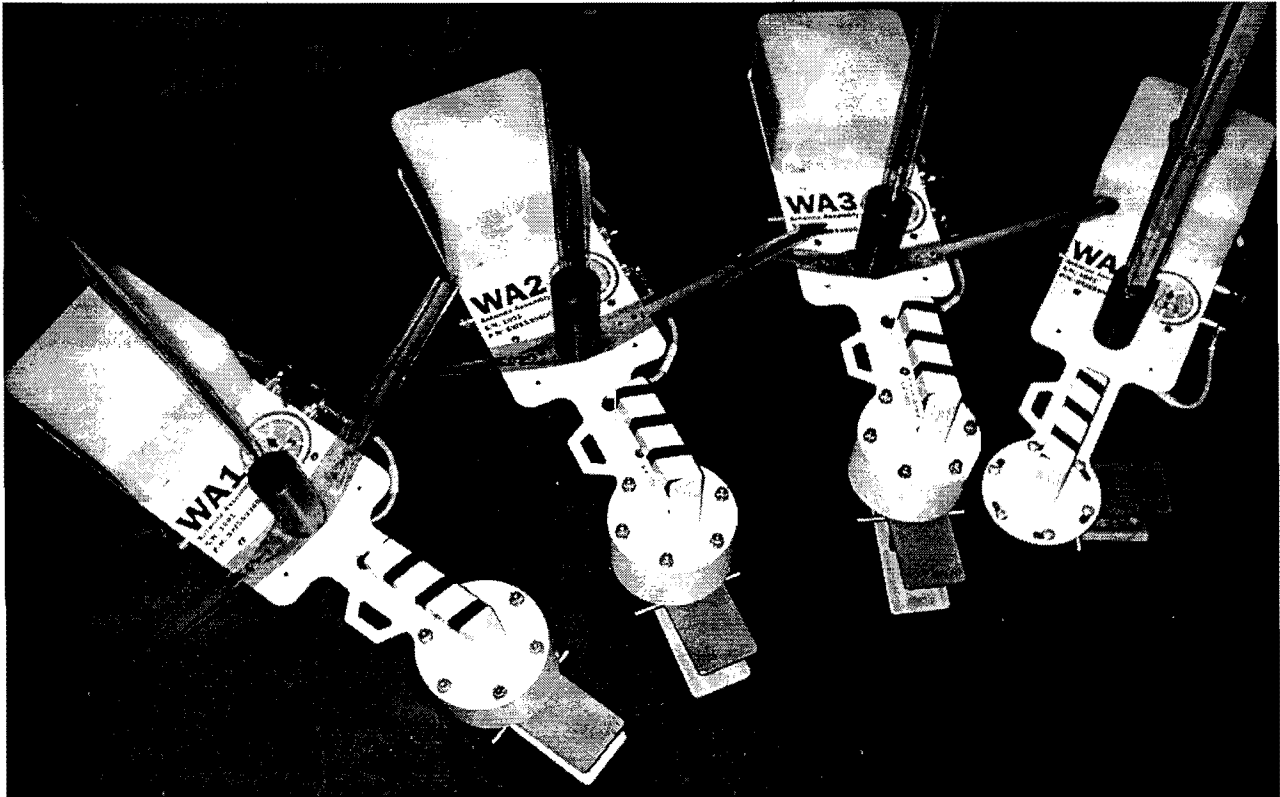
Antenna Systems WA1-WA4
Figure 12

Antenna Handrail WA1
Figure 13

Russian EVA Connectors
Figure 14

November. The antennas will be deployed during an EVA (spacewalk) by the Expedition 4 crew. This crew has performed extensive training of the antenna installation in the Russian Hydrolab water tank located at the Gagarin Cosmonaut Training Center (GCTC) in Star City Russia. See figure 15.
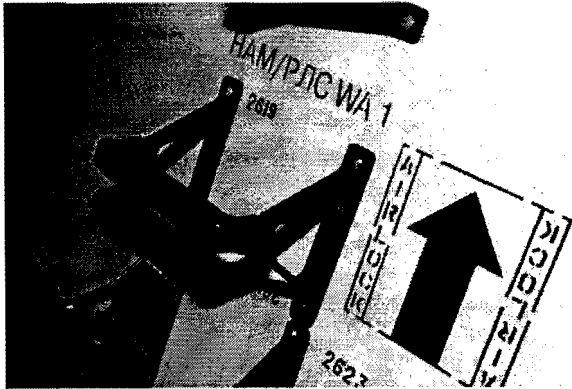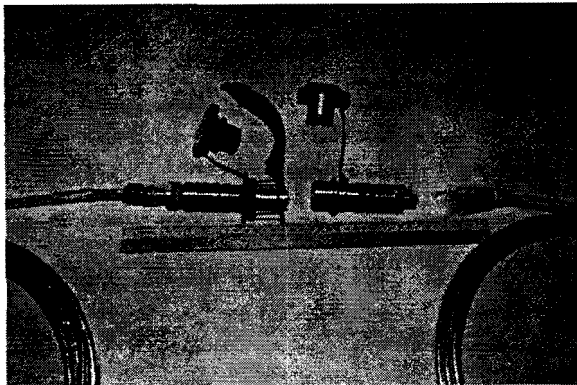
SSTV

The Slow Scan Television (SSTV) system for the ISS ham radio station is currently in development. This system will consist of a software interface, developed by the MAREX-NA team and a hardware interface, developed by the ARISS Hardware team. Prototype hardware and software systems have been developed and the flight system fabrication

has started. The SSTV system will allow digital still pictures to be uplinked and downlinked in both crew-tended and autonomous modes. The ARISS team expects the SSTV system to be operational on ISS sometime in 2002.

EVA Training for Antenna Installations
Figure 15

Conclusions

The year 2001 will be long remembered as the year that the ARISS team pioneered a new facet of amateur radio---permanence on the International Space Station. In the future, there will be new equipment, new modes of operation and exciting QSOs. Enjoy the QSOs, experimentation and School Group Contacts. And remember the international team that made it happen---ARISS.

For more information on the ARISS program, you are welcome to surf the ARISS web page at: http://ariss.gsfc.nasa.gov

Amateur radio operations on board the International Space Station
Will Marchant, KC6ROL
Frank Bauer, KA3HDO

Synopsis:

In 1996, the SAREX team proposed to the ISS management that amateur radio become a permanent feature of the ISS. Because of the success of ham radio on the Shuttle and Mir, this proposal was met with great support. Because of the international nature of the ISS, a multi-national amateur radio group called ARISS, for Amateur Radio on board the International Space Station, was formed to implement ham radio on the ISS. Amateur radio equipment was carried to the ISS on board the STS-106 mission and ham radio activity was inaugurated by the Expedition One crew in late 2000. Support for ham radio on board the ISS remains strong with numerous school contacts, frequent general voice QSOs, and packet activity. This paper will summarize ham radio operation activities by the Expedition One and Expedition Two crews. As this paper is being written the changeover between Expedition Two and Expedition Three is occurring. Expedition Three activities will be summarized in a future paper.

Expedition One: School contacts, General contacts, Packet Contacts.
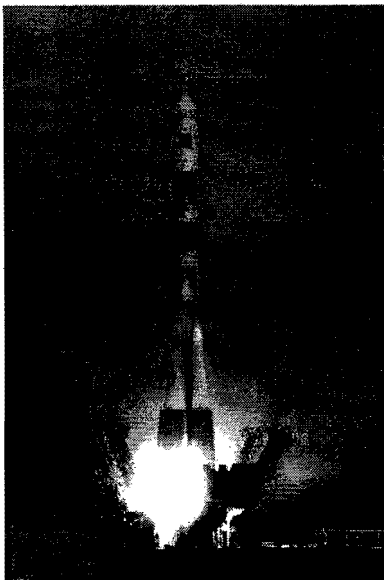
Expedition One was launched to the ISS on board a Soyuz rocket in October of 2001.

ISS commander Bill "Shep" Shepherd, KD5GSL, was the expedition commander. Yuri Gidzenko was the Soyuz commander. Sergei Krikalev, U5MIR, was the flight engineer.

Ham radio activity on the ISS started on 2000-11-13 at 06:17 UTC with a successful engineering test conducted with the R3K station. Later that day test passes were accomplished with NN1SS and W5RRR as well as several more R3K contacts. These all

demonstrated the excellent signal quality from the ISS. Shep repeatedly said that the amateur radio system provided the best quality air-to-ground voice link on the ISS. The crew built up familiarity with, and enthusiasm for, ham radio with QSOs with family and close personal friends over the next several weeks.

Sergei, U5MIR, with the ham rig.

School contacts started in mid-December. The crew had radioed down "we want to keep you busy [with school contacts]" but we could never get clarification about what that meant. We are working with the crew surgeon's office to establish the crew's wishes before they fly. We interpreted it to mean a school contact spaced at approximate week intervals.

We accomplished seven school contacts. Three of those were "crew picked" schools and the others were schools left over from the Shuttle and Mir, some from the mid-90s. Gaps due to shuttle missions to ISS and allowing the Exp1 crew time to "settle in" were the biggest reason for the limited number of school contacts.

Date	School	Teacher	Mentor	Uplink
19Dec00	Burbank School, Burbank, IL, USA	Rita L. Wright	AJ9N	AJ9N
05Jan01	Armstrong Fundamental School, Hampton, VA, USA	Denise W. Corson	AA8HH	KE4ZXW
18Jan01	Sheldon Elementary School, Varysburg, NY, USA	Karen Washburn	WA3GOV	WA2CAM
30Jan01	George West School, George West, TX	Keith Rogers	N6IZW	K5YFL
22Feb01	Merivale Public School, Ottawa, Ontario, Canada	Lori McFarlane	VE3PU, AJ9N	VE3TBD
01Mar01	Polynesian Voyaging Society	Bernie Kilonsky	KC6ROL	AH6NM
07Mar01	Arcadia High School	Cynthia Foss	AJ9N	KD7LAC

Several factors have had significant impacts to the school program: lack of good orbital predictions for ISS and getting final confirmation of the school contact time only a few days before the event. Unfortunately, both of these are endemic to the ISS program as a whole. It is not clear that there is a good answer for either problem. The ISS schedulers made heroic efforts on a number of occasions to fit school contacts into the schedule: they are to be commended. The schools certainly appreciated their efforts!

General contacts were almost non-existent. This primarily seems to have been a function of the extremely heavy work load for Exp1. A secondary issue was the relative "remoteness" of the ham gear at the temporary location in the FGB. The crew commented in the post-flight debrief that somewhere near the table in the Service module would be much more convenient. Of course, this is the location to be used once the external antennas fly later. Another complaint was a lack of a computer running the WorldMap tracking software near the ham rig. Ham radio from space is primarily a function of what part of the world you are flying over. Since there are no windows in the FGB and there is no WorldMap available, crew using the ham rig are in a state of "sensory deprivation." The large number of family contacts on the ham gear combined with the lack of general contacts produced a large amount of negative publicity. There needs to be a balance of the three goals of ham radio in space: school, family, and public ham radio contacts. (The work schedule for expedition two is producing a much more balanced use of the ham equipment.)

Packet contacts were non-existent during expedition one. Apparently the packet module was functioning early in the mission as a number of packets were heard during voice operations. It now appears that the battery maintaining the internal settings may have discharged, which would account for the lack of automatically transmitted "beacons" later during Exp1. But attempts to connect to the packet module from the ground failed. Once again, it was very difficult to get verification that the ham radio equipment was in a configuration that would support diagnosis from the ground. A procedure was developed and sent up to the crew to diagnose and correct the purported battery problem. Due to workload the crew never accomplished that procedure. The biggest issue was the lack of a laptop computer for use with the packet module. A dedicated laptop was not flown for the ham rig because the team was told a laptop would be available. This unit has never materialized. (Several weeks into Exp2 the packet function spontaneously started to work. The mode it is in seems to confirm the "dead battery" hypothesis.)

Expedition Two: School contacts, General contacts, Packet Contacts.

Expedition two is commanded by Yuri Gidzenko, with James Voss, and Susan Helms, KC7NHZ, making up his crew.

The Expedition Two crew accomplished fourteen school events. This increase from Expedition One reflects the slightly relaxed pace of ISS buildup. Expedition One had solved many of the critical teething problems of the ISS. While Expedition Two remained very busy, it was easier to fit highly desirable, but nonessential, activities such as school contacts into their schedule.

Date	School	Teacher	Mentor	Uplink
26Mar01	John B. Reible School, Santa Rosa, CA, USA	Kristie Weber	W6ISS	W6ISS
09Apr01	Woodford County Middle School, Versailles, KY, USA	Leslie S. Curtis	AA8HH	VK5ZAI
11Apr01	Vicksburg High School, Vicksburg, MS, USA	Michael Brantley	W5UE W8JE	AH6NM
16Apr01	Admiral Moorer Middle School, Eufaula, AL, USA	Brenda O'Neal	W8JE	NN1SS
17May01	Parkway Central High School, Chesterfield, MO, USA	Mary Jo Kohunsky	WA3GOV	KC0PCH
23May01	Moran Prairie Elementary School, Spokane, WA, USA	Theresa Darke	N6IZW	W7TRF
31May01	Daviess County High School, Owensboro, KY, USA	Harold Wilson	AA8HH	AH6NM
12June01	Henley Middle School, Klamath Falls, OR, USA	Walter R. Jones, Jr.	W6ISS	VK5ZAI
21Jun01	Boulder County Schools- Alpha Project	Christine Labozan	K5YFL	K0RZ
27Jun01	New Mexico Museum of Natural History	Jayne Aubele	K5YFL	KK5YY
04Jul01	Saint Petersburg Junior Technical Center, St. Petersburg, Russia	Boris UA1AAF	KC6ROL	RZ1AWO
12Jul01	Peebles Elementary School, Buzzards Bay, MA, USA	Jan Butler	K5YFL	W6SRJ
25Jul01	Boy Scout Jamboree, Fort A. P. Hill, VA, USA	John Cross	K5YFL	K2BSA
31Jul01	Joan Martin Elementary, Hobart, IN, USA	Suzanne Furgye	AJ9N	KF9WW

Susan Helms was performing random voice QSOs on the ISS ham radio rig within days. Susan's voice has become a familiar sound on many weekends. Susan was also quite active for the 2001 Field Day event. She logged over 250 callsigns and submitted 202 unique callsigns for Field Day points. Susan's score was 1010 regular points with 300 bonus points.

On 08Apr01 KA3HDO announced that the packet TNC on the ISS had been activated and was on frequency for general use. The packet rig was not automatically beaconing, and was only responding to the "NOCALL" callsign, the factory default built into the ROM. After a lot of investigation, the ARISS team determined that the backup batteries that maintained the programmed settings in RAM had discharged. A new TNC has been sent to the ISS with a good backup battery and factory defaults changed in ROM to be appropriate for the ARISS mission. This was not an option for the first TNC because callsigns were not known in time for the hardware to be ready for flight. The new TNC is scheduled to be installed by Expedition Three and will respond as RS0ISS.

Tourists in space
Many readers will be aware of the flight of American Dennis Tito to the International Space Station. Mr. Tito is listed as the first tourist to pay his own way into outer space. Mr. Tito's representatives contacted the ARISS team and requested that the amateur radio hardware be made available for his use during the visit to the space station. Because of the unusual nature of Mr. Tito's visit to the ISS, the ARISS team contacted ISS management to discuss the options for allowing Mr. Tito to use the ISS ham shack. ISS management was very professional and granted approval, so long as the use was on a "non interference" basis. These were the same terms that were imposed on all Mr. Tito's activities on board the ISS. Because of the short length of his flight, the ARISS team arranged for one contact every day for the duration of his mission. The ARISS telebridge network was used to support these activities. Dennis professed himself very happy with his stay on orbit and was ecstatic in his praise of amateur radio on board the ISS.

Conclusion
The first year of amateur radio operations on board the ISS has seen the realization of years of hard work and dreams. Regular school contacts, frequent random voice QSOs, and an active packet system make all the work worthwhile.

Expedition Three has expressed strong support for school contacts via amateur radio. We will have to see if they are as enthusiastic for random voice QSOs as Susan Helms. Packet will continue to be almost constantly available. Packet has proven that a modest terrestrial packet station has a chance to work the ISS.

Many astronauts are taking time from their very full schedules to get licensed. Interest by future ISS crews increases. An active training and mentoring effort by the JSC Amateur Radio Club, W5RRR, will ensure that future crews are excited about amateur radio.

The amateur community can look forward to many years of direct participation in the world's human spaceflight program through the ARISS project on board the ISS.

A Laser Receiver for AMSAT Oscar 40

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AMSAT-OSCAR 40 carries a laser communication experiment onboard[1], the first use of this technology on an amateur spacecraft. A laser transmitter aboard the Japanese ETS-VI spacecraft has been successfully tested[2] and various other projects are underway including spacecraft to spacecraft tests between SPOT-4 and ARTEMIS. A primary motivation for using lasers instead of RF for communication is the possibility for very high bandwidth at low power consumption levels.

Link Budget

Using the specifications of the transmitter Signals received from AO-40 will be extremely weak, see the link budget in Table 1.

Transmitter power	0.5 Watts
Wavelength	835 nm
Photons per second	2.1 E+18
Area illuminated on earth	1.2 E+12 square meters
Area of 100mm lens	0.079 square meters
Ratio of areas	6.5 E-15
Received signal	13,800 photons/sec (no losses)
After 30% atmospheric loss	9,630 photons/sec
After 20% Lens/Filter loss	7,710 photons/sec

Table 1. Link Budget

A laser receiver is a cross between a radio receiver and a telescope. The system described here is similar to a crystal radio set in the sense that it consists of an antenna, some modest frequency selection stage and a detector. Many simplifications are possible compared to an astronomical telescope because the laser operates over a very narrow band of wavelengths, and no image needs to be formed …we are building what is essentially a "light bucket".

Antenna

Many successful terrestrial laser communication experiments have used lenses from discarded magnifying glasses, overhead projectors and the like. Despite their relatively poor optical quality, they are entirely suitable for our purposes. Low or no acquisition cost is a major attraction to these elements, however, some creativity and effort is required to assemble a suitable mounting. Small amateur telescopes, on the other hand, are available at modest cost, but have a great deal of the work done for you. As with RF antennas, a larger lens/mirror results in higher gain, but with a narrower beam width.

Frequency Selection

Interference filters are available that will improve the signal to noise ratio of our receiver. Analogous to the LC network in a crystal radio, an optical interference filter is placed immediately before the detector. Photons from stars that might fall within the field of view of the detector are spread over a bandwidth of hundreds of nanometers. A standard 10 nm wide filter will reject most of the interfering stellar photons, yet pass 90% or more of all photons in the 2 nm wide laser signal.

Detector

Our next choice is a detector for the receiver. A time proven device for low light detection is the photo multiplier Tube (PMT). For use in the visible spectrum, they have no equal, however, in the near infrared spectrum, typical quantum efficiency (photons detected/incident photons) is only about 10%. Fiber-optical pre-amplifiers are another possibility, however their small collection area and limited availability at amateur price levels make them less than ideal candidates. This leaves us with PIN photodiodes, including the specialized PIN variant, the avalanche photodiode (APD).

Advanced Photonix provides a line of APD's that matches our needs well. Their SD 020-70-62-541 device provides a collection area of 0.5 mm diameter and a quantum efficiency of 90% at 835 nm. This device is a compromise between the smallest device offered (cheapest) and the larger devices provide a wider field of view. A drawback to the device is its cost, about USD100.00 in quantities of 1-9. A typical circuit for APD implementation is shown in Figure 1.
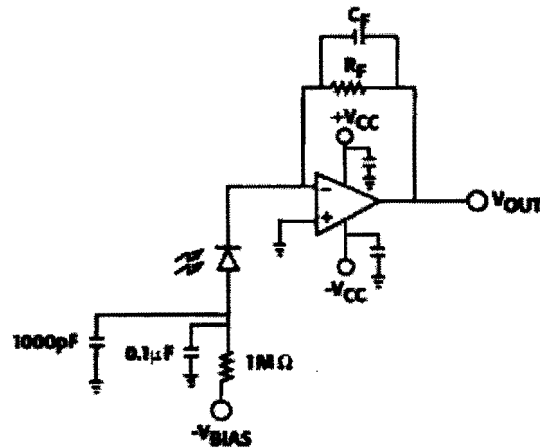
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Figure 1. Typical APD circuit[3]

Signal Processing

After a suitable buffer amplifier, the signal can be processed using a PC soundcard and digital signal processing software. The signal transmitted is 400 bps telemetry phase modulating a 1600 Hz square wave. Spectrum display software such as the open-source Frequency Analyzer program[4] should easily show the carrier frequency and modulation sidebands. Demodulation is another matter as it is not clear if existing hardware and software such as G3RUH's demodulator and AO40RCV will work properly with this signal.

Pointing

The high gain of both the transmitting and receiving antennas results in pointing challenges significantly more stringent than a typical S-band dish. Assuming our 100 mm lens has a F/D ratio of 2, we must aim within 2.5 mrad or 1/3 the angular diameter of the moon in order to have the collected energy fall on our 0.5mm detector. Perhaps the simplest technique to achieve this level of accuracy will be to use a guide star as viewed through an accurately mounted finder scope mounted to the receiver. The operator would identify a star near the expected position of AO-40, and then adjust the receiver position as appropriate. Unlike astronomical targets, however, the spacecraft will move with respect to the guide star over a period of 10's of minutes. It remains to be seen if this is a practical technique. An alternate possibility is to mount the detector on a computerized telescope such as the ETX series from Meade.

Pointing of the transmitter is also required. Due to the very small footprint of the laser beam, practical operation of the laser requires 3 axis stabilization. As of this writing, initial tests of the momentum wheels on the spacecraft have been successful. Once the flight controllers gain experience with the system and are able to accurately slew the spacecraft to a specific direction laser tests can commence.

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Summary

The basic design of an optical receiver has been discussed, and indicates that a suitable receiver may be constructed using amateur techniques. Now that AO-40's 3 axis stabilization system is being commissioned, experimenters are encouraged to begin building receivers and prepare to participate in this cutting edge aspect of satellite communication.

[1] K. Meinzer et al "Infrared Laser on P3-D" AMSAT-DL Journal January 2000
http://members.verizon.net/~km1p/IR_LASER_P3D.pdf

[2] M. Toyoshima et al The Telecommunications and Data Acquisition Progress Report 42-128, February 16 1997 , Jet Propulsion Laboratory, Pasadena, California http://tda.jpl.nasa.gov/tmo/progress_report/42-128/128I.pdf

[3] "Small Area (High Frequency) Avalanche Photodiodes" Advanced Photonix, Camarillo, CA
http://www.advancedphotonix.com/small.htm

[4] Available from Reliable Software 1011 Boren Avenue, Seattle, WA 98104
http://www.relisoft.com/freeware/index.htm

HOW TO FOR MICROWAVE SATELLITES
"Or Getting On AO-40 – The Microwave Satellite"

A.   How we got the Microwave Satellite

Phase-3D started out with an ambitious project constructed by an international team to provide a satellite that would provide a greater number of frequencies than previously done. This would include several microwave transponders for the first time, interconnected through a unique IF matrix. Many other special features were included, but that is beyond the scope of this paper.

Well, we are all aware of the loss of the VHF and UHF downlinks and other problems encountered early into the mission. Initially there was shock and the feeling that nothing of value remained. But the S-band transmitters were fine, and so were several uplink frequencies.

So it is that AO-40 has evolved into becoming our first "Microwave Satellite".

But how do you get on the "Microwave Satellite"? That will be the subject of this paper.

B.   Common misconceptions about microwaves.

The initial feeling amongst many satellite operators, who had operated AO-10 and AO-13, and other hams, was that microwaves were just to technical, too specialized, too expensive, and too hard.

"Everyone knows microwaves won't go farther than my backyard"! "I'm not an engineer." "I can't build this stuff". "Where will I get my equipment"? "It costs too much". "Besides, I have a mode-B station and now I can't use it"! "Why did we need this microwave stuff, anyhow"?

Well, many operators have found that help is available from microwave savvy hams [especially on the Amsat bulletin board], inexpensive surplus equipment is available, only minor changes are generally required, and you could use it with your existing station. I hope to cover this in a little more detail.

C.   Why Microwave Satellites.

Here I am going to take a few words from Ed Krome, K9EK, since he does such a nice job [1][2]:

1.   Quality of a communications channel is largely determined by the signal-to-noise ratio. Either increase signal strength or reduce noise, or both!
    a.   Microwave frequencies utilize physically small antennas to concentrate RF into narrow beams.
    b.   This increases the efficiency of transmitter power available on the satellite.
    c.   Real estate in space is expensive; smaller antennas make better use of room on the satellite.

        d.   Noise is grouped into those man-made, and natural.

        e.   Man-made noise drops quickly with increasing frequency.

        f.   Atmospheric noise drops quickly with frequency, and interstellar noise is mostly thermally generated. Space is cold and quiet at microwave frequencies above 1 GHz.

2. Microwave bands offer a lot of bandwidth "real estate".

        a.   There is room for analog and digital modes.

        b.   There is less competition from other users [though this is rapidly changing].

        c.   If we do not occupy our amateur microwave bands then how do we justify their existence?

        d.   The assault on the VHF and UHF bands already is reducing their usefulness for uplink bands in some parts of the world.

3. It's where the commercial and government satellites operate.

        a.   Must be a good reason for this.

4. Why not microwaves?

        a.   Trying something new can be fun!

        b.   ...And, as we will see, work well, also.

D. The frequencies and modes.
Currently, AO-40 has is two (or three) uplink bands and one down link band and two of them are microwave bands [3][4]:

1. Mode-V: 145.840-145.990 reserved for command uplink.

2. Mode-U: 435.550-435.800 uplink

3. Mode-L1: 1269.250-1269.500 uplink
Mode-L2: 1268.325-1268.575 uplink

4. Mode-S1: 2400.225-2400.475 high gain downlink
Mode-S2: 2401.225-2401.475 medium gain downlink

5. Beacons: 2401.323 is the Middle Beacon (MB)
2400.573 is the Engineering Beacon (EB)

E. Analyzing your requirements:
To start looking at what is needed to operate on AO-40, lets begin by looking at a few system specifications and requirements. Since we need to hear the s-band downlink in order to operate on AO-40 we will begin there:

1. Antenna gain
Before the launch of AO-40 path link margins were calculated on estimated performance for the satellite:

a.   For 2400 MHz it was estimated that a ground station consisting of a 20 dBi antenna with a system noise figure of 1.5 dB would result in a signal strength that would produce a 23 signal to noise ratio.

b.   A couple examples were given using a 60cm dish (20 dBi) or an 8-turn helix (13 dBi).

Experience indicates this is inadequate for copying the S2 beacon or transponder:

c.   It appears that using a 20 dBi gain antenna will require a system noise figure of 0.7 dB.

d.   Better performance is obtained with 24 dBi antennas which requires a minimum 1.5 dB noise figure.

e.   Helical antennas do not achieve theoretical gains and do not appear to perform as well as dishes for AO-40.

f.   Linear polarization adds a 3 dB penalty in when receiving the right-hand circular polarized satellite signal.

2.   Noise Figure

Experienced AO-10/13 operators are familiar with the need for the use of low noise preamps on 144 and 432 MHz. This becomes even more critical for good reception on microwave.

Atmospheric and manmade noise drops quickly as frequency rises into VHF frequencies. Above 1 GHz normally only celestial thermal noise is detected and that continues to drop from around 20 Kelvin to the minimum background level of about 3 K at 10 GHz.

System noise performance can be characterized by the following formula:
$T_{sys} = T_{sky} + T_{rx} + T_{gnd}$

T_{sys} is the equivalent system noise temperature in Kelvin.
T_{sky} refers to sky noise power express in K.
T_{rx} refers to the total receiving system noise performance.
T_{gnd} is the stray pickup of thermal ground noise by the antenna.

At HF T_{sky} runs above 2000 K and determines system noise performance.

At 144 MHz T_{sky} is around 250 to 300 K and still is a significant limiting factor in achieving low system noise performance.

At 2.4 GHz Tsky becomes approximately 10 K. Now the other two factors have primary significance:

a.   Tsys = 10 + 80 + 29 = 119 K
b.   NF = 10 Log (1+ Tsys/290) = 1.49 dB
c.   This is a reasonable maximum system noise figure for AO-40 reception. Trx of 80 K is a NF of 1 dB and Tgnd represents an antenna with sidelobes of −10 dB (i.e. the ground appears as a 290 K thermal source and the antenna suppresses viewing it by a factor of ten)
d.   If a low noise preamp is used to obtain 0.7 dB NF, then Trx becomes 52 K and Tsys = 91 K, system NF is 1.19 dB, and receiver S/N has improved about 1 dB!

Although a 1.5 dB noise figure was cited in pre-launch articles, this is barely adequate for good reception. A better minimum specification would be 1 dB NF.

3.   Uplink power

a.   For 435 MHz good signal quality is achieved using 200 to 300 watts ERP when squint angle is favorable (under 10 deg.). Capability for up to 1000 w ERP may be required under unfavorable conditions of high squint, heavy satellite use, and for communications with stations with poorer receiving capability.
b.   This can be achieved with as little as 10w and a 13 dBi circular polarized yagi or helix.
c.   1200 MHz uplink requirements are less well known, but it appears that 1000 watts ERP is a minimum requirement.
d.   An example would be a 20 watt transmitter and 20 dBi loop-yagi. Since the antenna is linearly polarized it suffers a 3 dB loss. A 4-foot dish would supply an equivalent gain.
e.   Circular polarization for uplink antennas benefit by avoiding polarization loss and spin fading. Use of the AO-40 momentum wheels for attitude stabilization holds promise for not requiring spin. In practice, linear antennas with adequate gain will work well on the uplink.

4.   Doppler
What kind of frequency shift will be seen on AO-40? Many operators became familiar with Doppler shifts on AO-10 and 13 using 145 and 435 MHz. With a microwave downlink on 2.4 GHz that is going to be much larger:

a. Using Doppler formula from the Satellite Experimenter's Handbook [5], assuming a perigee of 400 km and an apogee of 59,000 km the following estimates can be obtained:

b. At perigee 2.4 GHz Doppler will be about 37 KHz, assuming one is in the plane of orbit [i.e. near the equator]. 1269 MHz Doppler will be about 19.8 kHz, and 435 MHz Doppler will be about 6.7 KHz.

c. At apogee 2.4 GHz Doppler will be about 5.7 kHz, 1269 MHz Doppler will be about 3 kHz, and 435 MHz Doppler will be about 1 KHz.

d. My observations are that 2.4 GHz Doppler varies from a few KHz at apogee to near 20 KHz at lower altitudes. Since at my latitude (60.7N) I am only able to track down to a minimum satellite altitude of 7,000 km, I do not see the higher perigee frequency shifts.

e. General consensus among AO-40 operators is to expect up to 25 KHz Doppler on 2.4 GHz. This appears to agree with the calculations, above.

f. With exception of near perigee, manual frequency tuning is adequate to keep up with Doppler on 2.4 GHz. Auto-tuning becomes desirable for unattended operations such as telemetry reception or digital operations.

5. Squint angles

The importance of squint angle (the alignment of the satellite antenna with your location) becomes more important on microwave frequencies because path loss is higher and high gain antennas are often used.
Nominal AO-40 path loss at 144 MHz is 170 dB, but becomes 194 dB at 2.4 GHz and 214 dB at 24 GHz!

Current spin stabilization means that satellite earth orientation varies throughout each orbit and precesses over time. The successful tests of the momentum wheel system promises no-spin stabilization with earth-centric orientation all the time.

At apogee that implies a max squint of ten degrees with good signal levels in general though about 10 dB weaker than at an altitude of 10,000 km.

Squint at 10,000 km is worse at extreme north and south latitudes with angles up to 28 degrees, since the satellite is closer to earth. Though the path loss is lower, antenna footprint may lower signal levels by 10 dB or more.

It is therefore important that the home stations be designed with up to 10 dB extra performance to offset this effect.

6.	Tracking

    a.	I'll not go into detail here, but state that many computer tracking programs are available with Instant Track and NOVA being well know examples. Radio and rotator interfaces are available to interface equipment with your computer with Kansas Tracker, UniTrac, and FODTrack as examples.

    b.	Tracking with high gain microwave dishes requires finer angle movement. A 3-foot dish on 2.4 GHz has a beamwidth of about ten degrees which is within the tolerances of many ham rotators. At 10 GHz the same dish has a 2 degree beamwidth and pointing accuracy and stability become critical.

G.	How to get started
Now lets talk specific equipment:

1.	Antennas
As seen above, for 2.4 GHz dishes work best and a gain of 24 dBi is desirable:

    a.	BBQ grill dishes of 32 by 34 inches.
    b.	Aluminum dishes from ham dealers.
    c.	Satellite-TV dishes 33-inch diameter and larger.
       RS, Channel Master, Prime Star
    d.	Commercial microwave dishes (4-foot).
    e.	Large satellite-TV dishes 5, 6, 7.5, and 10-foot.
    f.	Long helix antennas. 30-35 turn best gain 18 dBi
    g.	Loop yagis.

Feeds:
    e.	Commercial dipole and log-periodic linear polarized.
    f.	Home-built short helix.
    g.	Short helix in a circular cavity or "cup".
    h.	Circular feed horns.
    i.	Patch antennas.

2.	Converters
For reception at 2.4 GHz:
    a.	MMDS surplus converters:
Originally 2500-2686 MHz with an IF of 222-408 MHz that average NF of 3 DB and 30 dB gain. They can be used at an IF of 122-123 MHz without modification but with diminished performance.
- Drake-2880 NF= 6 dB and gain = 15-20 dB for 2400/144 MHz.
- TranSystem NF = 1.8 to 4 dB depending on mods
- AIDC-3733 NF = 2.3 dB, gain = 30 dB
- Cal Amp 31545

      b.   UEK-3000 NF=0.7 dB, gain = 30 dB.
              The only converter that needs no preamp.
      c.   DEM 2400/144 NF = 2.0 dB, gain =
      d.   Kuhne (db6nt)
      e.   Parabolics AB

For transmission at 1.2 GHz:
      a.   FT-736R - 1.2G module (some able to output 25w)
      b.   DEM 1268/144 Tx converter (18w)
      c.   SSB
      d.   Kuhne
      e.   Other xvtrs (modify from 1296)

3.   Preamps
      For reception at 2.4 GHz:
      a.   Kuhne MKU-232
      b.   DEM 13LNA
      c.   SSB
      d.   Home-built.

4.   Connecting it all together.
      a.   Coax cables
      b.   Testing your equipment
              Gene Marcus W3PM

G.   References.

1.   "The View from Below: Thoughts on Phase 3D Ground Station Requirements", Ed Krome, "P3G to P3D", Amsat-NA, 1997.
2.   AO-40 Articles in QST, Sept. 2001
3.   "Mode S: The Book" available from AMSAT; $15 for 120 pages.
4.   http://www.amsat-dl.org/p3dqrg.html
5.   http://www.amsat.org/amsat/sats/phase3d/p3dmagic.html
6.   Drake mods by WC0Y http://communities.msn.com/wc0y
7.   Mark - N0NSV http://www.markfossum.com
8.   JN1GKZ Drake 2880 Mod. Info for 144 IF.
http://www.din.or.jp/~m-arai/sband/convmode.htm
9.   http://www.g3pho.free-online.co.uk/microwaves/drake2.htm
10.   http://www.downeastmicrowave.com
You can buy a kit 2.4 GHz downconverter for about A$230 (less than US$115 at present) from VK5EME see link at
http://homepages.picknowl.com.au/vk5eme/minikits/index.html
11.   TranSystem mods http://www.ozoni.com/n4ip
12.   3373 mods http://downtown.ala.net/~mkingery/
13.   www.ssbusa.com
14.   www.db6nt.com

15. Charles Suckling www.g3wdg.free-online.co.uk
16. AIDC 3733 from Bob Seydler k5gna@aol.com
17. Great site for a helix calc: http://vhf.worldsbest.com.au/Helix.htm
18. for 13cm helicals please look at www.wimo.com
19. http://home.swbell.net/k5oe
20. http://www.starkelectronic.com
21. ao40_s2 http://home.hiwaay.net/~mmarcus/download/ao40_s2.xls
22. Ao40-Rcv http://www.qsl.net/ae4jy/
23. Amsat-bb http://www.amsat.org/amsat/listserv/lists.html
24. Amsat-bb Archive http://www.amsat.org/amsat/archive/amsat-bb/index.html.
25. http://www.webcom.com/af9y
26. http://www.uk.amsat.org/phase3d.htm
27. Simon GM4PLM www.emn.org.uk
28. http://www.qsl.net/zl2amd/

http://www.setileague.org/software/spreadsh.htm) based on Richard
Flagg's equations and instructions given at (cascade.xls) (g-t.xls)
http://www.setileague.org/articles/g-t.htm

The current solar flux at 2400 MHz is around 140 (interpolated from
http://solar.sec.noaa.gov/getftp.cgi?get=lists/radio/rad.txt).
29. www.g0mrf.freeserve.co.uk/source2.htm
30. http://www.w1ghz.cx http://www.qsl.net/n1bwt/contents.htm
http://plaza16.mbn.or.jp/~palau/images/mini-sg.jpg
Produces 48 times of 50MHz.
31. http://www.jrmiller.demon.co.uk/prods.html.
32. http://www.hyperlinktech.com/html/products/antennas_2400.html
33. http://www.phillips-tech.com/main.asp?page=3Dpage6.asp
34. feedhorn: tomfeed.zip http://home.san.rr.com/doguimont/uploads
35. coffee can feed http://www.qsl.net/oe1dmb/activity/coffecan/coffee_e.htm
36. http://camel.campbell.edu/~hammond/ham/coffee_can/
37. http://members.aol.com/k5oe/signal_gen.gif
38. It's a 50 mHz source with a 2400 Mhz tuned line :
http://www.havilandtelco.com/homepages/gregwycoff/tsld008.htm
39. signal source http://www.g4dmf.co.uk/2400/2400.html
40. FODTrack board http://www.cl.ais.net/farcir/control1.htm
41. www.amsat-dl.org
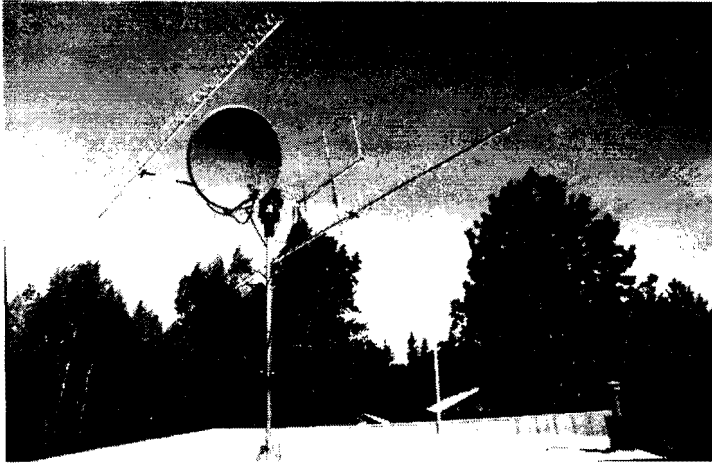42. www.uk.amsat.org
43.

Figure 1. AO-40 Antennas at AL7EB
45-element Loop-Yagi for 1.2G
33-inch dish, 5-turn helix feed for 2.4G
Kuhne MKU-232A preamp on helix
Yaesu G5400 az-el rotator
3-element 2m-Yagi (Arrow) temp for FD
42-element Crossed-Yagi for 432
Two Drake converters on mast

Figure 2. The ham shack at AL7EB
Battery on solar panel for Field Day
Rotator control boxes
FT-847 with coax switches above
DEM 1268 Tx conv. and 1296 xvtr
P100 computer with Ao40-Rcv

Figure 3. The AL7EB Antenna Farm
4-foot Andrews Dish on
mast supporting 6m Yagi.
1.0 m dish on left roof for TV.
85 cm dish on AO-40 array.
FD Solar Panel by house.
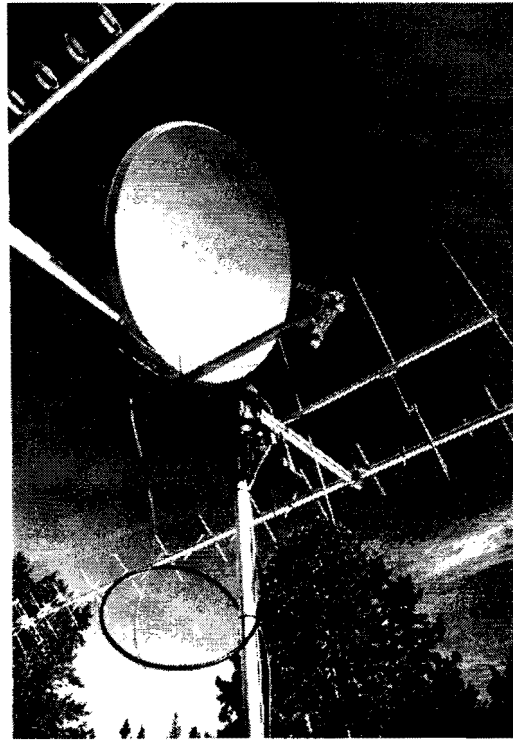Dual-Band Vertical side mount
To TV mast.

Figure 4. Close Up of 33-inch Dish,
5-turn LHCP Helix Feed
with MKU-232A Preamp.
LMR-400 coax run to
Drake Converters below
On mast.

Y.A.H.E.
(Yet Another Helix Experiment)

Gerald R. Brown, K5OE

The helix antenna has been around for quite a while and is used in many amateur radio applications, the most common being ATV and satellite communications. One would think this simple-concept antenna would be a mature field of study with general agreement on all the design parameters. That is far from the case, as I discovered in both research and in real-world building and testing of these antennae. Presented below is my voyage of discovery in helical antennae.

The AO-40 Experience:
I was ready for mode S. I had a converted Drake 2880 complete and checked out in late 1999.[1] I thought I had read all the pertinent ground station requirements—and thought I understood them.[2] I had a 16-turn helix that performed well on local ATV and I had a preamp (see Figure 1). We all knew if you could hear UO-11's S-band beacon, you would be able to hear AO-40.[3] Right? After all, I had been successfully copying the S2 beacon telemetry for months. Then, on 05-May-2001, AO-40's transponder was turned on for a "test" in mode UL/S. It was exciting. It was also disheartening, because I realized something was amiss. The darn thing was just not that *easy* to hear. I made some contacts, but they were far less than "armchair copy." CW was not too bad, but SSB was quite a struggle. I could not copy SSB signals well enough until the satellite was closer than 40,000 km. I would put 50 W into my 12 dBi UHF antenna and still could not hear myself until the satellite was under 30,000 km.[4] Surely there was something wrong. I quickly came to the (erroneous) conclusion an AO-10 class UHF uplink would be required.
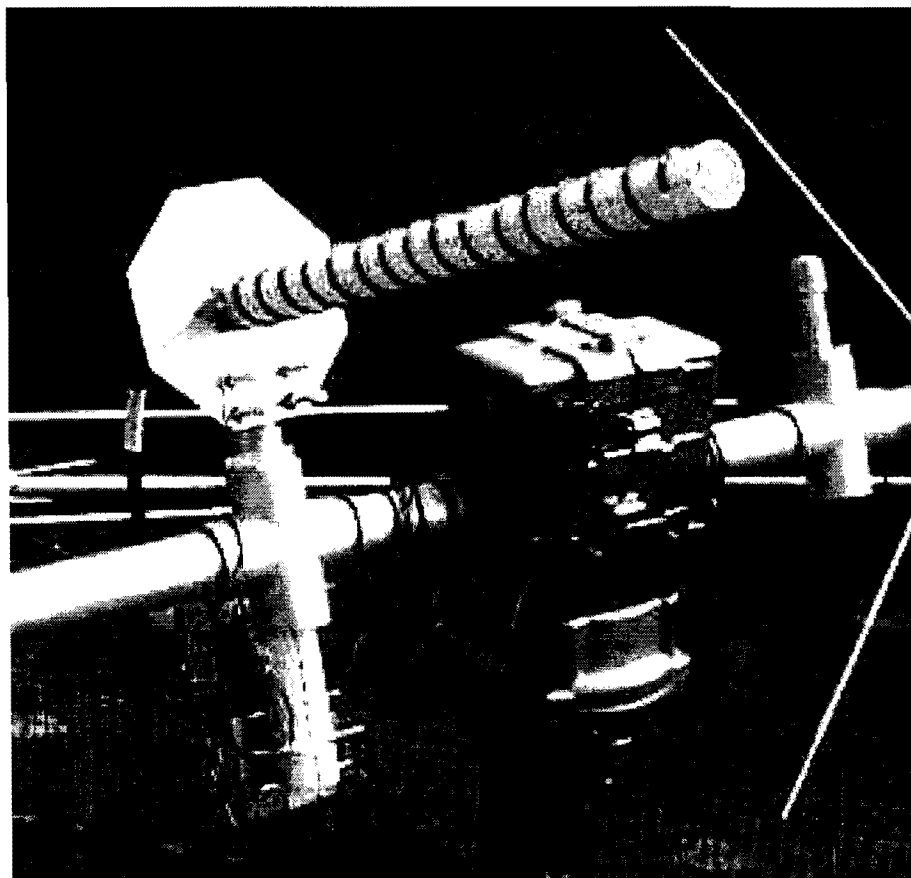

Figure 1: The "Base Case" 16-turn Helix with Preamp and Drake Downconverter

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The next weekend brought yet another first for AO-40: LEILA, the uplink policewoman, was turned on for the UHF uplink. This was strange: every time I got to where I could hear myself well enough to carry on a decent QSO, the darn thing would go off right on my frequency. Then it dawned on me: I was an alligator! It couldn't be true, could it? I had always prided myself on having fairly good receive on mode J. But, there was no avoiding the simple truth. If I wanted to be successful on AO-40, I would have to improve my downlink reception on S-band.

The ensuing banter on AMSAT-NA's bulletin board led to lots of invective, especially directed towards the inadvertent alligators, but also provided considerable enlightenment. Premier among the good things to emerge from that element was an excellent piece of analysis software from W3PM.[5] This AO-40 Groundstation Evaluation Tool allows you to enter your own particular parameters for equipment and see the resultant effect. It allows you to add, delete, and modify component specifications to accurately predict the performance (see Figure 2). This software helped me to understand exactly why my receive performance was inadequate. The W3PM software indicated I needed to do three things: 1) eliminate the first coax jumper, 2) increase the antenna gain, and 3) improve the system NF. So, I set off to design the "best" helix I could, with a design goal of 21 dBiC. This combination would give me a 24 dB S/N ratio on the S2 beacon-- predicting excellent SSB communication at apogee.
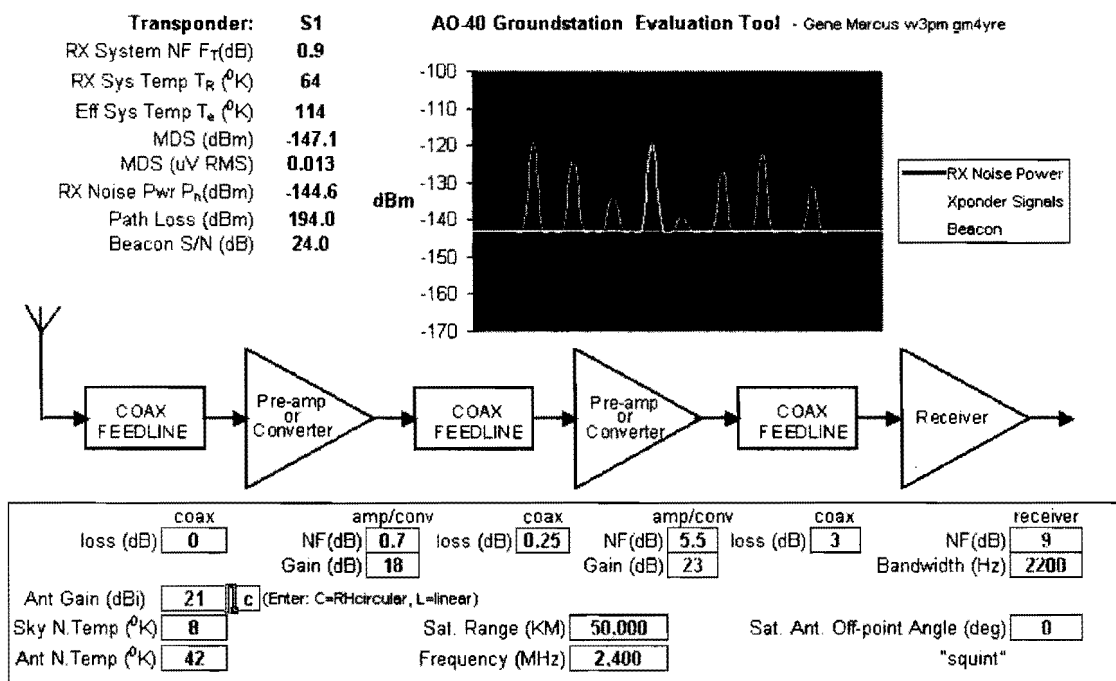
Figure 2: W3PM Program

The Quest For a Better Helix:
My particular antenna situation is far from optimum, or even flexible. I have only a small space where the antennae can rotate, about 3 m in diameter (between my chimney and my HF dipoles), and am very limited on height as they have to be hidden behind my roof line (deed restrictions). So, a small helix was the perfect antenna. I moved on to "bigger is better" ideas.

There is much discussion in the literature about the 'real" gain of a helix. This is summarized by Emerson, who collected and presents the findings of several authors as well as his own modeling analysis.[6] Of particular note in these various discussions are two findings: 1) the optimum diameter of a helix is inversely proportional to it's length (and gain), and 2) for an "optimized gain" helix the gain increase beyond 6 wavelengths (about 28 turns) is of ever-diminishing value 103

The Kirk & Wong data, based on a helix with a cup reflector, averages almost 2 dB higher than the Emerson data presented below in Figures 3 and 4.[7] My own models in NEC4Win were always overly-optimistic in gain rating by several dBi (as noted by various academics), thus are not presented here.[8,9]
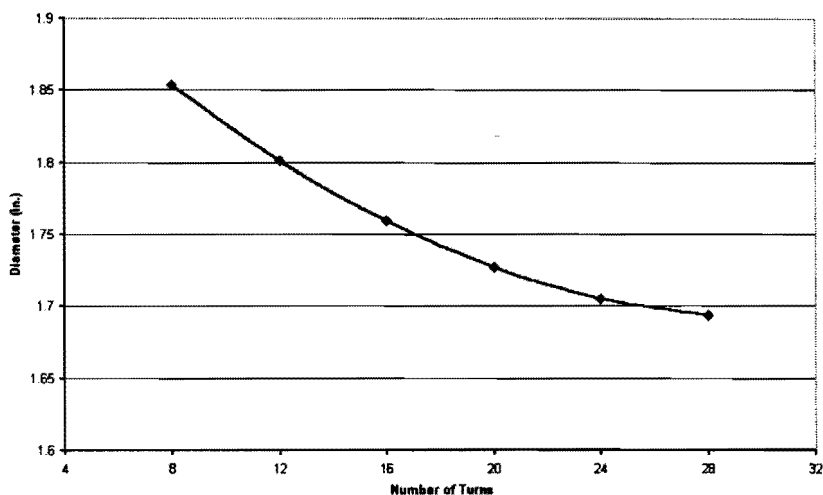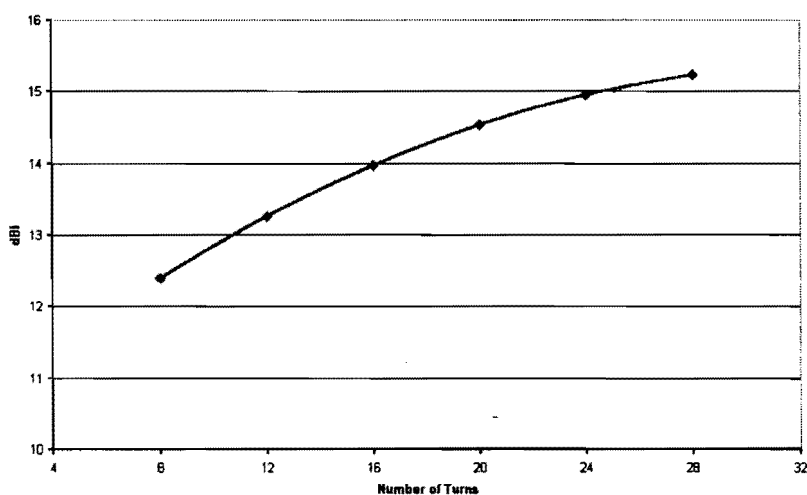

Figure 3: Diameter of an Optimized Helix

Figure 4: Gain of an Optimized Helix

I built two "big and optimized" test models. The first was a tapered version 30-turns long. I followed several examples, including one sent to me by ZL2AMD and the venerable AF9Y design using a ring reflector.[10, 11] This prototype was disappointing, as it performed about the same as my 16-turn base-case model, even though a good match to 50 Ohms was obtained. It is shown in Figure 5 below on the left, now serving duty as my Discovery Channel antenna. Next, I built a 28-turn model, using the Emerson optimized radius dimensions, with both a regular 1 lambda reflector and a RV3TH-style conical reflector.[12] I had a very difficult time getting a good match on this model, due I believe, to the increase in feedpoint impedance in proportional relationship to the diameter. This antenna is shown below right with the RV3TH conical reflector. I could detect no difference between these two antennae and neither had measurable/observable gain over my original 16-turn model. Frustration was growing and revelation number two came crashing down on my head: I did not have the test equipment to accurately measure the predicted 1.5 dB gain improvement and even if I did, that would not make a noticeable difference on AO-40 reception.
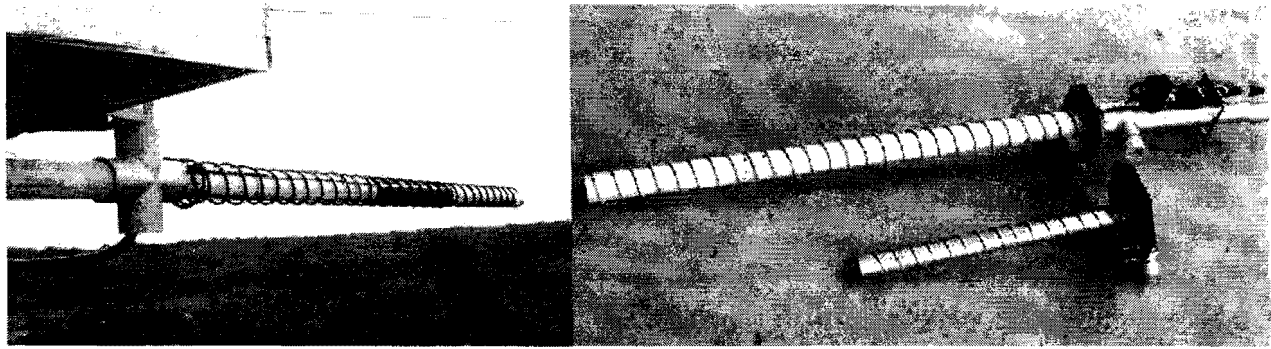
104

Figure 5: 30-turn Tapered, 28-turn "Optimized," and Original 16-turn Design

Trials and Tribulations:

What was really needed was SIGNIFICANT gain improvement. How? By stacking helices, of course! Maybe the high impedance of the 28-turn model could be an advantage if four helices were stacked and then phased to combine their impedances. I copied a design dredged up from antiquity for a 2x2 helix array.[13, 14, 15, 16] On paper, this helix array would come very close to the desired 21 dBiC goal. With 4 28-turn helices mounted on a steel backplane measuring 12" square (1.5 lambda spacing), I now had a monster of an array. Once built, however, I realized it was too large to mount, but I wanted to follow this "educational" thread to it's end. Results? I could not get anything even close to a decent match and it performed as well off the side lobes as it did in the front. See Figure 6 below for what I now refer to as my summer folly of 2001.
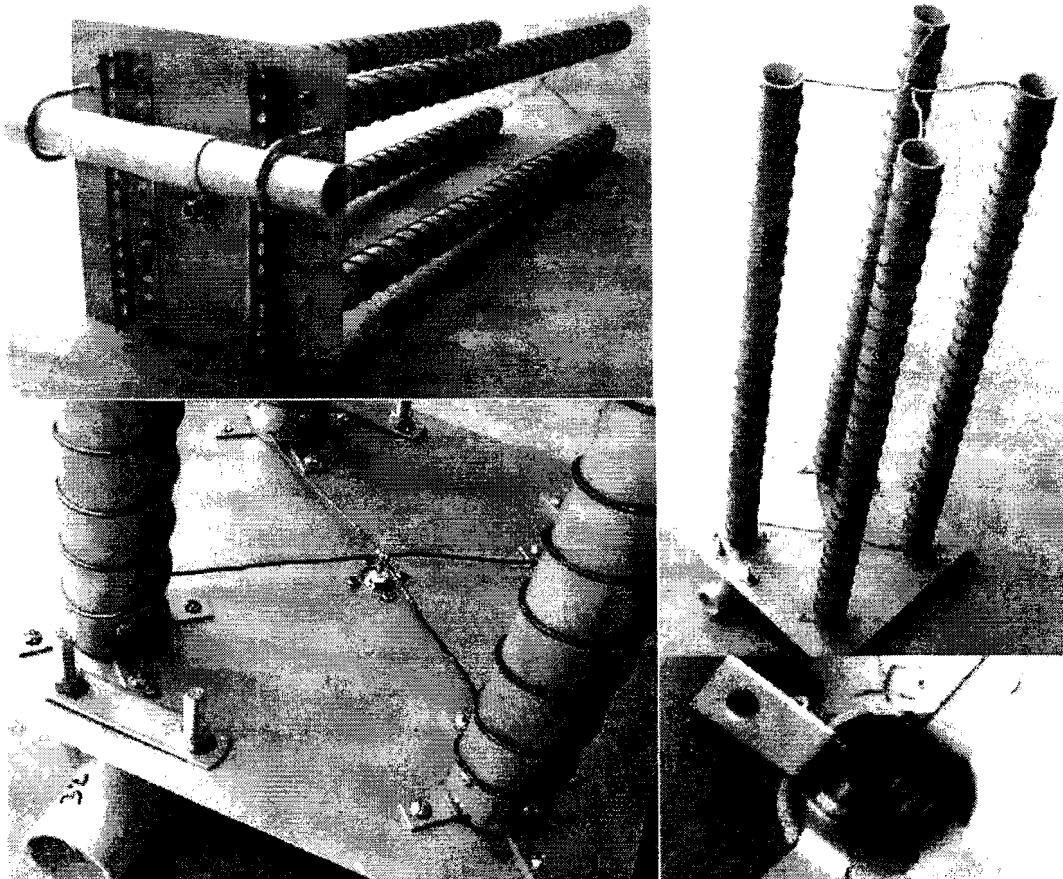

Figure 6: 4 x 28-turn Helical Array

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An Epiphany, Finally:

Now it was undeniable: I was not going to get the kind of performance I wanted/needed for AO-40 with a simple helix AND I was not likely to get a helix array to work well (if at all). I just could not see any profit in continuing these fruitless exercises with helices. Putting my original goals aside, I started looking at the practical (and now apparent) alternatives. There was no avoiding the obvious. I would need a dish. It just so happens I was also experimenting at the same time with a concept first proposed by Kraus—using a cupped ground plane.[17] I simulated this design by fabricating a temporary cup for my 16-turn helix and simply comparing the with/without signals on local MMDS channels. While the results are not quantitative, there was certainly an improvement.

Figure 7: The "Base Case" 16-turn Helix With Temporary "Cup"

A parabolic dish as an alternative was now the prescriptive remedy. I even had a small one, only 22" x 17" (55 x 45 cm) available. In order to maximize the signal potential for this small dish, I knew I wanted to use a helix feed—to gain the potential 3 dB circularity benefit. It occurred to me the cup could make an efficient feed horn for a dish. I decided to marry these two and produced the system shown below: the dish is covered with aluminum screen cloth, the cup is fed with a 3-1/2 turn helix, which feeds a MMDS preamp followed by a minimally-converted Drake 2880. The cup is 4" (10 cm) in diameter and 2" (5 cm) deep--a convenient cut-down coffee can.
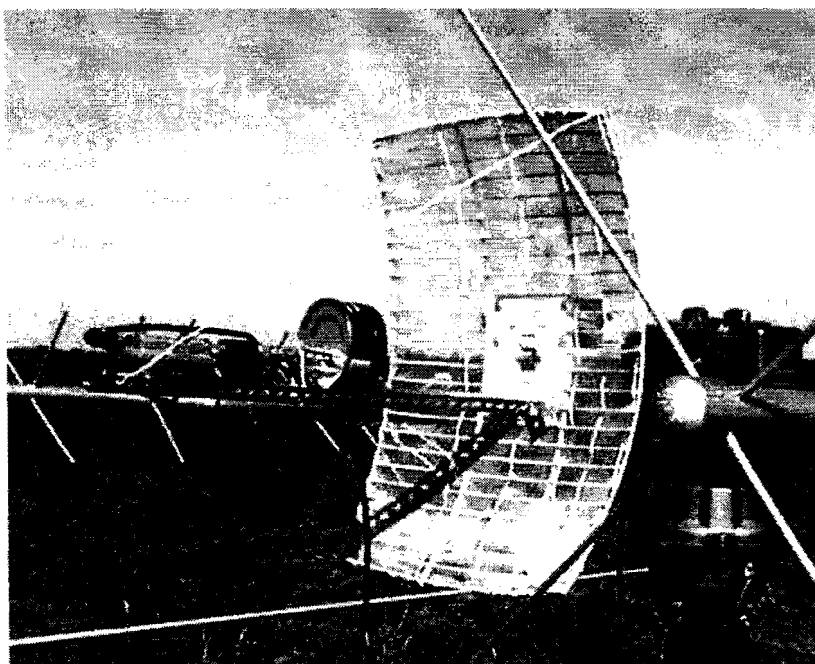

106

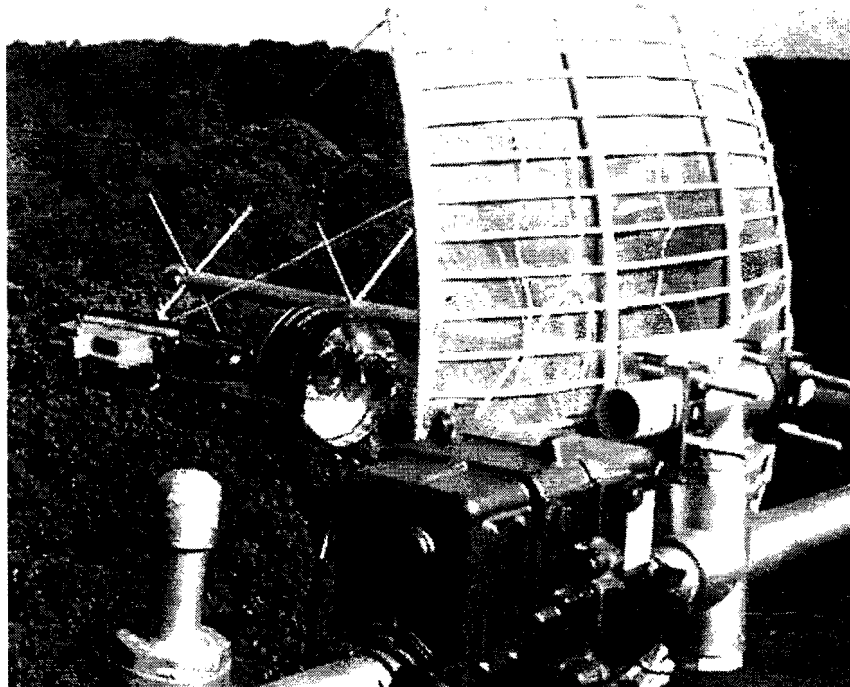Figure 8: The Parabolic Dish Assembled for Testing

Figure 9: A 3-1/2-turn Helix Inside the Cup

The results from this first attempt were breathtaking in comparison to the helix antennae I had been using. The first test was on UO-11's S-band beacon. On a 50 degree elevation pass I could hear the beacon at 5 S-units above the noise. This was 3 full S-units above any helix's performance with the same preamp and downconverter. Later that evening I listened to AO-40 and was rewarded with successful decoding of telemetry at a distance of 62,000 km using the AO40Rcv sound card program.[18] This was in early June with squint angles far from optimum.

The final stage of my receive system enhancements was to replace the MMDS preamp (a Conifer PA-1033 rated at 10 dB gain and 1.5 NF at 2,500 MHz) with a lower noise, higher gain unit. I built a DEM 13ULNA, rated at 18 dB gain and 0.6 NF.[19] This is a simple kit, but the small size of modern microwave components makes it a challenge—patience and a magnifying glass are the most critical requisite tools. Substitution of the preamp made an easily noticeable 1 to 1.5 S-unit improvement on UO-11's beacon. I now get a solid S7+ signal on the beacon on high elevation passes, with the noise level typically S2 or below. Monitoring of AO-40's S-band beacon is hard to quantify since it has been in a constant state of change for the last month.

Conclusions:
These experiences were frustrating, but educational. I have progressed from inexperience and ignorance to some semblance of understanding the requirements for a receive system for AO-40 mode S. By the time you read this, AO-40 may have successfully reached its final orbit, deployed its solar panels, and begun full transponder operation. The requirements for the receive system may end up being less demanding than what the experimental period provided, but it will never hurt to have a "better" receive system. I can summarize what I learned in two simple postulates:

- the gain should be in the antenna (first)
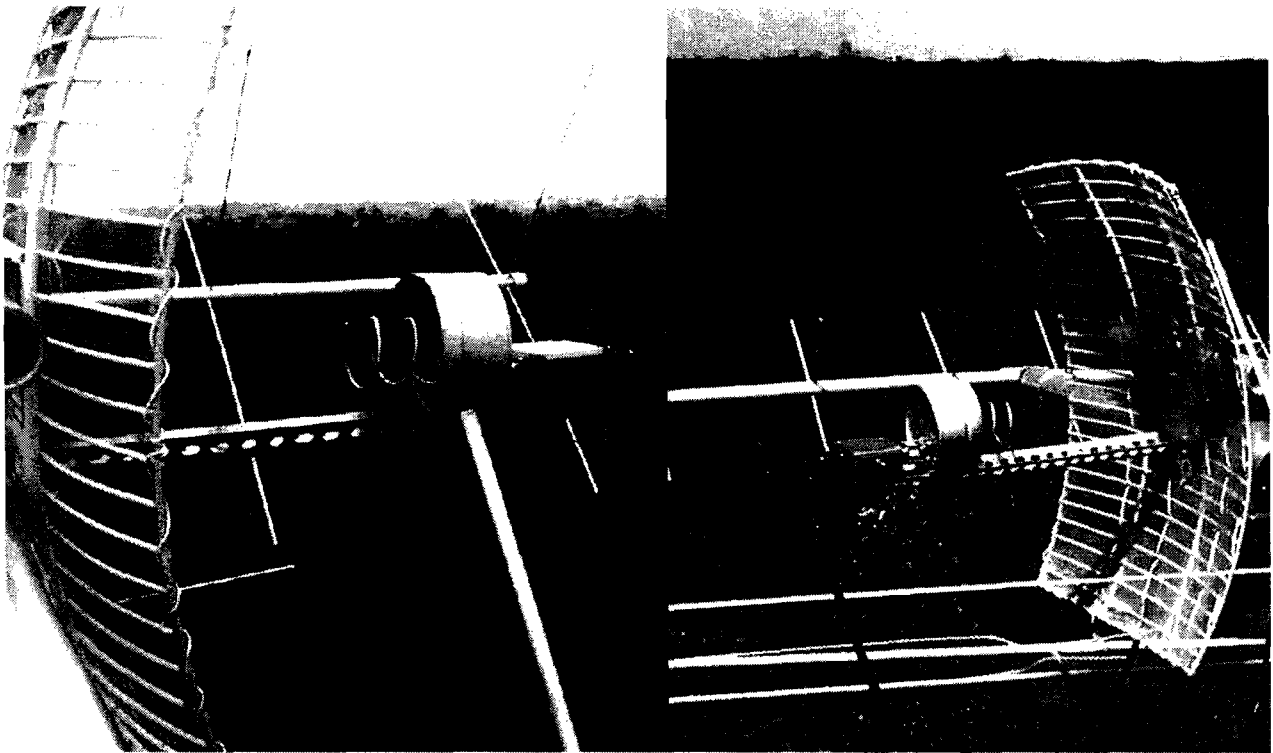- the lowest NF should be in the preamp (first)

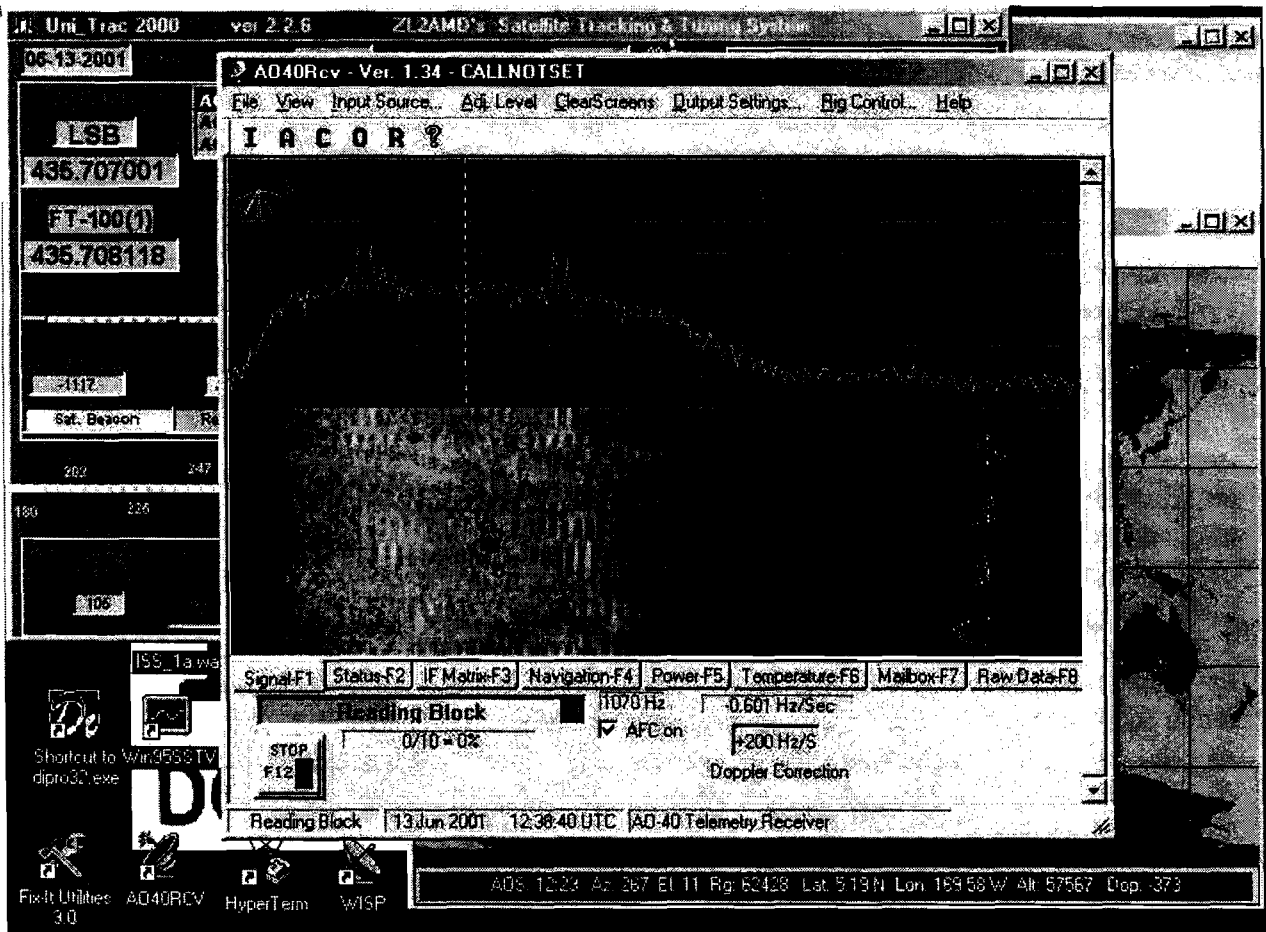Figure 10: Final Version of the Antenna With DEM Preamp

Figure 11: Monitoring the S2 Beaacon Telemetry at 62,000+ km

References:

1. Brown, Gerald R., "That Darn Drake," *The AMSAT Journal,* Mar-Apr 2000, also: http://members.aol.com/k5oe.

2. Sperber, Frank, *AMSAT-DL Journal,* see: http://www.qsl.net/dl6dbn/amsat/adlj-bod.htm.

3. Wallis, Clive. G3CWV, OSCAR-11 Satellite, see: http://www.users.zetnet.co.uk/clivew/index.htm.

4. Brown, Gerald R., *Proceedings of the 2000 AMSAT-UK Colloquium,* "A Low Cost Phase 3D Antenna System," pp. 79-86, also http://members.aol.com/k5oe.

5. Marcus, Gene, W3PM, AO-40 Groundstation Evaluation Tool, see: http://home.hiwaay.net/~mmarcus/download/ao40.xls.

6. Emerson, Darrel, "The Gain Of An Axial-Mode Helix Antenna, *Antenna Compendium Volume 4 (ARRL),* 1995, pp. 64-68; also: http://ourworld.compuserve.com/homepages/demerson/helix.htm.

7. King & Wong, "Characteristics of 1 to 8 Wavelength Uniform Helix Antennas," *IEEE Transactions,* AP-28, No. 2, March 1980, pp. 291-296.

8. Trueman, Kubina, & Slater, "Modelling Helix Antennas with NEC4," *IEEE Transactions,* 1997, pp. 1584-87.

9. NEC4Win95: http://www.orionmicro.com/n4w95/n95page.html.

10. Cook, Michael, AF9Y, "A New Helix Antenna Design for the Mars Observer Experiment ," www.webcom.com/af9y/helix.htm.

11. Kraus, John D., "A Helical-Beam Antenna Without A Ground Plane," *IEEE Antennas and Propagation Magazine,* April 1995, p. 45.

12. Lobachev, Oleg, RV3TH, builder of the conical reflector, see: http://home.swbell.net/k5oe.

13. Kraus, John D., *Antennas,* 1998, Chapter 7-12a Array of 4 Monofilar Axial-Mode Helical Antennas, pp. 321-323.

14. Troetschel, William, K6UQH (now W7LVO), "A Quadhelix Antenna for the 1215-Mc Band," QST, August 1963, pp. 36-38.

15. *The ARRL Antenna Book, 16th Ed.,* ARRL, 1992, pp. 19-25 – 19-26.

16. *Black,* William, K4BSN, "A Quad-Hlix Antenna For Hydrogen Line SETI," www.setileague.org/articles/helix.htm.

17. Kraus, John D., *Antennas,* 1988, Figure 7-16c Cupped Ground Plane, p. 281.

18. Wheatley, Maurice S., Jr., AE4JY, AO40Rcv Telemetry Decoder Project, http://www.qsl.net/ae4jy/ao40rcv.htm.

19. Down East Microwave, see www.downeastmicrowave.com.

An *Instant*Tune Update

Anthony Monteiro, AA2TX
AMSAT Space Symposium, 2001

Topics

- What is *Instant*Tune?
- New Radio Drivers
- QRP and mobile operation
- Using *Instant*Tune on AO-40
- Getting started

What is *Instant*Tune?

- Automatic radio tuning software for use with *Instant*Track
- Provides "*transparent*" Doppler-shift tuning[1]
- Makes satellite operating as easy as HF

[1]*The One True Rule for Doppler Tuning*, OSCAR Satellite Report #284, January 1, 1994 Paul Williamson, KB5MU

"*Transparent*" Doppler Tuning

- You tune your receiver with the radio's tuning dial
- *Instant*Tune tunes your transmitter for you
- *Instant*Tune corrects for Doppler-shift on both the receiver and the transmitter, maintaining a constant frequency at the satellite

*Instant*Tune - Operation

- Every second, *Instant*Tune gets new satellite velocity from OrbitDRV
- Reads receiver VFO
- Calculates new receiver frequency and sets VFO
- Calculates proper transmitter frequency and sets transmitter VFO

Anything Else?

- Sets receiver to satellite beacon frequency and mode when tracking started
- Transmit mode tracks changes in receiver mode based on transponder type
- Can tune up to 3 radios at the same time

Radio Drivers

- **Yaesu FT-736, FT-847, FT-100**
- **Mic-button radios**
- **Kenwood HF (TS-450/690 and later)**
- **Kenwood TS-790** *New*
- **Kenwood TS-2000** *New* **(G6LVB)**
- **Yaesu FT-817** *New* **(G6LVB)**

QRP with the Yaesu FT-817

- **Complete QRP MF/HF/VHF/UHF station in one box**
- **Tiny!**
- **Computer-Aided Transceiver (CAT) interface – RS232**
- **Not designed for satellite use - does not do full-duplex**

Satellites with the FT-817?

- **Can be used a receiver with another radio as the transmitter**
- **Can be operated as a transceiver in "split" mode (half-duplex)**

Cutest satellite station?

*Instant*Track on Compaq iPAQ
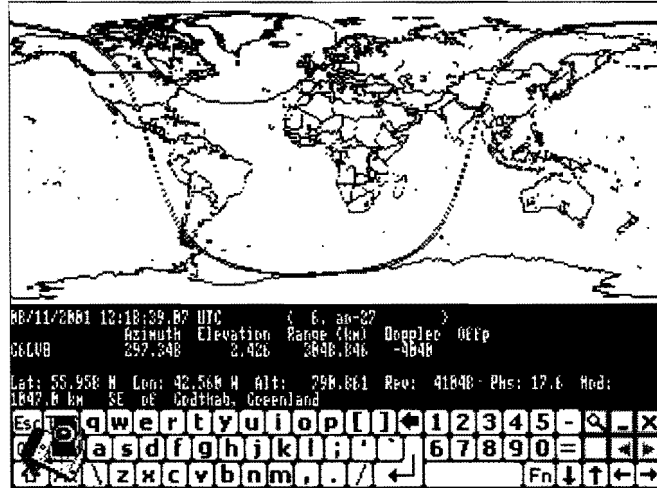
Satellite mobile...

- **Yaesu FT-100**
- **20 MHz 386SX laptop**
- **Yaesu ATAS vertical antenna**
- **1982 Mazda RX-7**

Satellites Worked

- **RS-12/13**
- *FO-20*
- **AO-27**
- **UO-14**

*Instant*Tune for AO-40

- **Configuring**
  - Receive Converters
  - Multiple transponders
  - Analog and Digital
- **Operating**
  - Switching transponder mode

Configuring for AO-40

```
;##### AO-40 analog examples ##################
satellite AO-40 U/S1     ; UHF up, S1 down
transponder 2836.024 invert
beacon 2400.323 usb
rxconverter 2256.0       ; = local oscillator


satellite AO-40 L/S1     ; L-band up, S1 down
transponder 3669.715 invert
beacon 2400.323 usb
rxconverter 2256.0       ; = local oscillator
```

Configuring for AO-40

```
;##### AO-40 analog examples ##################
satellite AO-40 U/S2     ; UHF up, S2 down
transponder 2836.989 invert
beacon 2401.323 usb
rxconverter 2256.0       ; = local oscillator


satellite AO-40 L/S2     ; L-band up, S2 down
transponder 3670.710 invert
beacon 2401.323 usb
rxconverter 2256.0       ; = local oscillator
```

Configuring for AO-40

```
;##### AO-40 digital examples #################
satellite AO-40 RA/U              ;RUDAK A UHF
downlink 436.006 fm
;uplink unknown at this time


satellite AO-40 RA/S1             ;RUDAK A S1
downlink 2400.768 fm
rxconverter 2256.0    ; = local oscillator
;uplink unknown at this time
```

Configuring for AO-40

```
;##### AO-40 digital examples #################
satellite AO-40 RA/S2             ;RUDAK A S2
downlink 2401.747 fm
rxconverter 2256.0    ; = local oscillator
;uplink unknown at this time


satellite AO-40 RA/X              ;RUDAK A X-band
downlink 10451.561 fm
rxconverter 8050.0    ; = local oscillator
;uplink unknown at this time
```

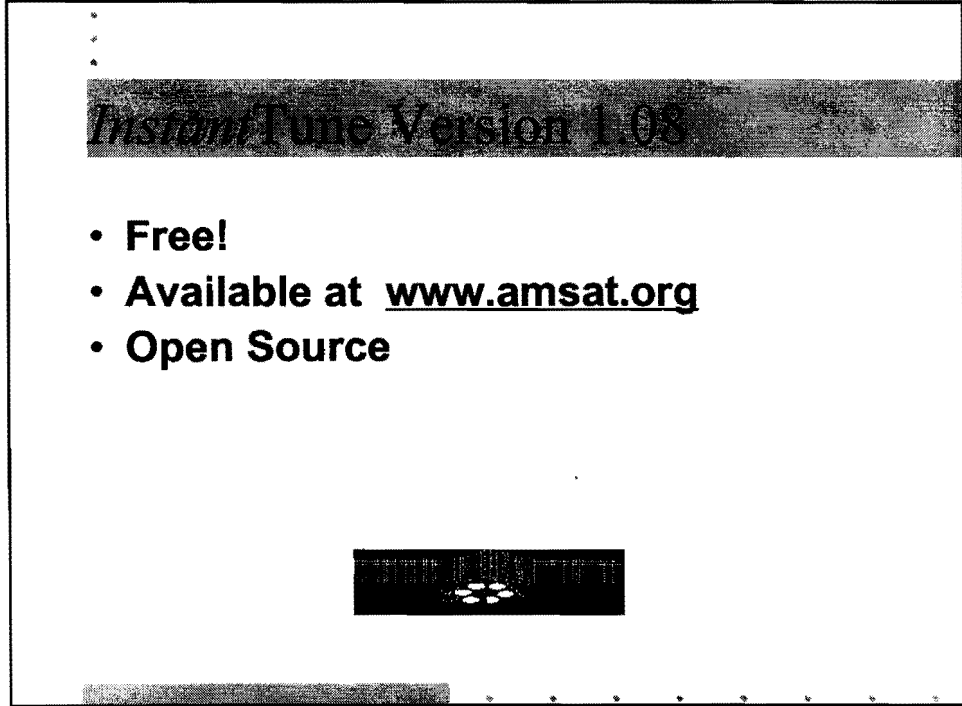## Changing Transponder Mode

```
C:\it>itune mode AO-40 U/S1


C:\it>itune m AO-40 L/S2
```

Getting Started

- **PC with at least x386 cpu**
- **No coprocessor needed**
- **No special cards - uses COM port**
- *Instant*Track
- *Instant*Tune software

InstantTune Version 1.08

- **Free!**
- **Available at www.amsat.org**
- **Open Source**

PROPOSAL FOR AN AMATEUR SATELLITE PAYLOAD ON AN INDIAN SATELLITE

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INTRODUCTION:

The role of Ham radio in public service is well known. From Morvi floods to Andhra cyclones to Gujarath earth quake, hams have played a vital role in providing a second line of communication. During medical emergencies and accidents too hams have rendered quick communication support. Not only this, since there are a sizeable population of school children involved, this hobby also develops scientific temper and promotes electronic culture in a country. Apart from this, the role of amateur radio in developing global fraternity and international friendship cannot be overlooked.

Realising the importance of this space-age hobby, advanced countries like America, Russia, Japan, England and smaller countries like Korea, Saudi Arabia, South Africa etc., etc., have launched amateur satellites.

The idea of making and launching an Indian Amateur Radio satellite is there in our minds for quite a number of years now. We have had good encouragement from ISRO for our ham activities. However, it is generally felt that hams have to make the instrument ready before asking for a launch opportunity. Now we'll have to make a meaningful amateur radio experiment to suit one of indigenous classes of vehicles developed in the country. Geo-stationary, Polar and small satellite configuration have their own distinct advantages as far as hams are concerned.

In a recent meeting (December 2000) at Hyderabad, we had a serious brainstorming session regarding building of an Indian Amateur satellite. During this Hamfest, we had a session describing the amateur satellite communication in general and making of a satellite payload in particular. It may not be out of place, if we mention here that Indian hams have been making contacts through the satellites since the very early days of OSCARs (Orbiting Satellite Carrying Amateur Radio). They used home-brew, war-surplus equipments to make history. School children from one of the schools in Bangalore were the first (and probably the only school) from India which made contacts with space shuttle.

In this connection, as a preliminary step, we sent a communication to all those concerned to get feedback on what kind of configuration they would like for a possible Indian amateur satellite. Based on these inputs a final configuration evolved. There has been a fairly good response from all parts of the country with suggestions ranging from ``repeater" to all combinations of hf-vhf-uhf uplinks and downlinks.

During the month of January 2001, we had a meeting of all hams who are involved in using amateur satellites launched by other countries. This working group is a voluntary, dedicated group of satellite enthusiasts interested in amateur satellite activity. This group, called Amsat-India defined the possible configuration which would be most

suitable for Indian Hams. International amateur satellite group (AMSAT) is supporting this activity on a world-wide friendship basis. Italian –Amsat is ready for a collaboration in this project.

A UHF uplink and a VHF downlink on the amateur radio frequencies was thought to be good for Indian hams. In addition, a satellite beacon transmitting on VHF downlink would enable the school students to get the thrill of satellite monitoring with the help of simple equipments. There is thought of adding useful circuitry to the beacon (like the voice chip) and make it more value-added

A ``payload'' is being developed Indian hams with the hope that one day it will find a place on a ISRO satellite . It will be a ``piggy-back'' ride on any satellite (not defined) may be along with some other ``payload''. In the configuration we are envisaging we'll have simple transponders and beacons. This has to be demonstrated on ground before qualification as a satellite payload.The present model will be called as a ``demo-model''. Further it can be demonstrated as a balloon experiment too before launching it on a satellite. The group which met in January has taken this as project `VUSAT' is keen to have a working transponder and a beacon at the earliest. Hams in other institutes have shown their inclination to participate in this experiment.

For the working model or demo model, total (transponders +beacons) power could be in the range of 5-8Watts. and the weight not exceed 10Kg The systems will have their own regulators and will derive power from satellite raw bus of 28-42Volts. Initial demo-model hardware development work will start with available commercial components. It is for hams to push forward dream project hard, have the hardware on hand and then approach for an opportunity and wait for it. Such being the case, we envisage a payload which is platform independent too.

To generate more interest in the field we have started a ``sat-chat'' radio discussion on the 7.070MHz every Sunday during 0730 - 0800hrs IST. Also started on the internet a forum ``www.yahoogroups.com/group/vusat'' for information dissemination. Apart from this, a website Amsat-India.org is getting ready.

With the latest amateur satellites like Phase-3D(AO-40) and SUNSAT having problems, international ham community too is looking toward India for the development of a ham payload. Infact Italian amateur satellite organization is very keen to extend help.

Radio Amateurs always had the good patronage of ISRO. Our Chairman, Dr K Kasturirangan while inaugurating a Hamfest(1998) in Bangalore said that hams could possibly put a payload on one of ISRO's missions in the future. Hams are looking forward to ISRO's continued encouragement and support.

The present proposal focuses on the development of a small satellite payload which can be upgraded and flown on Geo-stationary satellite and which can be used as a second line of communication backup for disaster communication.

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TYPES OF ORBITS: Indian satellites typically have the following orbits

1) Geo-stationary orbit: (with INSAT –type of satellites): This type of satellite will have a foot-print mainly over Indian sub-continent but extended over places like Mauritius, Srilanka, Singapore, Indonesia, Bangladesh, parts of China and Russia, Nepal, Pakistan, Afghanistan etc., A Ham payload on this type of satellite would enable hams in these countries to have communication using simple hand-helds. This will also provide continuous communication over a limited region in the world. However most of these Geo-stationary satellites will be used for commercial purposes. Hence opportunity costs of payloads works out to be very high. It is also a fact that long-distance (DX) communication enjoyed by the hams will not be possible with this arrangement. For disaster communication as a second line of back up for regular means of communications, this orbit would be ideal for Indian Hams.

2) Low-earth orbit: (IRS –Indian Remote Sensing type of satellites): An orbit of 600 to 1000km is considered to be home of many of amateur satellites. An Indian Amateur payload on one of these satellites is within the reach of local hams. Typically IRS satellites carry remote sensing payloads. However it is not uncommon to have other payload like the one on IRS-P3 which carried an X-ray payload. The satellite had the capability for stellar orientation too to point towards X-ray sources. A small Ham payload on one of the future missions could be considered as a beginning for Indian OSCAR programme.

INVOLVEMENT OF HAMS IN THE PROJECT:
VUSAT – thoughts on a first Indian Amateur Radio Satellite

India is a very large country. Being very large geographical area, we have many natural and man-made calamities year after year. Indian Hams have been doing yeomen service during the times of national/natural calamities. Traditionally they have been depending on hf and vhf modes of terrestrial communication.

These modes have their own limitations. HF is prone to vagaries of ionosphere and vhf is line-of-sight. Satellite communications offer definite advantage over other modes during disasters and their management. In the absence of any GEO-satellite dedicated for the purpose, amateurs have been using other orbit satellites for communications. Predicting their orbits with tracking softwares, amateurs have done long distance communications using satellites.

From these thoughts, arise the idea of an Indian Radio Amateur satellite called VUSAT. 'VU' is a prefix in the callsign code given to all Indian Amateurs. Indian Space Research Organisation having capability to fabricate and launch practically any type of satellite, should help Hams in the country to develop and launch a Ham payload as a beginning and first step towards building a full-fledged amateur radio satellite - OSCAR

First working group meeting of Indian amateur satellite held on 21st January 2001:

The meeting was held in Bangalore. The agenda was to :

        1> to discuss about the configuration of an
        Indian amateur satellite
        2> to discuss about the hardware development plans
        3> to form teams for realisation of the plans.

The need to realise a woking model in next two years was stressed upon. It was also made clear that presently there doesnot exist a chance for hams to make and launch a full-fledged satellite for themselves, but there exists a definite possibility to make a simple payload to go as ``piggy-back" payload on one of ISRO's future missions. Geo-stationary, Polar and Circular orbitting launch capabilties of Indian space program were described. It was also noted that there is no promise of a launch unless there is some hardware. In the light of this, it was told that we should make a platform independent stand-alone system.

    Following proposals were considered:

    a) 2-meters repeaters(FM) on-board   b) 2-m (FM) uplink and 70cm (SSB) downlink

    c) 2-m uplink and 10m downlink

    d) 2-m uplink and 70cm downlink

    e) 70cm uplink and 2m downlink(Mode UV)- CW/SSB

    f) ``Parrot Repeater" on 2m

    After carefully considering merits/demerits of each of the case finally it was agreed upon that we should go in for the option `e' (ie., UHF uplink and VHF downlink with CW/SSB mode)above for the following reasons:

1) VHF repeaters would be very difficult to accomodate with the weight volume considerations on the satellite.

2)It is difficult to accomodate HF antennas on-board.

3)There is extensive jamming, cable noise etc., which makes it impossible to have VHF uplink.

4)On ground, it is easier to make simple UHF transmitters for CW and down-converters for VHF to HF.

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    In addition, the satellite beacon project came up for consideration. It was decided to encourage development of this as a parallel activity. The beacon would be required to have a digital portion to broadcast a simple message, like the callsign of the satellite or the satellite id. If it is developed in parallel with the transponder, then there would be some portions common to both.

    In the discussion regarding orbits, it was felt that elliptical orbits like the Polar orbit offered by the PSLV class of ISRO or the small satellite in the circular orbit would be better for world-wide communication. But however, if there is a possibility for Geo-orbit

in the Phase-IV configuration, it can also be accepted **as it will be the first of its kind. It will offer excellent platform for disaster communications**.

Regarding hardware development plans, it was decided that one working model with commercial components will have to be made in about one+ years time. This will be housed on a tall building and hams will be made to use it to get accostomed to using the satellite. After this, we'll contact TIFR for a balloon launch of the transponder. Such a facility exist with TIFR in Hyderabad.

It was felt that international collaboration in the form of any existing hardware to suit our needs to be explored and adapted.

Deliberating on the teams for hardware the some teams/focal points were tentatively agreed upon. The teams/focal points could co-opt more members for the support.

In the end, it was decided to call the satellite project as VUSAT and group as AMSAT-INDIA and have the website soon.

INDIAN AMATEUR RADIO SATELLITE –VUSAT
What type of configuration for an Indian Amateur satellite ?

Based on the operating practices, Indian Hams can be broadly divided as 1) hf opeators and 2) vhf operators3)satellite operators

hf operators: In hf operations most of the hams would like to dwell in voice and a limited number operate on CW(Morse). There are a fraction of hams who operate in digital modes too. 40M band(7 to 7.1MHz) is the most popular followed by 20m band (14 to 14.25MHz). Though many of them use home made transmitters/receivers and army surplus, of late there is a tendency to use more and more commercial rigs covering all modes and all bands. However, still usage of higher bands by Indian hams is limited.

It may be possible to satisfy a large chunk of Indian Hams if a satellite is provided for 40m band!!! But the 40m band being as it is crowded with lot of disturbances by commercial, pirate stations as well as disturbances due to ionosphere, it would be difficult to think of normal operations except for local contacts. Added to this, from the satellite point of view lengthy antenna would be needed. Further as there is no direct, line-of-sight communication we cannot think of this as a viable means of operation.

So we may have to forgo the interest of those homebrewers who are still satisfied with those small ``qrps"(low-power equipments). The next best thing they can do is to have a converter from one of the higher frequencies in which satellite is operational.

vhf operators: Most of the vhf operations are limited to checking into the nets and minimal exchange of communication formalities. Many of them are restricted operators with limited terrestrial usage capabilities. This mode is also very useful for mobile communications. As mentioned earlier, if one can get a 2m repeater on the satellite that would also satisfy another half population of Indian Hams!! But probably it is complex to

make and qualify a repeater for space use. Added to this duplexer should have very good characteristics in separating the incoming signal from the outgoing signal.

Satellite operators: Need to have mobile communications with small hand-held transceivers is making uhf - vhf operations more attractive. Added to this is the low cost of the commercial equipments compared to hf equipment.

Justifications for UHF – VHF mode of operation:

Satellites have been around a long time now.
What actually works & what doesn't quite keep its promise
is already a matter of experience to many satellite users
and understood facts for designers. For the first VU bird,
best not to try to break new grounds, best to tread the
straight and narrow path of safe, realistic, achievable technique.
Put to use what we do know.
Implement Technology we are confident of.

FM might have better fidelity- in theory & ideal conditions,
but SSB is just fine - it is "R 5" when FM is nothing
but a carrier hiss. "Scintillation"
effects are not there on SSB. Hence there are no problems with Communicating via SSB!!
Nearest to this was the old AO-13 which had a "Spin Modulation".

SSB Mode
When working through satellites,
There are no problems with SSB.

Building SSB Gear
Presently many are on air with Home Brew HF SSB Rigs.
Home brewing VHF SSB gear is not difficult.
 Home Brewing UHF SSB gear would need only a
shade more care & and a little extra cost.
In building required equipment Hams would after all be doing
 just what the licence was issued to them for in the first place.
-"self training, intercommunication and
technical investigation in radio techniques..." part of
One can, of course, always buy ready made equipment
provided one has enough money.

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FM Mode
Any ham working SO-35 during a good pass would
be shouting from the roof tops that
FM was the only mode to go.
SO-35 is a delight to work through,
but, - on mode B, that is, Up UHF Down VHF.
When it worked the other way around, like UO-14,
Up on VHF & Down on UHF, QRM from non ham stations
made it next to impossible to use the satellite.
All active "FM" satellites presently have only
one, single usable channel. "One at a time" system.
User discipline is a Must if many are to use the bird in the
short time it is available. FM birds are pretty unimpressive
when the signal is not strong. Transponder for good
Rx sensitivity while accommodating doppler shifted off
frequency uplink signals, could be tricky for the designers.
Plus points are that, FM gear is readily available.

An ssb up-down mode :is not the easiest one
as far as equipment on the ground is concerned.
Concern about audio quality however is not justified, as the s/n
ratio required for a readable SSB signal may be approx 6 dB less than
for FM, for CW the advantage is as much as 10 dB.
A mixed mode, FM up SSB down, is hardly feasible and offers no advantage
at all.
To modify a 2 m handy or FM tx for CW should be possible, a tripler for
UHF requires less than a downconverter.
A full FM mode avoiding the problems of non ham VHF signals would
require a L (23 cm) up and U down solution being even more exotic
equipmentwise.

FM Repeaters :FM can handle only ONE station at
a time.. SSB/CW transponders can handle many at a time. As is you can see traffic on
ao10 compared to fm sats. a sat transponder even with a 20khz bandwidth ssb/cw would
put VU on the world map more effectively than a FM repeater..

An FM repeater sat or trasmoder will need to be more sensitive and
powerful because most of these rigs in VU are handies..

There are more FM handie users in the country
than all moders. But also there are enough FM sats to keep most satisfied! Taking a
global viewpoint need of the hour is a replacement for the ao40/10

VUSAT CONFIGURATION:- WORKING MODEL

The following description is applicable for a simple working model of the payload. This will have to be upgraded suitably for a Geo-stationary orbit
1. A platform-independent payload/stand-alone system will be configured. This means that it will have all interfaces suitable to adapt to a satellite bus.
It will have two transponders plus two beacons(they can be called as Transponder/Beacon Main/Redn. Or Transponder/Beacon-1/2)
Maximum dc input power =5- 8 W; Weight = 6 -8Kg

2. Transponders:

No. of transponders : 2(one Indian and one Italian)
power output = 1 to 3 W

.

    a. frequencies: UHF uplink 435.8MHz (70cm band);
                     VHF downlink 145.85MHz (2 m band);
    b. Bandwidth 20KHz or more
    c. modulation : CW/USB
    d. Voltage : 15V dc derived from satellite raw bus of 28-42V
    e. Output rf power: 1W (depending on the satellite)

Final frequencies have to be co-ordinated with AMSAT on a world-wide understanding basis. An application to them for a frequency allocation to VUSAT is already sent by Amsat-India. The final frequency will be fixed in Ham bands 434 –436MHz for uplink and 144 – 146MHz downlink
There will be two transponders. One will be totally indigenous effort of Indian Hams whereas the other will be an Italian transponder. Both of them will conform to same specifications expect the internal details which can differ depending on the individual design.
Italian transponder: Amateur radio is a world-wide fraternity. In this connection Amsat-Italia has come forward to give a transponder to Amsat-India on a international co-operation and friendship basis. They have sought an active collaboration in the project vusat The second transponder offered by Amsat-Italia on a global friendship basis will co-exist alongwith transponder developed by Indian hams. These two will be switched through telecommands between one another depending on the mode of operation. To the outside world, Italian transponder will have similar characteristics as Indian –developed transponder except for internal design details which will be left to individual designers.

3. Beacons:

Hams donot have very sophisticated tracking facilities. Beacons are a must as they indicate the AOS and LOS for any satellite. In the Geo-stationary orbit they will indicate the health of the amateur system onboard the satellite and aid during the initial phase of payload operation.

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Beacons also serve another important purpose in education. Thousands of school children who are not hams can be motivated to participate in the satellite activity by allowing them to track/monitor the satellite. Since beacon reception doesnot need transmitting licence, it is much easier to motivate the younger generation and get them involved in satellite activity by allowing them to have simple receivers which give out informations from satellite. Monitoring messages from the satellite and decoding the satellite parameters will give an immense pleasure and boost satellite – based technical activity in whole of the country.

Power output : 100 mW to 500 mW

        a. Frequency: 145.85MHz(CW)/145.90MHz(NBFM)

        b. Voltage: 15V dc

A.Message beacon:

Message beacon – transmitting pre-recorded voice messages at regular intervals. Very simple circuit with a few Ics is thought off.

 Messages: digitally modulated voice or CW messages

                (containing satellite id, name etc.,)

   modulation: FM

   No. of messages: 2 or more

B: Telemetry beacon:

Modulating beacon – will transmit some of the vusat parameters in a digital Morse coded format

Operation of the Morse generator works as explained below:

Analog Voltages corresponding to various satellite parameters are selected one by one by the Analog MUX (can be implemented using 2 numbers of Analog mux/demux CD4051).

Channels are selected by giving address generated by a 4 bit binary counter (named as channel select block). Voltage in the selected channel fed to the ADC that converts the analog voltage into three BCD digits. This multiplexed digits are demuxed and stored in 4 bit tri-state latches D0,D1 and D2. The channel number of which conversion is taking place is latched in another 4 bit tri-state latch (cd).

Latch output of only one latch or CH at a time together with channel select bits is given as the msb part of the address of the Morse EPROM, where data corresponds to the Morse code to be generated is stored.

This MSBits portion is actually acts as the index pointer for the start of the Morse sequence to be generated. If channel bit is "1" then Digit bits are treated as the channel number and Morse code to identify the channel is transmitted. If ch bit is "0" then the digit bits are treated as BCD of the data digits (D0) being the LSD.

In the above memory scheme, We will be able to transmit the actual value of the parameter and the name of parameter in Morse.

For example, if Battery voltage can be transmitted like " BATTERY VOLTAGE IS 012 " and temperature like " TEMPERATURE IN DEGREE IS 124" or so in Morse.

The implementation using discrete chips involves 12 ICs. If we implement it in an FPGA, the number of chips can be reduced to 3 or 4.

Another scheme is to use a microcontroller. This scheme is very simple, low cost and reliable. The Only limitation is the difficulty in getting space qualified microcontroller for satellite application:

4. **Power** from raw bus: not greater than 5W for the complete payload of this type
5. **Weight** : not more than 5 - 8 Kg for the completer payload
6. **Volume**: to be decided later(TBD) - housed in a independent box
7. **Telecommands**(TC): Unit will take the commands from main satellite TC system
    It will have interfaces to receive these commands. Commanding will be done
    by the satellite people.
    Interface will include relays and relay drivers which will be operated by TC
    All commands are `pulse type'(0,5V)
    a. One `vusat on' command to switch on the payload
    b. One `vusat off' command to switch off the payload
    c. One `transponder –1/-2' change- over command
    d. One `transponder/beacon' change-over command
    e. One `beacon msg1/msg2' change-over command
    f. one `beacon-1/beacon-2' change-over command
8. **Satellite Telemetry**(TM): Unit will interface with the satellite House Keeping(HK)
TM system
    It will have following analog channels of (0-5V) updated once in
    32secs. by the satellite TM
    a. transponder voltage
    b. beacon voltage
    c. payload tempr.
9. **Environmental specs**:
    a. Thermal: 0-40deg.C (operating); -15 to +55deg.C (qualification)
    b. Thermovac: with above qual. tempr. range and 10^{-6}mm pr. payload should
        survive for 21days in Thermovac; there'll be 5 `short cycles' and 1 `long cycle'
    c. Vibration: 10g(sine/random) - depends on satellite
    d. EMI/EMC : TBD
10. **Other specs**.
    a. A dc/dc converter needed to get 15V from 28-42V raw bus
        (readily available qualified module will be used)
    b. satellite will operate in either transponder mode or beacon mode
        (it will share the antenna and part of downlink circuitry)

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AVAILABILITY OF COMPONENTS:

- Amplifiers, Mixers, crystal filter etc., used in these designs are proven components and are easily available. Some of them are available in old stocks in ISRO which may be used for the project.
- Crystal oscillators are critical elements. Survey has indicated that these can be indigenesouly made available from sources like, Bharath electronics, Andhra electronics or Keltron
- Voice recording chips and FM transmitter chips for beacon have to be tested and qualified.
UHF filters, antennas etc., can be fabricated or ordered with local manufacturers.
Mission operations, Commanding and maintenance of the satellite: Most of the other amateur radio satellites are commanded and managed by the Hams themselves. Keeping the present scenario and state of technology with the Indian amateurs, the present proposal calls for management of the satellite and the payload by ISRO. Amateurs will be restricted to giving the schedules of operations of transponders and/or beacons.
They will track the satellite with their own softwares. ISRO will have to give Keplarian elements to hams time to time, which they will fit into their programs and derive the satellite position.
Apart from this House Keeping (HK)telemetry monitoring values can also given to know the health of the payload.
The above can be uploaded to Amsat-India web-site at a fixed schedule worked out in consultation with Hams.
As there are beacons configured in the payload, Hams will be able to monitor the satellite and the payload health to some extent. However, additional data about Keps, HK and operation schedule would further help in good working through the satellite.

TIME SCHEDULE:

Work on the first model has already started. Most of the components needed for the working model are on hand. The circuit is simple and proven design. However some tuning will be needed to align the frequencies in the final configuration. The lab model work should be completed in another 4 months time. Once there is some confidence on the working of this lab model, parallel efforts will be initiated to make the qual. Model with required components. This would take about another 6 months time. The final flight model would take about 4months. Overall it would take about 1 year's time from the date of approval of the platform to deliver the flight model hardware.

The qual. Model and flight model will have to be tested as per ISAC QA guidelines. However since this is an experimental package there should be some relaxations and this could be treated on par with other payloads of this category.

Implementation plan would involve keeping the working model on a tall building in various cities, and flying it on a balloon at the facility in Hyderabad. This will give enough confidence as to the working of the payload.

Ground Segment:

This would involve millions of Ham stations all over the world. In addition, it would also involve millions of school/college/educational institutions which can monitor the satellite beacons.

To work through the satellite, the ground station would need a uhf to vhf transceiver operating in the dual mode. Such commercial transceiver from vendors like Yaesu, Icom, Kenwood etc., are available with Hams. In addition, small single frequency uhf transmitters can be ``home-brewed'' by the Hams. Circuits for such developments are available with Hams. Simple vhf receivers and vhf to hf down converters are also well within the reach of Indian Hams.

CONCLUSIONS:

This is a first step for what could be a first Indian amateur satellite. However, before we could talk of a system to work on the satellite, we need to make one of all of the above combination which should be working on ground for atleast few months. It may also be noted that satellite qualification requirements need to be met for such a system if it has to fly in space. The weight, volume and power constraints on the satellite are quite stringent. Ingenious designs and readily available components will not only make such a system more attractive but also speedup the delivery schedule. Working groups could come forward to deliver different electronics subsystem of such a payload. Schools, colleges and Universities could involve students in such projects.

By launching such a satellite experiment which would involve people of all walks of life, a tremendous awareness and interest in satellite technology can be envisaged. The educational uses of such a project are innumerable and there could be a number of projects which could be initiated by the launch of such a satellite.

Making of a transponder of the ``working model'' type described in the report is well within the capability of Indian Hams. However to make a transponder for Geo-stationary orbit, deeper ISRO involvement would be required. In addition, ground station support in the form of infrastructure, receiving antennas etc. will have to be thought off. If the emphasis is on disaster communications then Geo-stationary orbit being ideal for such purpose, it would be useful to define the ground station support and involvement of Hams in the ISRO project.

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An Efficient Digital Mode Transponder
By Phil Karn, KA9Q

To view the current version of the written presentation, go to

http://people.qualcomm.com/karn/amsat/