Cliff Buttschardt
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AMSAT

RADIO AMATEUR SATELLITE CORPORATION

PROCEEDINGS OF THE

AMSAT-NA

Ninth Space Symposium, AMSAT/ARRL Educational Workshop and AMSAT Annual Meeting

November 8-10

1991

Los Angeles, California

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First Edition

Foreword

These papers, prepared for the 1991 AMSAT Technical Symposium and joint AMSAT/ARRL Educational Workshop, represent the state of the art in Amateur Radio space experimentation. Many readers will recognize the names of authors who have long been associated with AMSAT's and ARRL's efforts to further the amateur space program. Others are less well known, but bring an equally farsighted vision to these Proceedings.

The ARRL is pleased to have the opportunity to publish these Proceedings. We trust that it will serve to stimulate even greater interest in the amateur space program. If you're among those whose interest has, thus far, been latent, why not contact AMSAT and see where your talents and abilities might fit in? You could soon find yourself contributing to a deep-space probe or a mission to Mars!

David Sumner, K1ZZ
Executive Vice President, ARRL

November 1991

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AMSAT/ARRL Educational Workshop

MOTION AND COLOR VIDEO VIA THE PHASE 3D SATELLITE: REPLACING ATV WITH ADV

A STATUS REPORT

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As part of the developmental planning to construct the AMSAT Phase 3D Satellite, an advanced communications OSCAR in high earth orbit, there has been discussion regarding provisioning of a hard limiting wide bandwidth digital transponder, generally with the capability of handling traffic in the range of 56-64 Kbps, or even higher speeds.

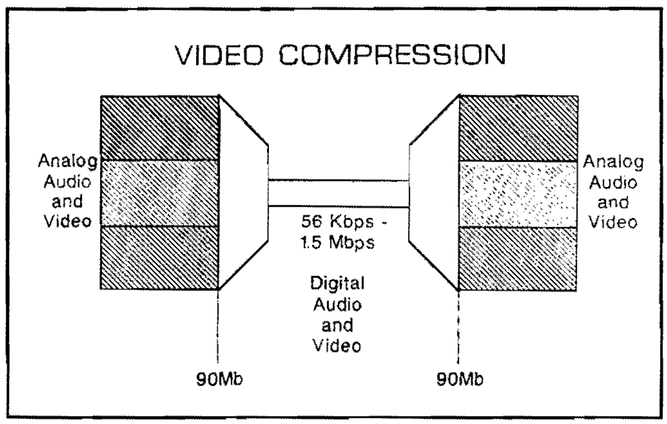

Fig. 1

In this paper we'll discuss the possibilities of using an Amateur digital video (ADV) communications system based on a coder/ decoder (codec) device installed in a high speed 80386 PC. Such a configuration could be used to digitize the motion video output from a standard baseband video (NTSC) source, such as a home video camera or VCR for a digital transmission uplink to the Phase 3D Satellite. This PC based codec could also take an incoming digital video motion signal from a downlink receiver and convert it to an analog video motion signal for display on an appropriate monitor.

Using data compression techniques such as vector quantization, the digitized motion video can be taken from it's uncompressed digital form of approximately 92 Mbps down to 56 Kbps or less for more efficient transmission (see Fig. 1) between ground stations and the satellite. Current techniques, even at this tremendous compression ratio, provide acceptable color contrast and image resolution, with moderate motion compensation capability.

Technological developments in digital video compression over the past few years have resulted in a steady decline in digital bandwidth requirements and equipment cost, while the motion image quality level has improved dramatically (see Fig. 2). We are now quickly approaching the development stage where a PC based codec system for digital video transmission and reception will start to come within range of the more advanced Amateur television and satellite operators within the next several years, and certainly long before the launch of the Phase 3D Satellite, now tentatively scheduled for 1995.

This type of highly compressed digital video motion signal has sufficient quality for Amateur digital video (ADV) contacts, and it is far more suitable for relay through an Amateur satellite transponder than conventional analog Amateur Television (ATV) signals. ADV would provide an acceptable signal to noise ratio and link margins for Amateur ground stations without the need for excessive power levels as recently indicated for even low earth orbit activities during the SAREX space shuttle video reception tests. This is an important consideration when planning such future Amateur activities from the space station. ADV could also provide a type of terrestrial video communications which is considerably more spectrum efficient than ATV.

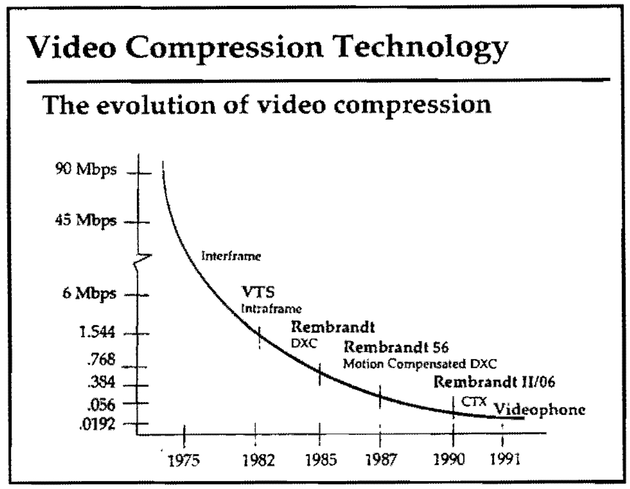

Fig. 2

THE EFFICIENCY OF FACE-TO-FACE COMMUNICATIONS

Meeting face-to-face generally provides the most effective means of interpersonal communications for many purposes. The apparent reason for this, as researchers have observed, is that as much as 80% of the communications which takes place in such meetings is non-verbal in nature. This important observation is one of the driving forces behind the explosive growth in the use of digital video teleconferencing by business. Developments in the area of very large scale integration (VLSI) and digital video compression technology are approaching the stage where radical changes in the economics of the situation are about to take place. The day of the video telephone for interpersonal communications, envisioned long ago, is no longer that far off.

So, why doesn't everyone own a video telephone now? The answer is cost effectiveness. The technology exists. The trick is making it reasonably affordable. Even businesses with far larger telecommunications equipment budgets than the average Ham, are seeing a rapid growth in voice only or audio teleconferencing for conducting meetings. The reason for this situation is that although video teleconferencing is the obvious choice, audio teleconferencing is less expensive and "good enough" for the moment. As we mentioned before, developments in the fields of VLSI and digital video compression are about to radically change the economics of the situation.

WHY DIGITAL VIDEO?

You have been watching a wide bandwidth form of digital video for years and may not have realized it! To digitize an analog video signal takes about 92 Mbps. The national TV broadcast networks take this digitized video signal, compress it 2:1, and broadcast it to their affiliated stations. The digitalization and compression of television broadcasts allows networks to send their programming over special terrestrial circuits that handle the resulting 45 Mbps digital video signal. Digital video compression at this level, when converted back to analog, retains all of the characteristics of the original NTSC video.

You're about to see a lot more digital video! The high definition television (HDTV) currently under industry development and FCC review for the consumer entertainment television broadcasting field is essentially a form of high bandwidth digital video. Commercial direct digital video satellite broadcasting of movies and other forms of video entertainment was proposed to start this past summer, but has been delayed. There is also serious consideration being given to replacing conventional private analog business television (BTV) broadcasts, generally via commercial Ku-Band satellites, for university educational seminars, product announcements, training programs, etc. with digital video broadcasts, either via terrestrial commercial fiber optic lines or via commercial satellite.

If video signals are further compressed, say by a factor of 60:1 to 1.5 Mbps, there is still more than sufficient quality remaining to use digital video for relatively economical business two-way communications. This allows commercial organizations to hold group meetings without having to travel to the distant locations. True, you would probably not want to use this highly compressed digital video medium for sending images of a fast action hockey game, but for purposes of meetings and presentations, it's more than adequate. Further developments in data compression techniques have allowed for the commercial use of digital bandwidths down to 384 Kbps, and recently, even to 128 Kbps while still maintaining acceptable quality.

Although these developments are impressive from a commercial perspective, they do not presently provide many alternatives for Amateurs. However, Amateurs are more resourceful and deal more effectively with reduced quality of communications, in order to put a new technology to use in a different way or in a more affordable manner. Thus recent developments to reduce the video bandwidth to as little as 19.2 Kbps start to look promising. In case you haven't realized yet what an accomplishment digital video compression to this level means, stop to think about what data compression ratio is required. This is roughly equivalent to pouring the sand from a large dump truck into a small bucket!

At the bandwidth of 56-64 Kbps or less the video image quality is significantly reduced as compared to standard television (NTSC), but it is still more than adequate for most Amateur two-way motion video communications. More importantly for the Amateur Satellite Service, future OSCAR satellites may be able to transpond such a signal. Because of bandwidth and signal to noise requirements of present ATV analog signals it is not feasible for any current envisioned Amateur satellites to transpond these signals. Digital video techniques must be used. According to Dr. Karl Meinzer DJ4ZC, based on a guideline of 350 bps per watt EIRP, approximately 64 Kbps are achievable on the Phase 3D satellite. By using QPSK or some similar method of modulation, such a transponder would probably be suitable for ADV purposes.

It is clearly possible that by the time the Phase 3D satellite is launched, acceptable compressed digital video may be possible down to a bandwidth of 19.2 Kbps. Although this is twice the speed of the highest Amateur satellite communications accomplished to date, it is only about one third of the digital transponder bandwidth now considered feasible for the Phase 3D Satellite. This means that three digital video transmissions could be handled at the same time. More likely, one or two digital video channels would be used, with the balance of the digital transponder reserved for high speed packet communications trunks.

There are tremendous possibilities in the Amateur satellite community for technology which allows handling of motion video signals in this manner. Not only would two-way digital video contacts via Amateur satellite be possible, but long duration connectivity via digital video with the space shuttle / space station relayed through the Phase 3D Satellite for educational activities could also become a reality. An ADV team at an emergency site, with not much more gear than presently used by Pacsat operators, could transmit color motion video of the disaster to all suitably equipped sites on the satellite downlink across the country, greatly facilitating the shipment of the most appropriate relief supplies and assistance. The possibilities are numerous when you can see what it is you're talking about, aren't they? That sounds like a statement of the obvious, but unless you've experienced a two-way video contact you may not appreciate its true meaning. Think about it, not just in terms of your hobby, but also in regard to your way of life. The telephone changed people's lives in unanticipated ways. Digital video will do the same for us!

WHAT'S IT GOING TO COST?

Presently, a commercial digital video codec retails for approximately $35,000! This figure is expected to drop quickly with the improved availability of codec chip sets employing the new international CCITT H.261 digital video standard (see Fig. 3). Codec manufacturers are introducing models of PC based codecs which operate satisfactorily at 384 Kbps and currently sell for less than $10,000 (including the PC). These prices are still well beyond the Amateur market, but they are about half what they were when this presentation was made last year at the 1990 AMSAT-NA Space Symposium in Texas. As all of you who may have long ago purchased a 9600 bps modem for nearly a grand well know, that's not the end of the story.

When the codec chip sets become more available in 1992 they are expected to initially sell for between $1500 and $2500. This price will fall as supplies become plentiful, other manufacturers enter the market, and the initial supplier has recouped its research investment. Digital video codecs which are PC based are already on the market, and video telephones will begin to make an appearance on the consumer scene in the not too distant future. Further along, it is likely that a codec-on-a-chip will be introduced which will make PC based systems and video telephones even more economical.

STATUS OF CCITT VIDEO STANDARDS — JUNE 27, 1991

ELEMENT	RECOMMENDATION SUBJECT	STATUS	ADOPTION DATE
H.221	FRAME STRUCTURE FOR A 64 TO 1920KBIT/S CHANNEL IN AUDIOVISUAL TELESERVICES.	ADOPTED	12/90
H.230	FRAME SYNCHRONOUS CONTROL AND INDICATION SIGNALS FOR AUDIOVISUAL SERVICES	ADOPTED	12/90
H.242	SYSTEM FOR ESTABLISHING COMMUNICATION BETWEEN AUDIOVISUAL TERMINALS USING DIGITAL CHANNELS UP TO 2MBIT/S.	ADOPTED	12/90
H.261	VIDEO CODEC FOR AUDIOVISUAL SERVICES AT Px64KBITS.	ADOPTED	12/90
H.261	STILL FRAME VIDEO GRAPHICS	PROPOSED	6/92*
H.320	NARROW BAND VISUAL TELEPHONE SYSTEMS AND TERMINAL EQUIPMENT.	ADOPTED	12/90
G.722	ADAPTIVE DIFFERENTIAL PULSE CODE MODULATION (ADPCM) AUDIO 48/56/64KBIT/S.	ADOPTED	1986
G.711	PULSE CODE MODULATION (PCM) AUDIO 64KBIT/S.	ADOPTED	1984
AV.254	LOW BIT RATE AUDIO (16KBIT/S).	IN DEVELOPMENT	6/92*
AV.231	MULTIPOINT CONTROL UNITS FOR AUDIOVISUAL SYSTEMS.	IN DEVELOPMENT	6/92*
AV.243	SYSTEM FOR ESTABLISHING COMMUNICATION BETWEEN THREE OR MORE AUDIOVISUAL TERMINALS USING DIGITAL CHANNELS UP TO 2MBIT/S.	IN DEVELOPMENT	6/92*
AV.441	CALL-CONTROL PROCEDURES FOR REAL-TIME AUDIO-VISUAL CONFERENCE CALLS - PROCEDURES NOT REQUIRING SPECIAL NETWORK CAPABILITIES.	IN DEVELOPMENT	6/92*
AV.442	CALL-CONTROL PROCEDURES FOR REAL-TIME AUDIO-VISUAL CONFERENCE CALLS - PROCEDURES REQUIRING SPECIAL NETWORK CAPABILITIES.	IN DEVELOPMENT	6/92*
AV.233	PRIVACY SYSTEM FOR NARROW BAND VIDEO SYSTEMS (ENCRYPTION)	IN DEVELOPMENT	6/92*
AV.270	USER DATA TRANSMISSION (MULTI-LAYER PROTOCOL)	IN DEVELOPMENT	6/92*
JPEG	JOINT PHOTOGRAPHIC EXPERT GROUP, HIGH RESOLUTION GRAPHICS	PENDING	?

NOTE: * THE FULL CCITT BODY MEETS EVERY FOUR YEARS TO RECOMMEND ADOPTION OF STANDARDS TO THE MEMBERSHIP. THE NEXT SCHEDULED CCITT MEETING IS 1992. RECOMMENDATIONS ADOPTED BY THE COMMITTEE ARE SENT ON FOR MEMBER RATIFICATION. RECOMMENDATIONS OR PROPOSALS THAT ARE NOT READY FOR APPROVAL CAN BE APPROVED BY EITHER A SPECIAL PROCEDURE OR WHEN THE FULL CCITT MEMBERSHIP CONVENES IN 1996.

Fig. 3

These factors, coupled with the new international standards developments relating to digital video telecommunications, will quickly combine to drive prices rapidly downward. I expect that by the time the Phase 3D Satellite is launched there will be available for about $500, a card which can be inserted into an expansion port on your PC. This card, coupled with perhaps a minor modification to your satellite transceiver, will allow you to receive a full motion digital video transmission from an Amateur satellite or terrestrial source. The output would be converted for display on your computer monitor. By connecting a home video camera or other NTSC video source such a VHS VCR, you could digitize the video and uplink it to the Phase 3D satellite for a two-way motion and color ADV contact. With the current digital developments in commercially manufactured Amateur Radio equipment, perhaps even the minor modification to your radio will not be necessary.

COMPRESSED DIGITAL VIDEO OPENS A NEW WORLD FOR AMATEURS!

Amateur Digital Video (ADV) contacts will not only be possible via future OSCAR satellites, but the terrestrial use of ADV instead of analog ATV would be much more spectrum efficient. This would allow far more users to be accommodated in the increasingly popular 440 MHz and 1.2 GHz video bands segments. Once the feasibility, efficiency, economy and DX capability of digital video is demonstrated, existing AM ATV operations will go the way AM voice communication went when SSB was introduced. Just as importantly, it will be possible to have a wide area digital ADV telecast via a Phase 3D satellite for Amateur Radio bulletins and educational purposes. Digital video from the space shuttle or the space station could be uplinked to an OSCAR for viewing directly by Hams, ADV satellite gateway stations, and schools. This would certainly give new meaning to the phrase "See you on the bird!"

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Comments on Proposed AMSAT MARS-A Experiment

1991 AMSAT-NA Technical Symposium
Los Angeles, Nov. 9-10

Martin Davidoff, Ph. D. (K2UBC)

BACKGROUND

At the July 1991 AMSAT-UK meeting Dr. Karl Meinzer (DJ4ZC) announced that the European Space Agency (ESA) had formally agreed to launch the AMSAT Phase 3D spacecraft with a mass of 500 - 600 kg in mid 1995. The allocated payload capacity would permit AMSAT to include on this mission an experimental system consisting of a subsatellite designed to be placed in orbit around Mars (referred to here as AMSAT MARS-A). Initial calculations indicate that the propulsion requirements are attainable. However, there remain a number of serious questions concerning the feasibility of such a mission. These include: the effort and cost associated with mastering the technical aspects of designing/constructing/ controlling an interplanetary spacecraft, and "mundane" matters such as whether the P3D antenna system will require the volume which may be used for MARS-A.

The MARS-A mission is probably a once in a lifetime opportunity for many of those currently involved in AMSAT-OSCAR design/construction. I feel very strongly that AMSAT should devote the effort necessary to clearly define the requirements for the MARS-A mission so that an accurate assessment of the costs and probability of success can be made before a proposal to undertake the mission is accepted or rejected. Table 1 summarizes previous Mars missions.

MISSION GOALS (proposed)

The MARS-A mission should be thought of as one of several technology experiments on the P3D spacecraft. As a result, it is not necessary to add scientific experiments to MARS-A to justify its existence.

I'd like to see the goals of the MARS-A mission defined as follows:
Primary Goal: To orbit satellite about Mars.
Secondary Goal: To develop low cost, high reliability spacecraft technology for <u>interplanetary</u> (1) navigation, (2) command and control, (3) propulsion, (4) communication.

Every precaution must be taken to see that MARS-A does not have a negative impact on P3D either through its design or by siphoning off critical work force or funds. To minimize impact on the primary P3D spacecraft the MARS-A mission should be kept as simple as possible consistent with the stated objectives.

THE PROJECT

A minimal mission will require at least the following: (1) propulsion system, (2) attitude sensing and control system, (3) power system, (4) IHU, (5) thermal control system, (6) integrated telemetry, command, and communications system.

The various subsystems are, of course, interrelated. One key question is whether it's possible to accomplish the mission using a spin stabilized spacecraft or if a more complex 3-axis stabilized design is required. Some general comments about the various subsystems follow with special attention devoted to the integrated telemetry, command, and communications system.

Propulsion System

The propulsion system must be capable of handling a minimal energy transfer from P3D orbit to Mars orbit. This means multiple burns. Possibilities include liquid fuel engines as employed on AMSAT-OSCARs 10 and 13, electrical plasma thruster (being investigated by Professor Messerschmidt at the University of Stuttgart), solid fuel rocket (for major maneuver, used in conjunction with other systems), solar sail (serious technical obstacles). Spacecraft design should consider the possibility of using multiple propulsion systems and integrating propulsion and attitude control systems if such an approach simplifies overall system design without having a negative impact on reliability.

Attitude Sensing and Control System

As mentioned previously, the key question here is whether its possible to use spin stabilization or if a more complex 3-axis stabilization scheme is required. Solar sensors don't appear to present any serious problems though design must take into account changing solar intensity and solid angle over the course of the mission. Although multiple solar sensors can be used to uniquely determine attitude it may be desirable to include a second sensing system capable of operating in deep space and a third (horizon) sensor system for use in vicinity of Mars and Earth. Several obvious questions arise: can we handle complexity of star sensor? can multiple uplink directive antennas be used as attitude sensor? Attitude control system may rely on elements of propulsion system.

Power System

Only option is solar cells and battery. This should suffice. Available power at Sun-Mars distance will seriously limit spacecraft transmitter power.

IHU

I believe an 1802 CPU and 32 K of error detecting and correcting RAM memory is the way to go. Although this could be labeled antiquated technology it fits mission needs due to the fact that power available on the downlink will limit data throughput.

Thermal Design

Thermal design will be considerably more complex than with an earth satellite because spacecraft must operate at changing distances from sun, at varying orientations with respect to sun, in deep space with negligible eclipse time and in the vicinity of planets where it may experience considerable eclipse time.

Integrated Telemetry, Command, and Communications System

The question of whether we can provide a downlink capable of handling the required data throughput is a major concern, especially when one takes into account the fact that relying on high gain spacecraft antennas jeopardized system reliability. This is so because problems with spacecraft attitude control that might otherwise be minor could prematurely terminate mission.

From a communications viewpoint it will probably be useful to think of the mission as consisting of three stages. During the first stage two way communications with the spacecraft will be relatively easy, even when using the omni antennas on the satellite and "high" data rates. During this stage all critical software must be uploaded and tested and back up versions stored on the spacecraft. The second stage is a transition stage. During the third stage communication with the spacecraft will probably only be possible using directive antennas on the satellite and "low" data rates. During this stage it may be possible to verify the reception of short uplink command messages but longer uplink messages will only be partially verifiable via overall checks of self consistency. During this stage loss of attitude control will probably result in loss of mission.

Transponder Overview. If we want the amateur radio community to support this experiment I think it's critical that the spacecraft have some type of communication capability and that individual amateurs have direct access to the spacecraft. One approach is to employ a single band ROBOT transponder (somewhat similar to the ones employed on many RS spacecraft [Morse cw]) integrated with the telemetry system. The downlink would consist of a single beacon timesharing between telemetry and QSO confirmations. The uplink would consist of a window (about 30 kHz) for ROBOT input and a command channel offset from the ROBOT by about 200 kHz.

The unique nature of the mission (including the Mars/Earth time delay) requires that careful attention be given to ROBOT design. One possible approach is to use a single band transponder which cycles between receiving and transmitting. When the spacecraft is close to earth a 5 or 10 minute cycle with transmit/receive time shared 50/50 would probably work well. As the spacecraft recedes from earth the percentage of time allocated to the downlink could be increased. This will be necessary since spacecraft communications will be downlink limited and we will probably have to decrease the downlink data rate over the course of the mission. As the spacecraft recedes from earth a 20 minute cycle might be more effective.

The single band communications system will simplify spacecraft antenna design and the time sharing arrangement will minimize intermodulation problems on the satellite. Another consequence of the single band design is that EME stations will be able to access the spacecraft without any changes in their stations. This gives us immediate access to a very highly motivated and technically competent pool of potential command stations.

As to transponder frequency, either 70, 23 or 13 cm appears most appropriate when one takes into account sky noise, existence of active high EIRP EME groundstations, spacecraft gain antenna size, etc. There are, however, regulatory problems associated with single band transponders on 23 and 14 cm. This decision should be made after we have some idea of spacecraft design and can make some calculations as to which frequency provides maximum access distance using state-of-the-art amateur groundstation and omni or pancake pattern backup antenna on spacecraft.

Transponder design must take into account (and encourage) the natural competitive urge of amateurs to make the longest amateur QSO. To discourage amateurs from transmitting to the spacecraft continuously when it's in view, distance awards should be quantized: any QSO during a GMT day is considered to have occurred at the geocenter-spacecraft distance as of noon GMT. Since amateurs transmitting to the spacecraft will often send for long periods of time (until the ROBOT acknowledges them) a single input frequency would result in intolerable uplink QRM and encourage the use of illegal power levels. This problem can be somewhat alleviated by using a 30 kHz window on the ROBOT uplink. The transponder would scan the window (starting at a random point) searching for a valid uplink signal. The ROBOT would acknowledge a call by repeating the logged callsign and assigning a serial QSO number. Since the downlink is the weak link careful thought should be given as to what constitutes a valid QSO and procedures set up to reward groundstation hearing ability (we do not want to design technology and an award procedure that encourages individuals to transmit at the spacecraft when they can't hear it). I suggest that a QSO be considered valid if the ground station (1) confirms his/her call as being logged correctly, (2) receives the correct serial number and (3) logs the correct call of the preceding or following QSO (for cross checking).

There should also be a serious award structure for downlink reception. Special acknowledgement should be given to those operators providing reliable telemetry and ROBOT logs over a long time period.

Using a command link separated from the transponder input window by a couple of hundred kHz simplifies transponder design in that we can simply use dual taps from a single receiver front end, i-f chain, and antenna. Also, this facilitates attracting command stations from the EME operator community.

As a result of spacecraft transmit power limitations downlink performance will be at least 20 dB weaker than the uplink. This means the downlink will probably require a variable data rate, one that can be decreased as the spacecraft recedes from the earth. Perhaps a variation of the 400 bps system used for Phase 3 spacecraft with provisions for switching to 100 bps, 25 bps, and maybe even lower. [Mariner 4 returned 240,000 bit picture frames at a speed of 8.3 bps!]. Attention should be given to the possibility of data encoding so as to increase the effective data rate of the downlink. By launch time DSP based modems will hopefully be available to minimize ground station complexity.

Spacecraft antenna requirements cannot be determined until path loss has been closely examined and a preliminary selection of the spacecraft stabilization system has been made.

Mars Log

Mission	Launch Date	Arrival Date	Comment
U.S.			
Mariner 3	05/11/64	---	launch failure
Mariner 4	28/11/64	14/07/65	first successful fly-by
Mariner 6	25/02/69	31/07/69	successful fly-by
Mariner 7	27/03/69	05/08/69	successful fly-by
Mariner 8	08/05/71	---	launch failure
Mariner 9	30/05/71	13/11/71	first successful Mars orbiter
Viking 1	20/08/75	19/06/76	first Mars landing (20/7/76)
Viking 2	09/09/75	07/08/76	successful Mars landing (3/9/76)
U.S.S.R			
1960A	10/10/60	---	launch failure
1960B	14/10/60	---	launch failure
Sputnik 22	24/10/62	---	remained in earth orbit (3rd stage rocket failure)
Mars 1	01/11/62	06/63	radio contact lost before fly-by (contact lost 21/3/63)
Sputnik 24	04/11/62	---	remained in earth orbit (3rd stage rocket failure)
Zond 2	30/11/62	08/65	radio contact lost before fly-by (contact lost 5/63)
Zond 3	18/07/65	?	communications successful out to Mars orbit
1969A	27/03/69	---	launch failure
1969B	14/04/69	---	launch failure
Cosmos 419	10/05/71	---	launch failure
Mars 2	19/05/71	27/11/71	successful orbiter, lander unsuccessful
Mars 3	28/05/71	02/12/71	successful orbiter, lander unsuccessful
Mars 4	21/07/73	10/02/74	retro-rocket failure caused orbiter to flyby
Mars 5	25/07/73	12/02/74	successful orbiter
Mars 6	05/08/73	12/03/74	radio contact failed during lander descent
Mars 7	09/08/73	09/03/74	guidance system failure caused lander to miss Mars
Phobos 1	07/07/88	---	radio contact lost late August 88
Phobos 2	12/07/88	---	radio contact lost 27 March 89 during final approach to Mars

Table 1. Brief summary of Mars missions.

A SIMULATOR FOR PACSAT-1 DOWNLINK TRAFFIC

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ABSTRACT

PACSAT-1, LUSAT-1, and UoSAT-3 have been providing file server and file broadcast services for approximately one year. Application software aboard the satellites continues to be improved and other store-and-forward satellite projects are being contemplated by a number of groups around the world. It is likely that some people involved with project development have wondered about the effects of changes in system operation and/or design. This paper describes the current status of the development of a PACSAT-1 downlink traffic simulator. The design is based on the characterization of typical PACSAT-1 operating conditions. The characterization of operations was accomplished through the analysis of a large amount of captured downlink data.

INTRODUCTION

Between January, 1991 and July, 1991, a total of six downlink data samples were collected--four from PACSAT-1 and two from UoSAT-3. These are summarized in Table 1. Only data from samples no. 1(D), 2, and 3, which represent the data collected using a beam antenna (KLM-18C) and computer-controlled tracking, were analyzed prior to development of the simulation model. PACSAT-1 sample nos. 1(O) and 4 were collected using an omnidirectional antenna (Cushcraft AFM-44DA). Details of the analysis of the PACSAT-1 omni-directional antenna samples and the UoSAT-3 samples will be published at a later date.

The "Percent of Capacity" column in Table 1 gives an estimate of the data captured assuming that the downlink was busy for the entire time the satellite was in view of the monitoring station. For PACSAT-1 the downlink is busy almost 100 percent of the time when its footprint is over the continental U.S. Even on an individual pass it is hard to account for more than about 90 percent of the downlink time. This is due to periodic pauses in downlink data transmission and bit errors in received frames caused by propagation anomalies and ground station local noise conditions.

DOWNLINK TRAFFIC MIX

Table 2 gives the frame and byte counts for each of the three primary traffic types--broadcast (QST), file server (BBS or FTL0), and telemetry (TLM). Digipeating constituted such a small part of the downlink traffic that it has been ignored in this

Table 1
PACSAT-1 and UoSAT-3 Downlink Data Sample Summary

Sample No.	Satellite Name	Time Period	Orbit Count	Downlink Time HH:MM:SS	Byte Count	Percent of Capacity
1(T)			52	09:49:59	3.6 Mb	68.1
1(O)	PACSAT-1	01/01 - 01/20	28	05:06:43	1.5 Mb	52.5
1(D)			24	04:43:16	2.1 Mb	84.9
2	PACSAT-1	02/01 - 02/28	48	09:40:47	4.4 Mb	83.4
3	PACSAT-1	03/17 - 05/29	32	06:41:28	3.2 Mb	87.7
4	PACSAT-1	03/23 - 06/14	32	06:37:14	1.5 Mb	42.7
5	UoSAT-3	03/04 - 04/29	27	05:19:06	12.7 Mb	55.2
6	UoSAT-3	05/05 - 07/14	29	06:05:41	7.6 Mb	28.9

Table 2
PACSAT-1 Downlink Traffic Mix

	Sample No. 1(D)	Sample No. 2	Sample No. 3
QST			
Frames	6,272	12,081	11,860
Bytes	981,891	1,915,835	1,630,643
Percent	45	44	51
BBS			
Frames	9,706	19,226	10,281
Bytes	1,062,230	2,150,138	1,353,752
Percent	49	49	43
TLM			
Frames	1,409	3,261	2,211
Bytes	120,108	293,132	184,259
Percent	6	7	6
TOTAL			
Frames	17,387	34,568	24,352
Bytes	2,164,229	4,359,105	3,168,924

analysis. The percentages are of the total byte count for the sample. Because the percentages in each category are relatively uniform, it would be interesting to further subdivide the traffic into a few more categories. For example, daytime versus evening and weekday versus weekend.

FILE SERVER TRAFFIC STATISTICS

The results of the data analysis for sample nos. 1(D), 2, and 3 is given in Table 3. These are the statistics upon which the computer simulation model is based. The column "χ^2 Stat" shows the result of a Chi-Square goodness-of-fit test of the data

Table 3
Summary of PACSAT-1 Downlink Traffic Analysis

--- Successful Connection Interarrival Times ---

Sample No.	Number of Observations	Mean (Seconds)	Std Dev (Seconds)	χ^2 Stat and Test
1(D)	299	61	45	53.1 E
2	682	54	45	81.7 E
3	477	55	49	44.2 E

--- File Server Transaction Service Times ---

Sample No.	Number of Observations	Mean (Seconds)	Std Dev (Seconds)	χ^2 Stat and Test
1(D)	228	128	104	22.8 E
2	472	115	90	42.6 E
3	330	108	95	35.2 E

--- File Server Data-Link Layer Response Time ---

Sample No.	Number of Observations	Mean (Seconds)	Std Dev (Seconds)	χ^2 Stat and Test
1(D)	225	5.0	2.3	31.0 N
2	464	5.1	2.6	42.3 N
3	326	5.2	3.0	54.3 N

--- File Server Transaction Byte Counts ---

Sample No.	Number of Observations	Mean (Bytes)	Std Dev (Bytes)	χ^2 Stat and Test
1(D)	212	3,120	3,371	16.1 E
2	446	2,637	2,845	34.8 E
3	306	2,700	3,692	20.6 E

against the indicated distribution--E for exponential and N for normal. A more complete discussion of the data analysis phase can be found in [1].

COMPONENTS OF THE MODEL

The statistics given in Table 3 have been incorporated into the simulation model. Particular attention has been given to parameters associated with file server system operations, since the file server is the primary communications resource. The arrival rates for successful and unsuccessful file server connections, file server transaction service times, byte counts per connection, and data-link layer response times have all been included in the model with distributions based on those determined from the analysis phase.

The model should be considered valid only for the case of directional, computer-pointed downlink antenna systems. For the directional antenna case, there is usually enough E_b/N_0 margin to counteract intermittent periods of fading. Even though the model does not include the effects of the link margin on BER, it does perform link margin computations and displays the effect of the satellite slant range at the simulated clock time. The simulator user has the option of having the link margin computations based on the use of either a directional or omni-directional downlink antenna.

Spacecraft telemetry of some type must be broadcast periodically on the downlink, therefore the simulation allows a list of frame types, frame lengths, and transmission intervals to be specified by the user. This component of the model is useful because there may be times when a higher-than-usual telemetry transmission rate must be used. It would then be desirable to know the effect of the higher rate on other downlink traffic. For example, how much file broadcast traffic would be preempted by the higher telemetry rate?

The highest priority is given to file server transaction processing during execution of the simulation program. Telemetry traffic has the next highest priority and file broadcasting has the lowest priority.

The simulation clock and other program variables are assigned values from an orbital prediction data base file maintained separately. This particular approach has been used for two reasons: (1) Since part of the model validation process requires checking on how well the model predicts the past, it is convenient to make simulation runs for exactly the same orbits as found in the system measurement data; and (2) If the simulator were to be run to model some yet-to-be-launched satellite system it would still be possible to generate prediction "history" based on pre-launch orbital elements supplied by the launching authority.

In addition to supplying the simulation start and stop clock times, the orbital prediction history supplies the antenna heading, sub-satellite point, and the slant range used in calculating the path loss for determining the link margin.

IMPLEMENTATION OF THE MODEL

The simulation program, written in PL/I, has been compiled and tested on 8-bit CP/M microcomputers using the PL/I-80 compiler version 1.3 supplied by Digital Research. The program has also been compiled and tested on 16-bit MS-DOS microcomputers using Digital Research PL/I-86 version 1.1. The testing and validation of the program was done on a 20 MHz AT-class 80286 MS-DOS microcomputer system, with a few support routines written in 8086 assembly language.

The simulation is implemented using the periodic scan approach with a fixed clock increment of 0.1 seconds, since for the system of primary interest, PACSAT-1, the shortest simulated event duration is the transmission of an unnumbered or supervisory frame. Either of these events takes longer than 0.1 seconds. The method of implementation is satisfactory from a run-time viewpoint because satellite visibility periods to be simulated are generally shorter than 15 minutes and the simulator runs in nearly real time. The time increment can easily be modified should requirements dictate the use of some other value.

MODEL CALIBRATION AND VALIDATION

Three criteria were established for validation of the downlink traffic simulator. First, the total downlink byte count from the simulation should be within +/- 10 percent of the total byte count from the actual visibility periods being simulated. Second, there should be no more than +/- 10 percent difference between the simulated and actual byte count totals in any of the individual categories--file server, broadcasting, and telemetry. Third, the total byte count less telemetry traffic should be about evenly divided between file server and file broadcasting. These requirements are meant to apply to a group of simulated visibility periods when compared to the same group of actual satellite visibility periods but not necessarily to a single visibility period. The idea was to obtain a degree of accuracy over a reasonable time period rather than on any single visibility period.

The model validation has been done in three parts. First, the simulator has been used to generate downlink traffic for exactly the same PACSAT-1 orbits that are contained in sample no. 3 (see Tables 1 and 2). Sample no. 3 was used because it contains the most recent actual system data prior to the development of the simulator. Second, based on comparison and tests of the actual and simulated downlink data, calibration of the model has been performed. Third, the refined model was used to simulate a new set of PACSAT-1 orbits for which actual system data is available to be used for comparison, yet not previously analyzed. The results of the analysis of the actual system data and its comparison to the simulation output is in this section.

Initial Testing and Calibration

Table 2 shows the total downlink byte count and the byte count by category for the three directional antenna data samples from PACSAT-1. From this table it can be seen that telemetry data makes up about 6 to 7 percent of the downlink traffic and that the remainder of the traffic is about evenly divided between file server transactions and file broadcasting.

Table 4 summarizes those samples used during simulator testing and validation. Sample no. 3 was examined during the data analysis phase and is used during initial testing of the

Table 4
Statistics from Data Samples Used During Testing and Calibration

	Sample No. 3 (Old Data)	Sample No. 7 (New Data)	Sample No. 8 (New Data)
Total Bytes	3,168,924	2,107,941	808,896
File Server	1,353,752-42.7	897,444-42.6	432,803-53.3
Broadcasting	1,630,643-51.4	1,089,510-51.7	320,574-39.6
Telemetry	184,259- 5.8	120,987- 5.7	55,519- 6.9

simulator. Sample nos. 7 and 8 are new samples collected especially for validation purposes. Neither sample no. 7 or 8 was used during the model building process.

Three downlink traffic simulation runs were done for the complete set of visibility times contained in sample no. 3. The results of these runs is shown in Table 5. Columns of byte counts and percentages are shown. For the total byte counts, the percentages are with respect to the actual data sample. Thus, for run no. 1, the total byte count is 22.4 percent greater than the actual total byte count. The other percentages are with respect to the total for a particular simulator run. The same conventions are used for the percentages shown in Tables 6 through 10. The results shown in Table 5 were not considered acceptable due to the large differences between the generated and actual total byte counts.

Table 5 Results of Initial Simulator Test Runs for Data Sample No. 3			
	Simulated Sample No. 3 Run No. 1	Simulated Sample No. 3 Run No. 2	Simulated Sample No. 3 Run No. 3
Total Bytes	3,878,581/+22.4	3,884,795/+22.6	3,873,721/+18.2
File Server	1,259,904/ 32.5	1,430,673/ 36.8	1,398,823/ 36.1
Broadcasting	2,414,325/ 62.2	1,248,425/ 57.9	2,268,950/ 58.5
Telemetry	203,352/ 5.2	205,697/ 5.3	205,948/ 5.3

Several changes were made to the model and a another set of test runs were made to verify the corrections. The major changes included changing the method of generating file broadcast traffic and improving the method for generating file server transaction

Table 6 Results of Additional Simulator Test Runs for Data Sample No. 3			
	Simulated Sample No. 3 Run No. 1	Simulated Sample No. 3 Run No. 2	Simulated Sample No. 3 Run No. 3
Total Bytes	3,182,812/+ 0.4	3,327,038/+ 5.0	3,294,931/+ 4.0
File Server	1,425,334/ 44.8	1,604,844/ 48.2	1,577,020/ 47.8
Broadcasting	1,549,495/ 48.7	1,515,856/ 45.6	1,511,553/ 45.9
Telemetry	208,026/ 6.5	206,298/ 6.2	206,298/ 6.3

service times. The results of the additional simulator runs made after the changes are shown in Table 6. Note that there is now much less variation between the actual and simulated total byte counts for sample no. 3, Furthermore, the byte counts for file broadcasting and file server data are more evenly divided.

Validation

After the initial calibration of the model described in the previous section using sample no. 3, three simulator runs were made for the same visibility periods contained in sample

Table 7
Summary of Simulator Validation Runs
for Data Sample No. 7

	Simulated Sample No. 7 Run No. 1	Simulated Sample No. 7 Run No. 2	Simulated Sample No. 7 Run No. 3
Total Bytes	2,134,748/ +1.2	1,967,225/ -6.7	2,059,713/ -2.3
File Server	1,003,234/ 46.9	889,988/ 45.2	957,003/ 46.5
Broadcasting	1,000,170/ 46.8	946,895/ 48.1	971,808/ 47.2
Telemetry	125,010/ 5.8	130,382/ 6.6	130,902/ 6.3

nos. 7 and 8. The results of these runs are shown in Tables 7 and 8.

The data in Tables 5 through 8 show percentage figures corresponding to two of the three validation criteria. The percentages for the total byte count for each run are given with respect to the actual data sample totals. The percentages for

Table 8
Summary of Simulator Validation Runs
for Data Sample No. 8

	Simulated Sample No. 8 Run No. 1	Simulated Sample No. 8 Run No. 2	Simulated Sample No. 8 Run No. 3
Total Bytes	854,947/ +5.7	820,830/ +1.5	800,635/ +1.0
File Server	402,463/ 47.1	390,606/ 47.6	367,410/ 45.9
Broadcasting	400,203/ 46.8	377,943/ 46.0	380,964/ 47.6
Telemetry	52,281/ 6.1	52,281/ 6.1	52,281/ 6.1

each data type are given with respect to the simulated total byte counts. Table 9 repeats these same figures but includes the percentages in each simulated category with respect to the corresponding category in the actual data sample.

The data in Table 9 shows that the validation criteria have been satisfied in almost all cases for simulated data sample no. 7. The simulated total byte count is within 10 percent of the actual total. Moreover, the file server and broadcast traffic is about evenly divided. The only values outside the criteria are a few of the category totals when compared to the same category in the actual data sample. For example, file broadcast traffic for run no. 3.

Like sample no. 7, simulated sample no. 8 shows good agreement with validation criteria for simulated total bytes with respect to actual total bytes and distribution of file server and broadcast traffic with respect to the simulated total byte count.

Table 9
Summary of Validation Criteria Measurements

	-- Run No. 1 --		-- Run No. 2 --		-- Run No. 3 --	
	% of Actual Total or Category	% of Sim. Total	% of Actual Total or Category	% of Sim. Total	% of Actual Total or Category	% of Sim. Total
Sample No. 7						
Total Bytes	+1.3		-6.7		-2.3	
File Server	+11.7	46.9	-0.8	45.2	+6.6	46.5
Broadcasting	-8.2	46.8	-13.0	48.1	-10.8	47.2
Telemetry	+3.3	5.8	+7.7	6.6	+8.1	6.3
Sample No. 8						
Total Bytes	+5.7		+1.5		+1.0	
File Server	-7.0	47.1	-9.7	47.6	-15.1	45.9
Broadcasting	+24.8	46.8	+17.9	46.0	+18.8	47.6
Telemetry	+5.8	6.1	+5.8	6.1	+5.8	6.1

Sample no. 8 does, however, show larger variation when comparing the simulated category totals with the actual totals. This is thought not to be a problem with the simulator, but rather is a manifestation of unusual traffic patterns in the actual data sample caused by work on the file server system software during the time the actual data sample was collected (July and August 1991).

It should be remembered that the analysis given in Tables 5 through 9 results from a single simulation of each visibility period found in the actual data sample. There are 32 visibility periods in sample no. 3, 20 in sample no. 7 and 8 in sample no. 8. The final validation procedure consisted of runs having multiple replications of each visibility period in each data sample. These final test results are shown in Table 10.

Table 10
Summary of Validation Criteria Measurements
for Multiple Replications

	-- Run No. 1 --		-- Run No. 2 --		-- Run No. 3 --	
	% of Actual Total or Category	% of Sim. Total	% of Actual Total or Category	% of Sim. Total	% of Actual Total or Category	% of Sim. Total
Sample No. 7						
Total Bytes	-7.7		-7.0		-6.4	
File Server	-14.9	47.6	-13.7	47.9	-13.3	47.8
Broadcasting	-0.4	45.9	-0.6	45.5	+0.3	45.6
Telemetry	+5.8	6.5	+5.7	6.5	+5.8	6.5
Sample No. 8						
Total Bytes	-2.2		-3.1		-0.7	
File Server	-11.5	48.4	-14.1	47.4	-10.6	48.2
Broadcasting	+11.0	45.0	+12.2	45.9	+13.6	45.3
Telemetry	-6.0	6.6	-5.9	6.7	-6.1	6.5

Each run in Table 10 consists of 10 replications of each visibility period in the actual data sample. For sample no. 7 each run is ten replications of the 20 visibility periods and for sample no. 8 each run is 10 replications of the 8 visibility periods. The data in Table 10 shows good agreement of byte counts in the actual and simulated data for sample no. 7 except for file server traffic. The percentage of file server traffic is also lower than in the actual data for sample no. 8. However, due to the satellite software testing mentioned earlier, the sample no. 7 data should provide a more accurate comparison.

SIMULATION OF ALTERNATIVE SYSTEM OPERATIONS AND CONFIGURATIONS

Since the simulator is driven by tracking data for a specific location, it is easy to predict how much data of each particular type--file server, broadcasting, and telemetry--it will be possible to receive. However, the simulator is also useful for assessing the effects of changes made to the original design or to current operating parameters. The results of some simulated operational changes are described in this section.

When studying the simulated operating conditions presented in this section, the reader is reminded that they are heavily dependent on hardware and software capabilities both at the spacecraft and at the ground station. Furthermore, the simulations assume the same user traffic patterns that were encountered in the data analyzed.

The two changes simulated were: (1) the assumption that the maximum allowable number of uplink users are always connected; and (2) increasing the maximum allowable number of uplink users from four to five. It should be noted that the simulator assigns each of the uplink users to a separate uplink channel even though this may not occur in practice. For example, two of four users could be on uplink A and the other two on uplink B while uplinks C and D are idle. However, such an assignment does not change the maximum number of concurrent users allowed. The simulator assigns one user per uplink because the uplink utilization was found to be very nearly uniform during the data analysis phase. The all-uplinks-busy condition is simulated by generating a new connection on an uplink as soon as the service time and byte count for the current connection have expired rather than waiting for some random interarrival time before generating the new connection.

Table 11 shows the result of the simulation of additional uplink traffic along with a simulation of sample no. 7 under the usual traffic conditions. For the case of four uplinks busy, there is an increase in total traffic and file server traffic and

Table 11
Simulation Results for Various Uplink-Busy Conditions

	Simulated Sample No. 7 Normal Mode	Simulated Sample No. 7 4 Uplinks Busy	Simulated Sample No. 7 5 Uplinks Busy
Total Bytes	2,074,196/ -1.6	2,524,954/+19.8	2,283,952/ +8.3
File Server	986,201/ 47.5	1,611,211/ 63.8	1,929,322/ 84.5
Broadcasting	959,883/ 46.3	786,573/ 31.2	227,897/ 10.0
Telemetry	128,112/ 6.2	127,170/ 5.0	126,783/ 5.5

a decrease in file broadcast traffic. These results would be expected since the additional uplink users are taking downlink capacity away from file broadcasting. Telemetry traffic remains nearly constant because it is a fixed amount of traffic generated at regular time intervals.

For the case of five uplinks busy, these is a further increase in file server traffic and decrease in file broadcast traffic. The fact that total downlink traffic decreased slightly was not viewed to be a problem with either the model or the simulator. Such a decrease could be caused by a change in composition of the file server traffic, for example, the five concurrent uplink users could be doing mostly file upload transactions. Furthermore, the extra uplink traffic could easily reduce response time which, in turn, would result in reduced overall traffic rate.

SUMMARY

Construction of an accurate model of PACSAT-1 operations based solely on the statistics which can be extracted from monitored downlink traffic is not an easy task. However, while there is still room for improvement of the simulation model, the results have been encouraging. Further work is being done to reduce the differences between statistics computed from actual data and those produced by the simulator for file server traffic. While making the changes, attention will have to be given to the possible effects of recent changes to the file server and file broadcasting software aboard the satellite. Namely, allowing hole lists to be broadcast and lengthening of the broadcast frame data field from 139 to 255 bytes. The user traffic patterns will be re-examined to see if there have been any significant changes since the first analysis.

REFERENCES

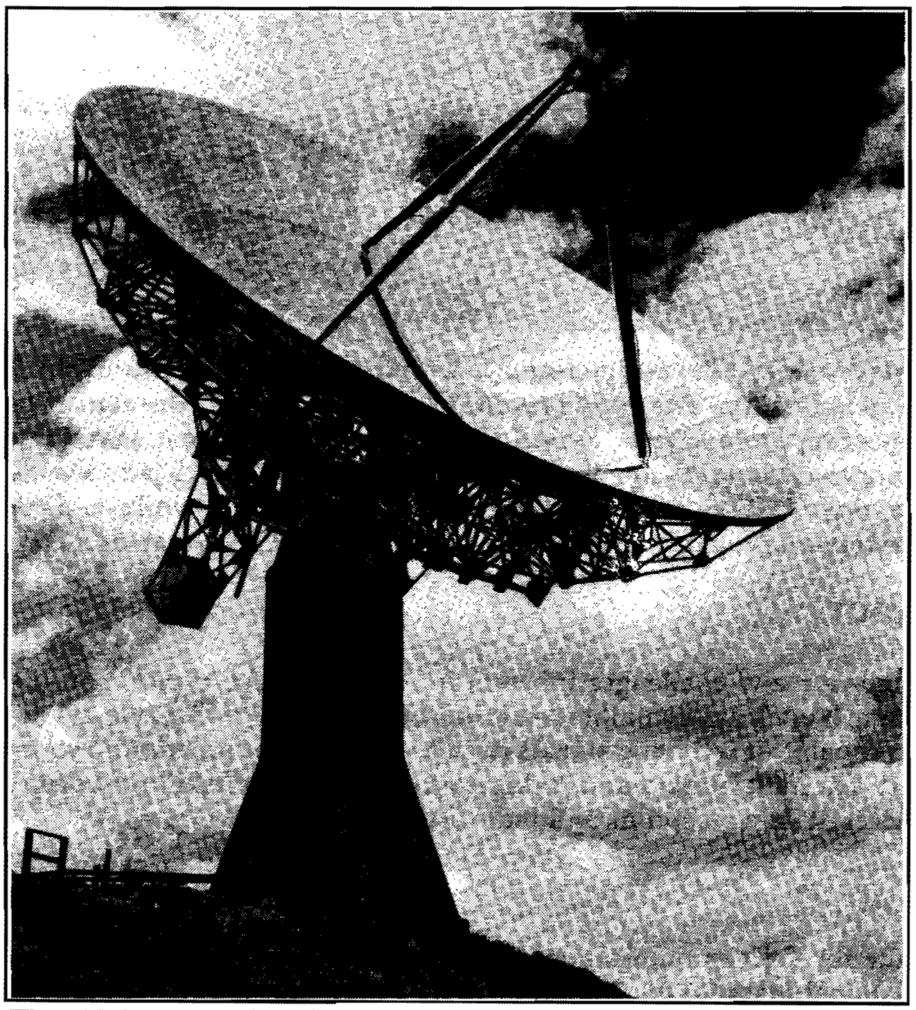
1. Diersing, R.J., "Characterization of PACSAT-1 Traffic Via Downlink Monitoring," *Proc. ARRL 10th Computer Networking Conference*, to appear.

AN AMATEUR SPACE EXPLORATION GROUND STATION

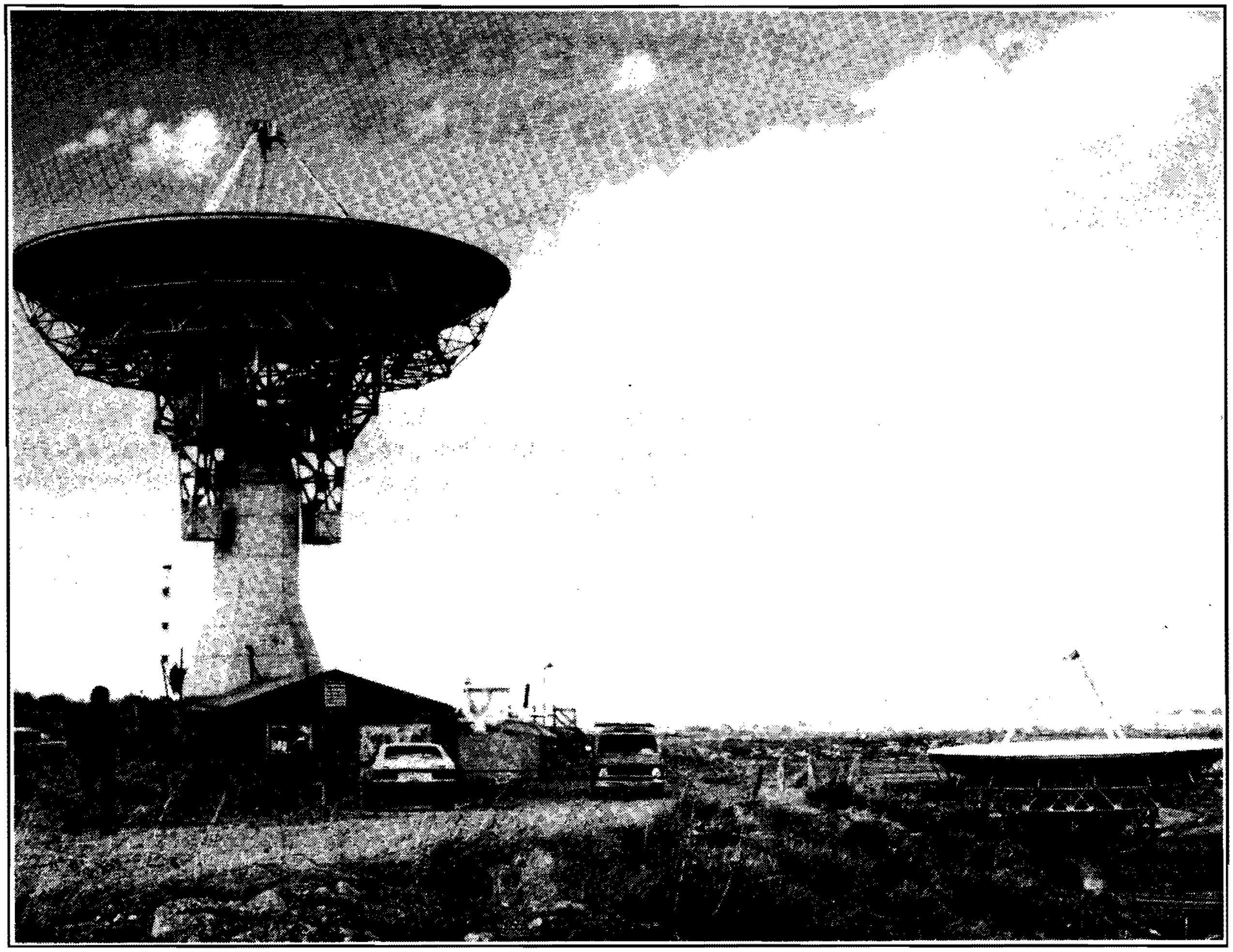
By Peter D. Goldman
and Brent Helleckson

INTRODUCTION

The success of the Radio Amateur Satellite Corporation (AMSAT) in designing, building, launching, and operating amateur communications satellites has prompted a small but significant number of people to seriously consider an "amateur" approach to space exploration. Following the path blazed by the Amateur Radio Relay League (ARRL), AMSAT, and the amateur astronomy community, the Deep Space Exploration Society (DSES) has been formed by a group of individuals who are interested in doing amateur space exploration. The purpose of the organization is to bring



The 18.3 meter dish in a photo which dates back to the original installation. (Photo from W3GEY)



together those individuals who are interested in learning by doing, specifically by doing hands-on projects in space exploration. The makeup of the founding group includes aerospace professionals, electrical engineering professionals, amateur radio operators, amateur astronomers, builders of currently orbiting amateur radio satellites, students, and many others. It is hoped that the DSES will evolve into an organization similar to AMSAT, which enjoys a world-wide organization of volunteers that constructs, launches, and operates satellites for the amateur radio community.

INITIAL PROJECT

While there are many challenges inherent in amateur space exploration (i.e. fund-raising, spacecraft design, launch opportunities, etc.), one of the most significant is the development of a ground station capable of receiving signals from a spacecraft, or other radio source at the Moon, Mars or beyond. The initial project undertaken by the DSES is the creation of a deep space receiving station for spacecraft data reception, and radio astronomy.

HISTORY

The Institute for Telecommunications Sciences (ITS), a subgroup within the Department of Commerce, National Institute for Standards and Technology, owns two, 18.3 meter, steerable, parabolic antennas located on Table Mountain, approximately 5 miles north of Boulder, Colorado. Built in the late 1950's or early 1960's, and unused for approximately the last 10 years, the antennas themselves seem to be in good condition. It has been estimated by calculation and some old records that the dishes should be useful in the 100MHz to 10GHz range.

ORGANIZATIONAL RELATIONSHIPS

AMSAT is currently serving as the parent organization for the refurbishment effort. Active AMSAT members, including a member of the AMSAT board of directors, serve on the DSES board of directors. AMSAT and the ITS have reached a five year agreement for use of the antennas. Under this agreement, AMSAT and the DSES have access to the site 24 hours a day, have the right to refurbish the equipment, perform experiments, publish results, etc. A mechanism has been set up whereby other interested organizations can have access to the dishes based upon their contributions of time, equipment and money, relative to AMSAT's. In return AMSAT and the DSES have agreed to abide by the existing rules and regulations applicable to the site, limit the number of keys to the site, carry the appropriate insurance, and devise and follow an appropriate safety plan.

EXISTING CONDITION

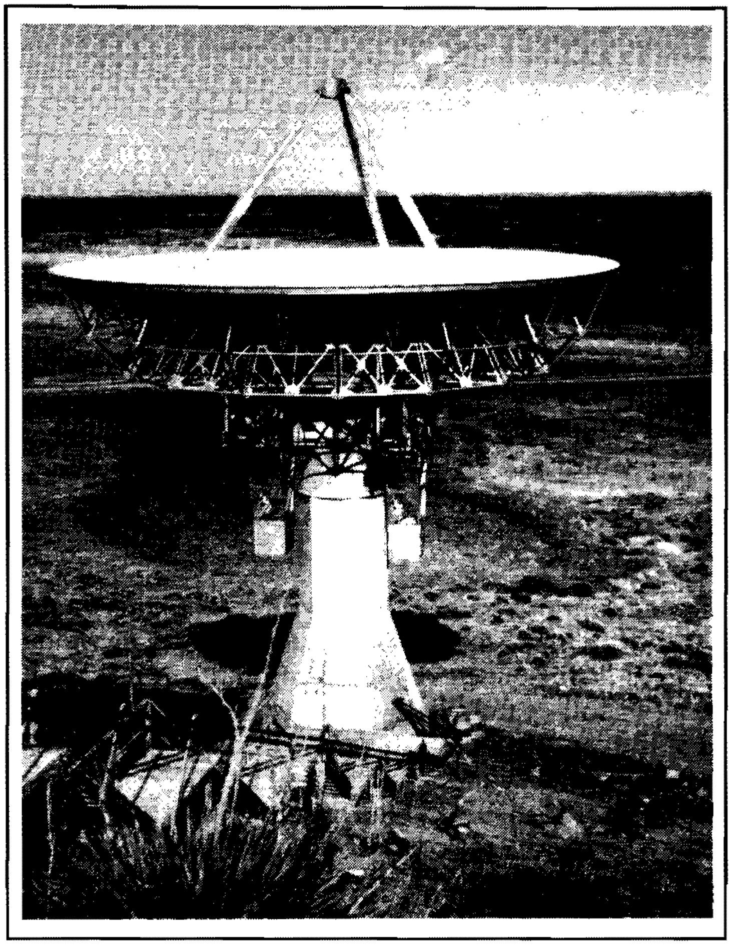
The two dishes are at considerably different elevations and hence we will refer to them as the upper and lower dishes. The two dishes and the skin of the tower are constructed of welded aluminum and show no signs of corrosion. The dishes themselves have an aluminum skeleton with aluminum screen welded to it to provide a smooth parabolic surface with minimum wind resistance. There is a large fiberglass tripod at the center of the dish, with the top of the tripod at the dish's focal point. This is where the feedpoint antenna and amplifier are located.

Each dish is steerable in azimuth and elevation. The dish is driven in azimuth by two motor/clutch sets driving a 6 foot diameter ring gear. The motors are counter-rotating, such that if each motor/clutch set drives the gear with the same torque (but opposite directions) the antenna will be stationary. The clutches are of the eddy current type, allowing precise control of the torque by changing the voltage applied to the clutch coils. Running the motors continuously eliminates backlash. Moving the dish in the azimuth direction is accomplished by making the clutch voltages unequal, allowing one motor/clutch pair to drive with greater torque than the other.

Elevation is controlled by a pair of motor/clutch sets mounted on a platform just below the dish. The platform rotates with azimuth, requiring a commutator to supply power to the motors and clutches. Each motor/clutch set drives a large geared nut which drives a jack screw. The jack screws are on opposite sides of the dish. Similar to the azimuth drive, these motors are driven in opposite directions to eliminate gear backlash. Differentially driving these jack screws tilts the dish. Maintaining a precisely controlled voltage on the clutches allows a constant velocity drive in both elevation and azimuth.

The facility has two motor control racks which contain the control and position measurement electronics for each dish. Position indication is accomplished with selsyns. Selsyns are self-synchronous rotary transformers, also known as synchros, that are used to transmit angular position from one place to another where a mechanical linkage is impractical. Two identical selsyns, a transmitter and a receiver, are used in a measurement-indicator system. Each selsyn consists of a single phase rotor and a three phase stator. The two rotors are connected in parallel as are the two stators. The system is powered by AC connected in parallel with the rotors. When one rotor is turned, the other rotor turns by the same angle. In our system selsyns are used to transmit the elevation and azimuth angles from the dish to mechanical indicators on the control rack. The original system has circular dials to indicate the rough position and mechanical counters for finer resolution.

It appears that the control system is open loop, with no feedback to assure that the velocity is actually constant, and no facility to point to a preset position.



The electronics is very old, utilizing vacuum tube technology. We have noted electrolytic capacitors dated 1958 and switches dated 1947! The radio equipment did not appear to be complete. An old tube parametric amplifier was found, several feed horns, as well as detectors and filters. Some newer (mid 1970s) hand built electronics with A/D and D/A converters with interfaces to a Data General Nova computer were found. These were apparently an early digital data acquisition system. The wide range of technologies indicates that the active work at this site spanned between ten and twenty years.

In addition to the small signal microwave receiving equipment, there are several cabinets of high power microwave gear. It appears that signals were transmitted from this site at one time, although it is presently a radio quiet zone. This status should help us with weak signal reception.

Other equipment at the site include wind measurement and recording systems, and WWV (time and frequency standard radio station) reception and decoding equipment. The WWV system was designed to give very precise time information. This precise time will prove to be useful in our application for tracking satellites and astronomical objects. The wind measurement system is essential for this location since Winter winds can exceed 100 MPH.

The building itself has a steel outside with plasterboard internal walls and ceiling. It is old, dirty and fairly rundown, but we are making great progress in renovating it. Luckily it also has heating, air conditioning and a vent fan in the attic. It even has a bathroom and an antique water cooler.

The surrounding area on Table Mountain is prairie, with Cactus and Yucca plants and a variety of animal wildlife. Farmland surrounds the mountain.

STATUS

The first phase of our operation could best be described as technological archeology and cleanup. We are starting with an old facility, but great enthusiasm. Work has begun on cleaning the building, pulling out and tracing old cables, painting and patching. Water is available from a cistern, and the plumbing and pump have been repaired. Plumbing and pump damage apparently occurred sometime ago from water freezing in the pipe. We are fortunate that DSES has members with considerable mechanical knowledge and experience. Heating and ventilation works, but the air conditioning has a defective power contactor.

Neither dish motor control rack is completely operational yet, but it appears one working rack could be made operational from the two existing racks. A simple but effective clutch power supply has been built to allow antenna movement. This will permit testing and repairing the drive mechanism as well as aiming the dish for early RF testing. The source for RF testing could be an existing antenna some distance away out on the plains east of the dishes, or a geostationary satellite. All of the motors and clutches (four) on the upper dish work, as do the azimuth motor/clutches on the lower dish. Elevation systems have not been tested on the lower dish at this time because there is a family of barn owls nesting there which we did not want to disturb. Unfortunately, time and weather has had an effect on some of the moving parts of the system. There are some bad clutch bearings that will have to be pulled and fixed or replaced. This will require lowering the 5 hp motor and its clutch from high in the tower down to the ground. Despite these problems, the upper and lower dishes can be moved in azimuth. The upper dish does not move in elevation because a drive nut and jack screw are stuck. Water probably leaked into this area from a deteriorated rubber boot over it. Soon after this is written, an attempt will be made to free the mechanism.

NEW EQUIPMENT PROJECTS

Our first priority is to make one working motor control rack from the existing equipment. Next, we must design and build an antenna feed, preamplifier, and downconverter for the frequencies of interest. A commercial radio receiver may serve as an intermediate frequency amplifier and detector for some initial tests and applications. An important early detail will be to install a working anemometer and wind vane with the ability to automatically "park" the antenna in a safe position in case of high winds. The original equipment had this capability, but it is no longer in working order.

Looking beyond the initial tests and system characterization, we intend to build a computer controlled antenna position controller with the ability to automatically move the dish to selected coordinates and track according to a program defined for a particular application. Replacing the selsyns with optical shaft encoders will provide the computer with the necessary feedback to precisely position the antenna to absolute coordinates and correct for antenna movement due to outside forces such as wind and thermal expansion.

Digital data acquisition will be a later addition that will allow us to store our measurements and received data and transfer them to other computers.

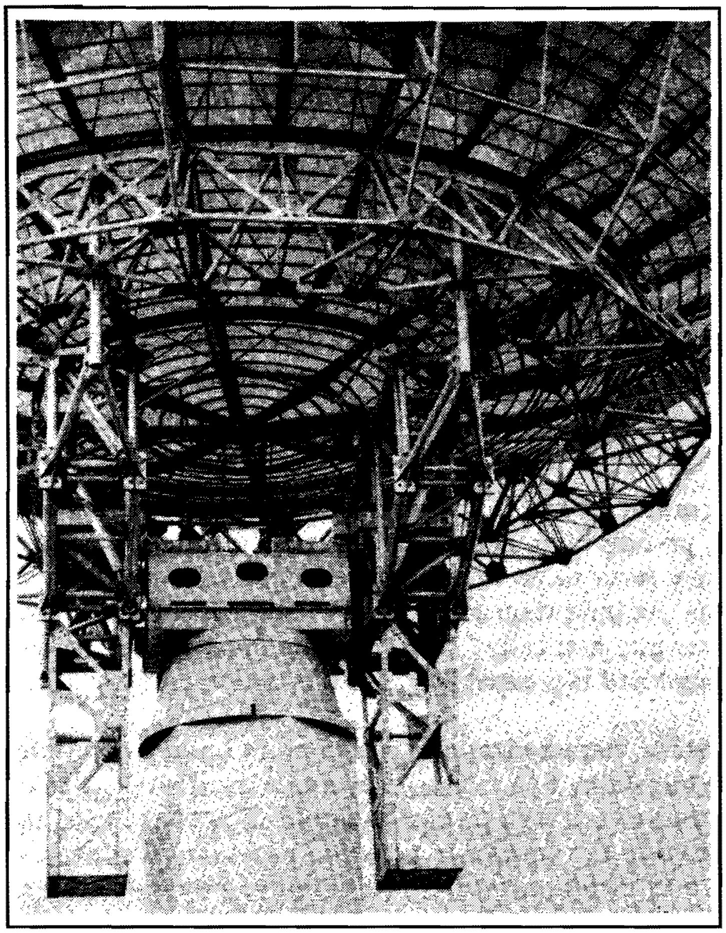
DSES GOALS

Education

A primary goal of the DSES is to educate members (and the public) interested in space exploration via spacecraft, radio astronomy, etc. Plans are being formed to provide field trips for local high school science classes. These field trips may include a brief introduction to the radio spectrum, an explanation of the mechanics of the dishes, the acquisition of an earth orbiting satellite, and the acquisition of a pulsar. Additional programs are being examined for the local undergraduate and graduate institutions.

Calibration Experiments

Prior to the start of any education program however, an extensive calibration and antenna characterization program will be performed. The precise characteristics and performance of the dishes are as yet unknown. A "full sky survey" is planned to test the capabilities of the dishes. This survey will involve acquiring signals from a number of existing geosynchronous and low earth orbiting satellites. Satellites have been identified that will allow a good set of signals to be received from 100 MHz to over 10GHz. Also, a local transmitter with a 1000 ft antenna will be used to obtain antenna pattern in two dimensions.



Lunar, Mars, Asteroid Missions

A number of planetary missions are being examined. The dishes, if they are in reasonable shape, are capable of supporting missions out to the orbit of Mars and, depending on the spacecraft transmitter and data rates, considerably beyond. Several organizations (i.e. Lunar Exploration, Inc.) have proposed lunar polar orbiters, a few (i.e. AMSAT and AMSAT-DL) have proposed Mars orbiters, and others favor asteroid missions. Each of these types of missions require fairly large receiving equipment on Earth. The Table Mountain Antenna Facility is ideal for these types of missions. As an aside, the balky antenna on NASA's Galileo satellite may force them to play back the recorded images of the October 1991 Gaspra asteroid encounter one year later, much closer to Earth and at a rate of as low as 40 bits/sec. The members of DSES may be some of the first people on the planet to see a close-up of an asteroid!

Deep Sky

Several deep sky projects can also be defined. Several members have expressed an interest in radio noise temperature calibration (i.e. Sun, Jupiter, Moon, Milky Way, deep sky pulsars, quasars, etc.). The radio astronomy community is encouraged to contact us and suggest ideas for projects.

CONTACTS AND MEMBERSHIP

Membership dues for the DSES are currently set at $50 per year. An as-yet-to-be designed newsletter will be published and volunteers for specific hardware, software, science, and educational projects will be sought from the membership. Dues and correspondence should be addressed to: Deep Space Exploration Society, c/o Rex Craig, 5921 Niwot Road, Longmont, CO 80503. Currently, our news and articles appear in *Satellite Operator*. The publisher is: R.Myers Communications, P.O. Box 17108, Fountain Hills, Az., 85269-7108. An electronic mail service and bulletin board has been provided by the Boulder Center for Science and Policy. The particulars are as follows: (303) 494-8446, 2400 baud, 8 bits, No parity, 1 stop bit.

WHAT'S UP WITH WEBERSAT

by Stephen Jackson & Jeffrey Raetzke

Abstract:

WEBERSAT, a 27 pound LEO satellite launched by the Ariane 40 on January 21, 1990 into a 500 mile polar orbit, carries several payload experiments that were developed as a learning experience for engineering students at Weber State University. The experiments include a color CCD camera, a CCD light spectrometer, video flash digitizer, 1.26 GHz NTSC video uplink, micro-impact sensor, and optical horizon sensors.

Operational command and control of the spacecraft and its payloads is performed by students in the College of Applied Science & Technology, from a ground station located on the Weber State University (WSU) campus. Here, the students and their advisors monitor on-board systems, plan & execute experiments, and observe test results.

This paper describes the satellite's results to date of the on-board experiments.

INTRODUCTION

Background

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

The 27 pound, 9" x 9" x 12.5" satellite is in a 500 mile, sun-synchronous, polar orbit with a period of 100.7 minutes. Four to six passes per day are visible from the ground station at WSU.

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

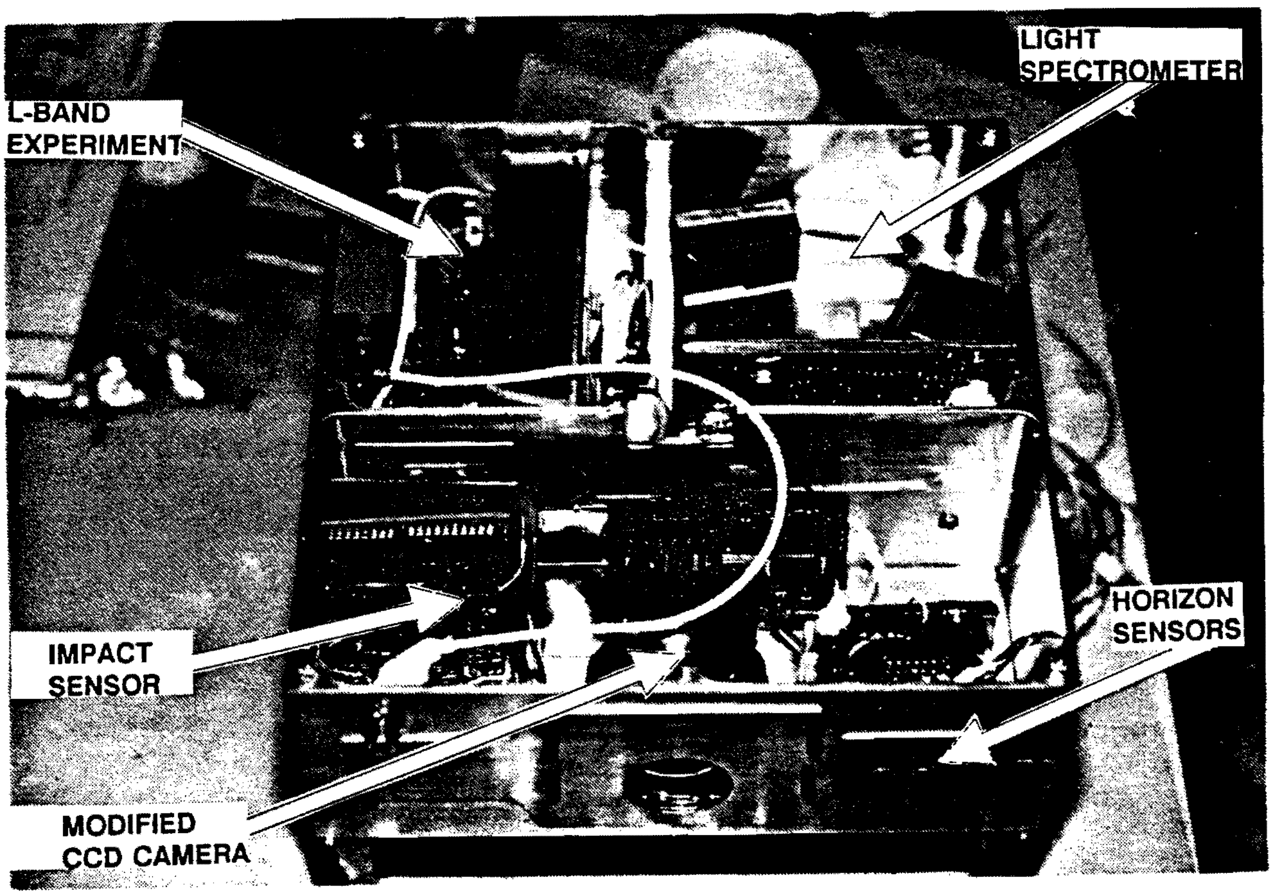


Figure 1: WEBERSAT

As shown in FIGURE 2, the satellite has six sections vertically stacked, which communicate through an on board local area network. The top two modules form the "attic" which contains various experiments, including:

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

Scope

The major topics that will be discussed in this paper are: the mission of the camera, the camera specifications, results to date, difficulties in shooting quality pictures, the steps taken to overcome some of these problems, the results of the other experiments and general plans for future operation.

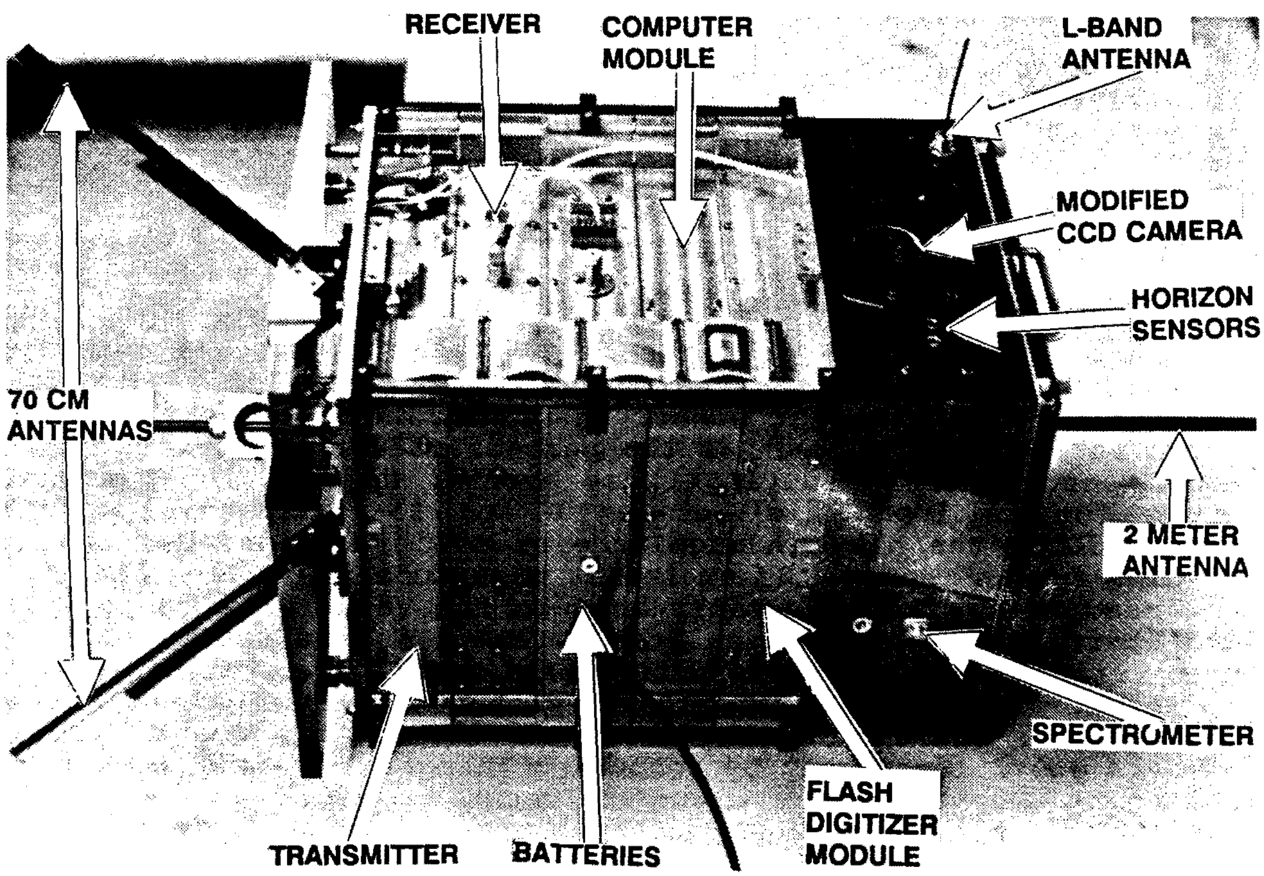


Figure 2: Webersat's Modular Construction

Impact Sensor

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

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

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

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

Impact Detection

The impact sensor has been recording events that would indicate impacts from micrometeorites and dust. Thermal expansion stress has also been occasionally observed. Whole Orbit Data (WOD) collection of the impact sensor was taken during several of the large meteor showers such as the persads meteor showers to see if the impacts increase during these events. used during The value given for an impact is between 0 and 256, depending on the magnitude of the hit. A magnitude of 10 is considered a minimum reading for an impact. If an impact magnitude is greater than 256, the reading may not be usable because the value will go past 256 and start from zero again. Iris movement in the camera also has been verified with corresponding impact readings at the time of the movement. Electrical noise and voltage fluctuations have been observed to cause a small change in the impact count. These effects are filtered out by comparing changes in 5 and 10 volt bus values to the variations in impact count.

L-Band Video Uplink

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

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

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

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

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

Horizon Sensor

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

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

Spectrometer

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

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

Flight software is under development for the spectrometer.

Flash Digitizer

The flash digitizer unit is common to Webersat's three video experiments. Analog signals from the camera, spectrometer, or L-band receiver are converted at 50ns per sample into an 8-bit digital format, then stored in RAM for transmission. The unit allows computer control of data array size, analog data channel, phase, and trigger source, making it capable of handling a multitude of data types and sources. Video compression algorithms are also available to maximize efficient use of memory, while minimizing required transmission time.

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

Other Sensors

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

Camera Mission Overview

The mission of the camera system is to provide images of the earth, moon, sun, and stars with a modified, off the shelf, low cost, Charged Coupled Device (CCD) camera. This serves as a platform for various experiments and projects which provide Engineering Technology students with the opportunity to plan, execute and analyze images from space, giving a real world dimension to their other assignments.

CCD Color Camera

Webersat's CCD color camera (FIGURE 3) is a modified Canon CI-10 with a 25 mm lens and automatic iris. It has 780 x 490 pixel resolution, and from its 500 mile orbit can see an area of 170 x 135 miles when it is looking straight down. The following changes were made to the basic design in order to make the camera space worthy:

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

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

3) Replaced focusing mechanism with a fixed focus support.

4) Replaced aluminum electrolytic capacitors with solid tantalum capacitors.

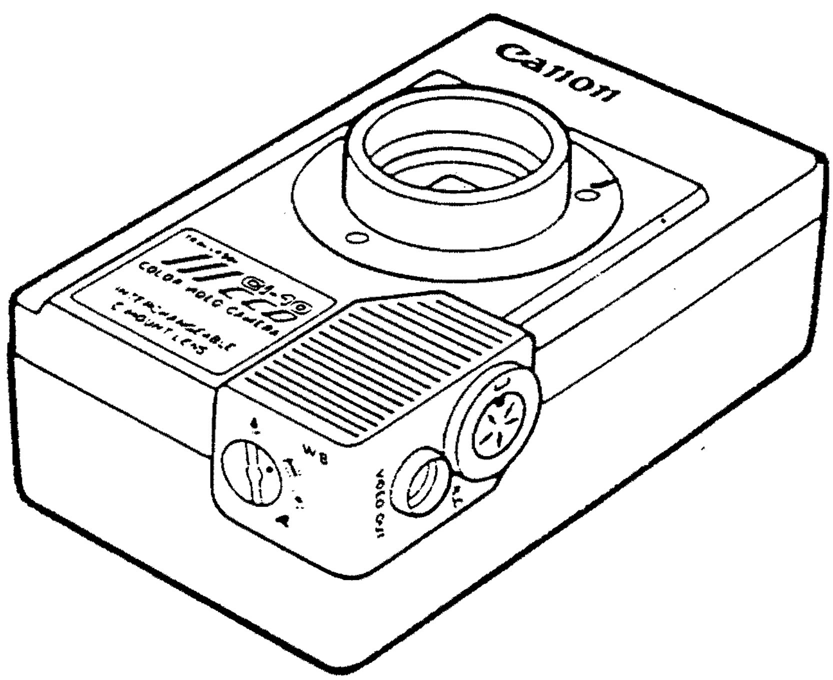


Figure 3: Webersat's CCD Camera

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

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

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

Method of Image Acquisition

WSU's ground crew is responsible for planning & executing takes, and analyzing the picture data. The process of taking a picture basically consists of determining the target, setting the appropriate sensor constraints so that the satellite CPU knows when it has acquired the target, and setting the maximum iris size & settling time. The step-by step process evolved as follows:

1) The operator must determine the time that the satellite will be over the target area and the appropriate iris setting for the target. This data is entered into a command called "Take". The iris constraint controls a feedback resistor in the automatic iris control circuit (FIGURE 4) which sets the maximum opening of the iris.

2) The operator must set up sensor parameters so the satellite knows when the camera is pointing at the desired object, such as the earth, sun, or deep space. There are two systems that can be set to accomplish this task: The horizon sensor which is composed of two photodiodes aimed through holes in the wall of the attic module, and the system of solar array current sensors which can be used to determine pointing angle from varying degrees of facet illumination.

3) The time out constraint, set by a separate command, is a safety value that forces the picture to be taken even though the photo parameters have not been met. This feature insures that the camera control algorithm will not cause the satellite's microprocessor to lock up, or the software to crash. The time-out delay is normally set at ten to fifteen minutes.

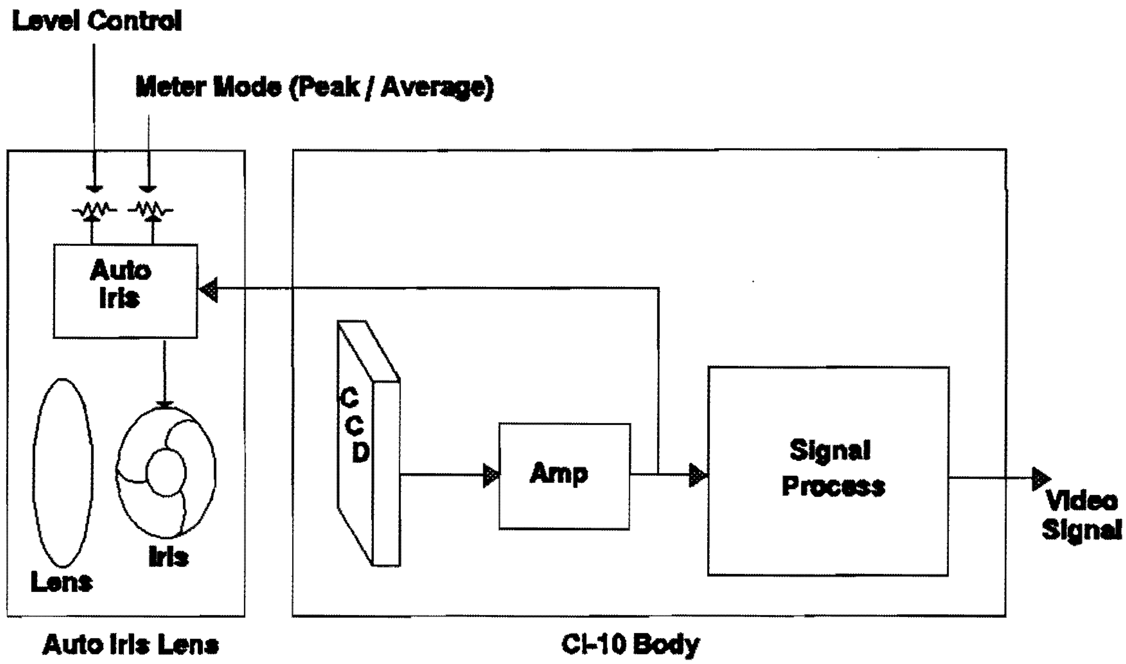


Figure 4: The Auto Iris Circuit

Development of the Image Acquisition Method

The current method of taking pictures is the result of months of observation, and has evolved from a shotgun approach to a more precise method. The first photo software went aboard the satellite on February 22, 1990 and the first pictures were taken shortly thereafter. The first method used was to set the iris to a prelaunch value and shoot all twelve pictures using only horizon sensors to locate the targets. The photos were later analyzed with hope that the camera was pointing down for some of the shots.

This method was soon abandoned, as more was learned about the rotation rate of the spacecraft and its attitude variation with latitude. However, this approach still did produce some interesting pictures.

Due to the interaction of the passive attitude control magnets with Earth's magnetic field, it is known that the Z-axis of the spacecraft is parallel to the surface over the magnetic equator. After careful observation of Whole Orbit Data, it was found that the attitude changes sharply within +/- 30 degrees magnetic, producing pointing angles adverse to earth imaging beyond this range of latitudes.

The present method of imaging therefore concentrates efforts in this equatorial band where the probability of favorable attitude is greatest. In addition, solar array constraints are also used to determine the orientation of the satellite, as the horizon sensor data alone is sometimes "noisy". Most importantly, operators have now bracketed the proper iris settings which seem to provide the best earth images. These changes have resulted in roughly a 40% success rate as opposed to around 1% for the old system.

Problems & Fixes

Many of the early photos from the Webersat camera were over or under exposed, seemingly regardless of the automatic iris control. Numerous attempts at manually commanding the iris size, and searching for possible software problems yielded no clues. A careful analysis of the on-orbit conditions proved helpful:

With 1.41×10^5 lux of Solar illumination at earth's orbital radius, and an average earth albedo of .39, the normal illumination seen by Webersat when observing the earth is 5.5×10^4 lux.

The camera has a standard sensitivity of 200 lux at an aperture diameter of F/2.8, or 8.9mm. This means that an aperture of roughly F/46.5 or .538mm diameter is required for earth observation. This is a rather small aperture for a camera iris system originally intended for general industrial applications where standard steps range from F/2 to F/22. The problem seemed clear: The auto-iris control couldn't accommodate the small aperture needed. A time delay feature was added to the next version of the software, allowing the camera to take pictures as the iris opened from full closure which the iris was known to do on power-up. This partial fix improved results, and permitted a number of excellent shots to be taken during the summer of 1990. However, results were not easily duplicated even with the same delay and nominal iris settings.

System characteristics remembered from ground tests, and considerable experimentation with delay values finally yielded another idea: The auto-iris was indeed working, but required much more time to step down to the aperture called for, it being so narrow.

By increasing the settling delay time by a factor of 100, and using what has been found to be nominal iris size values, repeatable, high quality earth images are now being produced.

More Questions

Several long-term observations have raised additional questions about Webersat and its camera system. In particular, it has been noted over the past year and a half that the vast majority of valid photo attempts have occurred between the months of March and October.

This has generated some speculation that seasonal variations in either sun angle, spacecraft attitude, or both may adversely affect the probability of receiving valid photos during the winter months.

Additional observation will be required to firmly establish the existence and possible cause(s) of this anomaly.

Experiments

Among the Webersat payloads, the CCD color camera has been the primary focus since launch, and several experiments have been performed. These experiments include: Taking pictures by moon light & during solar eclipses, testing various iris settings, and using the variety of sensors to help aim the camera as previously discussed. Imaging of the sun moon and stars has been accomplished.

Applications

Low cost imaging systems combined with small satellite technology will allow various institutions to explore space applications that may not be practical with higher cost systems now available. The development of these low cost systems will allow more experimentation with space-based imaging, and make new commercial applications more cost effective.

Considerable potential exists for similar imaging systems in the areas of attitude sensing (sun, earth, moon, & star sensors) and remote inspection.

Results

Webersat's camera system has provided interesting data, and a few surprises. The CCD camera has successfully imaged meteorological features of the earth, land masses and a number of astronomical objects.

One of the first better quality earth pictures (See Appendix 1, Figure 1) was taken April 14, 1991 over the Andaman sea. It shows clouds and a coast line of Sumatra.

The moon picture (Appendix 1, Figure 2) was taken March 21, 1991 as part of an experiment to image the earth by moon light. The image of the moon was unexpected because of the difficulty in detecting the relatively low reflected light level with the coarse sensors with which Webersat is equipped.

The sun picture (Appendix 1, Figure 3) caused some concern that the extreme brightness could cause damage to the CCD array in the camera, but after careful analysis it was determined that there was no evidence of any degradation in the camera performance.

The horizon picture (Appendix 1, Figure 4) surprised the ground station team not because it is the best horizon picture to date but because there are also three stars or planets visible in the image. Star pictures were considered unlikely because it was thought that stars like reflected moon light would not be bright enough for the CCD to pick up with a fixed integration time of less than 1/60 second. The three dots on the lower right hand corner were first thought to be single event upsets (SEU)s. After closer examination, it was found that they were several pixels wide, meaning that they are not SEUs and are more likely to be stars or planets.

Several attempts were recently made to photograph the earth and sun during a solar eclipse. Due to the spacecraft's attitude, the satellite was unable to get a picture of the eclipse. Whole-orbit data was collected during the event, which clearly show the satellite crossing the eclipse zone.

The pictures mentioned are only a sample of the very best photos to date. Pictures are taken on a continuing basis, and better images are being produced as techniques become more refined.

Conclusion

In conclusion, the Webersat CCD camera demonstrates that a low cost industrial camera modified and tested using good engineering principles can be used in space applications. It requires only minor modification, and that excellent results can be achieved with such a system.

In the future CAST would like to install receive only groundstations to receive Microsat data in schools all over the nation so that students can use the data to enhance their education. CAST is currently doing this with weather fax stations and hopes to expose students to science, engineering, amateur radio, and technology.

Since the launch of Webersat, CAST has strived to advance the state of the art; provide a public service with an emphasis on education; improve the skill of it's operators; provide a reserve pool of qualified radio operators and technicians; and promote international goodwill which is what amateur radio is based upon.

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APPENDIX 1: IMAGES FROM WEBERSAT

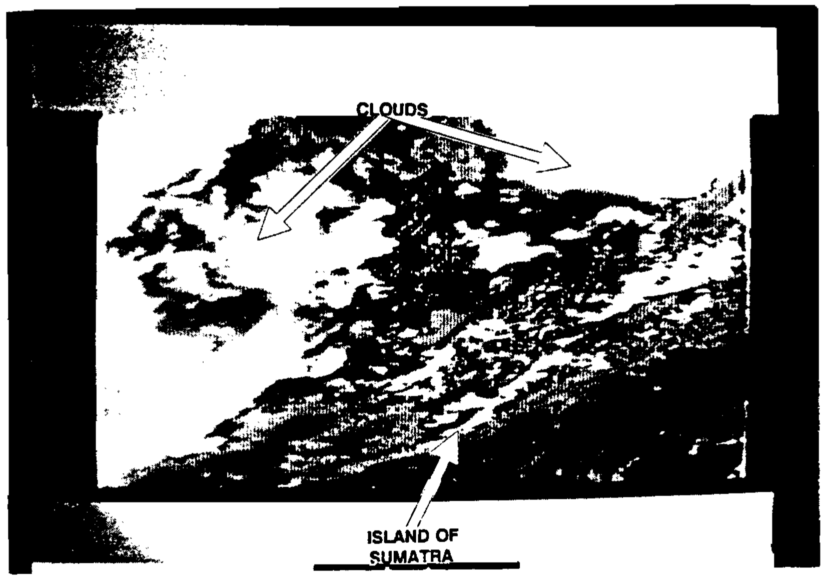


FIGURE 1
THE ANDAMAN SEA PICTURE
TAKEN APRIL 14, 1991

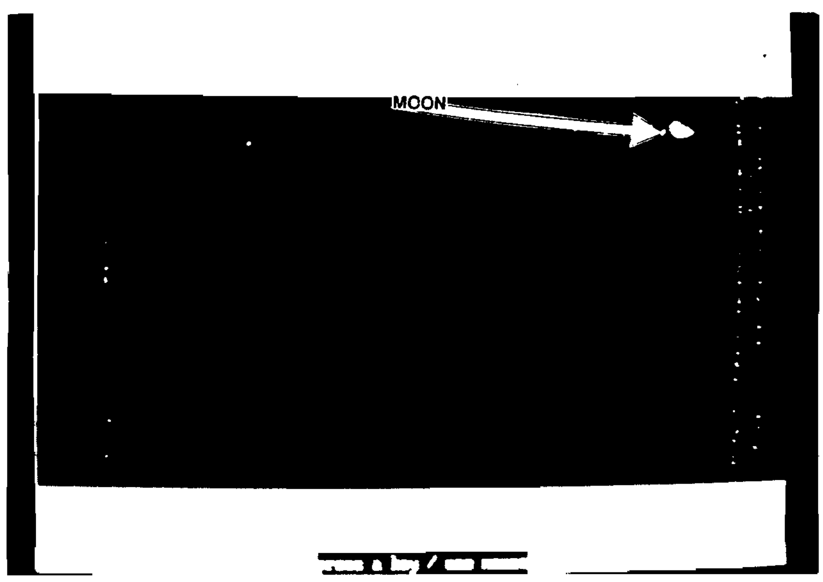


FIGURE 2
THE MOON PICTURE
TAKEN MARCH 21, 1991

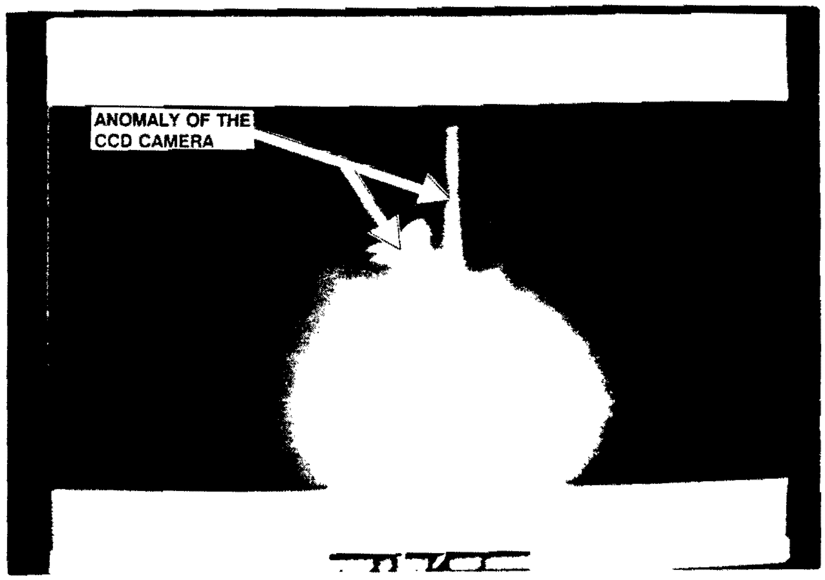


FIGURE 3
THE SUN PICTURE
TAKEN JULY 1990

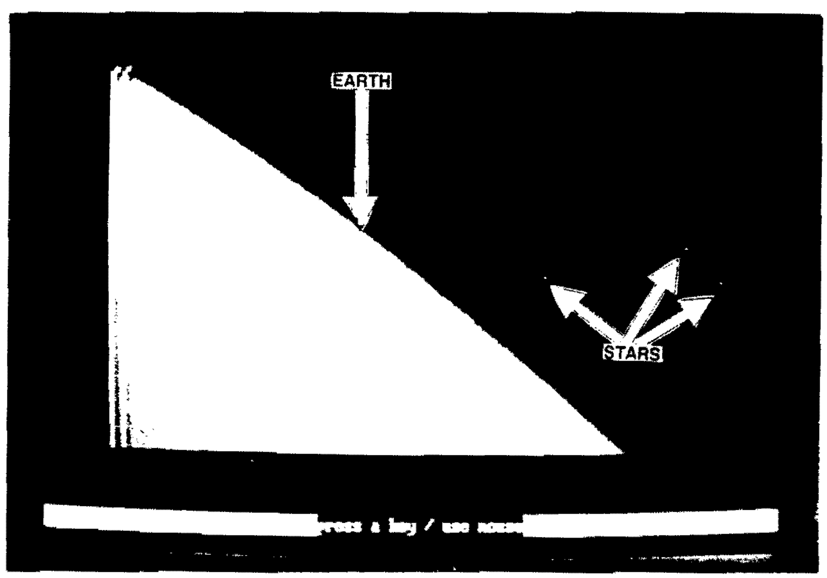


FIGURE 4
THE EARTH'S HORIZON WITH STARS
TAKEN JULY 2, 1991

The Shape of Things to Come

by Dick Jansson, WD4FAB
AMSAT, Assistant VP for Engineering

In the course of creating a new satellite, many decisions need to be made regarding the real mission requirements and parameters, including the spacecraft structure that will help meet those goals. Needless to say, many adjustments and compromises must also be made in finding an optimum solution to a myriad of options. The fledgling Phase 3D satellite program is no exception to these tenants.

An international group of Amateur Radio satellite interested Hams has met two times, in May 1990 and again in May 1991. Among many issues discussed regarding the mission, were those of the spacecraft structure. Even those intense meetings did not resolve just what configuration of spacecraft should be constructed to satisfy the needs. Computer Aided Design (CAD) studies have been conducted to assist this effort, using AutoCAD (TM) Release 11.0.

As this effort has progressed over a period in excess of a year, it is interesting to reflect upon all of the many configurations and variations of the theme that have been examined. I shall try to present this array of designs in a manner that will allow comprehension by all, especially by providing designs in three-dimensional perspective model drawings. All perspective views of spacecraft shown to the same scaling parameters and from the same approximate viewpoint. I shall start this "parade of pictures" by back-tracking a bit to show the roots of the Phase 3D design, the AMSAT-NA Phase 4 program, Fig 1.

At the meeting of the Phase 3D Experimenters in Marburg, FRG, in May 1990, Karl Meinzer, DJ4ZC, indicated that there were two possible spacecraft bus design approaches to be taken, a "Ring Design", much like the Phase 4 design and also one that Karl had illustrated in some of his early efforts. The second approach would be a "stand-alone" design, which we labeled the "Two-Cubic-Meter" design, a reference to the spacecraft volume. A Ring-Design spacecraft would provide support for other satellites mounted on top of the Phase 3D, while the stand-alone design would provide for no other support, save for its own mass. The later has a substantially lower mass than the former, as it is not burdened with the hardware for mounting upper payloads, hardware not needed for the Phase 3D mission goals. The Ring-Design, however, would stand a better chance for a low-cost launch as a part of a complex multi-launch mission.

A simple translation of the Phase 4 design into a spacecraft for the Phase 3D mission is shown in Fig 2 with deployable solar panels.

The 1990 cubical design of Phase 3D spacecraft is shown in Fig 3. This design attempted to maintain a high level of solar power generation by rotating the solar panels about their shaft axis, which in conjunction with spacecraft rotation about its Zaxis, would insure that the solar panels would be able to continuously generate full power, albeit with some undesirable complexity.

Studies by DJ4ZC showed that the solar panel rotation could be avoided if the orbit average power generation values were allowed to be compromised by 30% of the peak value. This power reduction was seen as an appropriate trade-off for complexity and Fig 4 shows this non-rotatable solar panel design on the Two-Cubic-Meter bus. This design was also the first to suggest a usable antenna design for the 145.9MHz operating band. Also displayed is another very interesting antenna, the "Roederer Cross", a 13dBic transmission line-type antenna that has tested to be very uniformly circular in its pattern. While the 'Cross antenna for 70cm is large, it is no larger than the capture area for any other antenna of that gain.

At the 1991 Marburg meeting it became abundantly clear that the Ring Design spacecraft bus design would be the accepted design to fly on the target launch vehicle, the ESA Ariane 5. At the time of that meeting AMSAT did not have a firm commitment from ESA for our mission, but the hints from ESA were quite clear. During the meeting a design was created and sketched for those in attendance. The limiting dimensions for the spacecraft are a bus height of 650mm (25.6in.), bus diameter of 3200mm (126.0in.), and an Adaptor height of 950mm (37.4in.). Fig 5 shows this seven sided spacecraft configuration, using the two long sides on the "backside" as simply deployable solar panels.

When the spacecraft is in its spin stabilized mode following separation from the launch vehicle, the closed solar panels will provide adequate power generation for the necessary station keeping and orbit adjustments. This phase of operation will be used for the motor burn operations and the placing of the satellite into its final orbit. Once reaching that orbit, the satellite will be despun to allow orienting the antennas toward the center of the Earth and the solar panels toward the Sun. The examinations of bus design following the 1991 Marburg meeting all follow that type of design precept.

The launch vehicle Adaptor in the 1991 Marburg spacecraft design is shown as a cylinder with a nominal diameter ϕ1920mm. At that time it was thought that the cylindrical Adaptor would be the most universally accepted by ESA. In mid-July, 1991, ESA gave AMSAT notification that the Phase 3D mission had been accepted for flight aboard the second test launch of the Ariane 5, mission designator AR502, in October 1995. The ESA defined interface documents shows the Phase 3D spacecraft with a conical Adaptor, with a separable ϕ1920mm "Frame" interface to the launch vehicle, and a ϕ1194mm "Frame" (actual outside diameter of ϕ1215mm) interface to the upper payloads mounted to the top of the Phase 3D spacecraft. Fig 6 shows the seven sided 1991 Marburg spacecraft configuration with the conical Adaptor in the middle.

Aside from creating a spacecraft design with adequate power generation and space for antennas (the cubical models were lacking in this point) room needed to be found to mount propellant tanks for the orbit-changing motor burn maneuvers. The requirements for this propulsion is for an increment to the orbital velocity, $\delta V = 1800 m/s$, which requires 46% of the spacecraft launch mass to be motor propellants. This propellant mass is sizable, and our largest payload.

An energetic effort was mounted to try to satisfy a number of conflicting spacecraft requirements. A number of trial designs were studied in a short time to examine the geometric and esthetic trade-offs. (The seven sided 1991 Marburg configuration offended the esthetic senses of some of the member of the designer group.) Fig 7 shows an array of the configurations drawn. Some others were considered but not drawn, but none of these configurations, save for the last, were considered to the extent of being drawn in a full three dimensional form to be portrayed. Some of these bus configuration shapes were so bad that they actually offended some of the design team members, one configuration even being called "ugly". The esthetic aspects of these configurations are related to their symmetry. In the middle of the effort, the use of a triangularly symmetric configuration was becoming clear to some of the design team members, resulting in the "Maxi" six sided configuration.

A number of antenna placement study drawings (not shown) were done to examine antenna placement on several of the designs of Fig 7. The issue here is the area of the Top Plate of the spacecraft, the satisfactory space for, and location of the communications antennas. Let us face it, Phase 3D IS as an orbiting antenna farm. The end result of this study, and the esthetic sensibilities of the design team, resulted in the tacit acceptance of the "Maxi" six sided configuration. This design had such an impact on the design team that one of us (Jan King) coined a name for it, calling it the "Falcon" from a reference to the movie Star Wars, Fig 8.

This illustration, Fig 8, shows the spacecraft in its stabilized configuration with the solar panels deployed to full 7.70m (25¼ft.) span. Antennas shown are a quad array of Roederer Cross' for 24cm, a twelve element CP array of microstrip "patch" antennas for 70cm, a four element canted turnstile for 2m and a three element canted turnstile for 10m. The illustrated 2m antenna is not the candidate, which is expected to be a 3x3 CP array of three-element Yagi antennas, with an expected gain of 14--15dBic. The 10m antenna may also end up as a form of "XBeam" by adding three reflectors. Antennas for SBand and XBand will be phased arrays of flush mounted horn radiators mounted into the Top Plate.

Most of us cannot really comprehend the size impact of the Falcon. It is in Amateur satellite terms - immense! Fig 9 shows a comparison of Falcon with two currently operational satellites. A full-scale mockup of the spacecraft has been constructed for use in the meeting of the Phase 3D design team, in early November 1991. Construction of such a mockup is very helpful to many members of the design team, even to the mechanical designer. The mockup has been fabricated even before some of the drawings have existed and has thereby influenced the spacecraft design and fabrication methods.

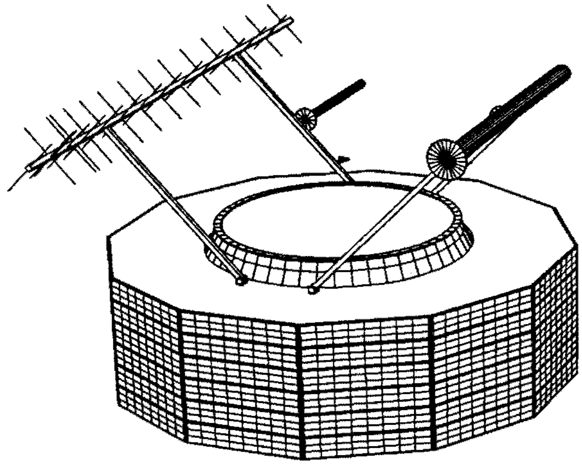


Fig 1--Phase IV, the AMSAT-NA geostationary satellite program. While not a part of the Phase 3 program, it shown here as a matter of reference, and illustrates the lineage of the later Phase 3D spacecraft designs. Diameter: 2.3 m; Mass:≈400kg; Power: 268 W

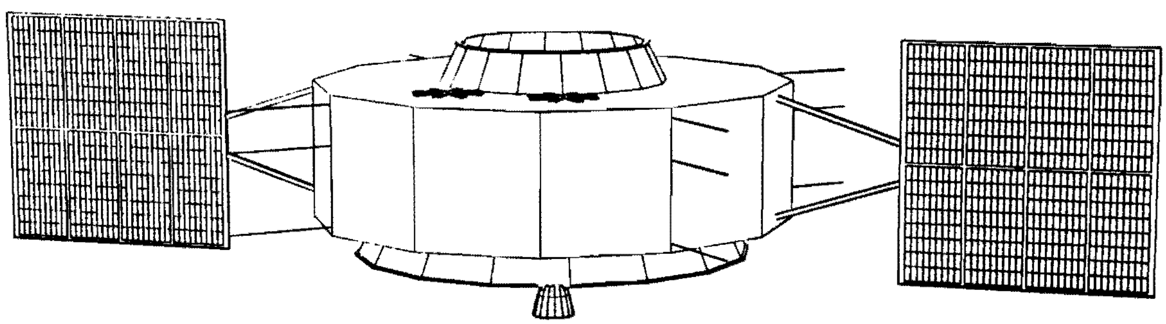


Fig 2--Twelve sided Phase 3D with deployable solar panels, using the basic Phase 4 spacecraft bus design. Diameter: 2.3m; Mass: 400kg; Power: 530W (peak).

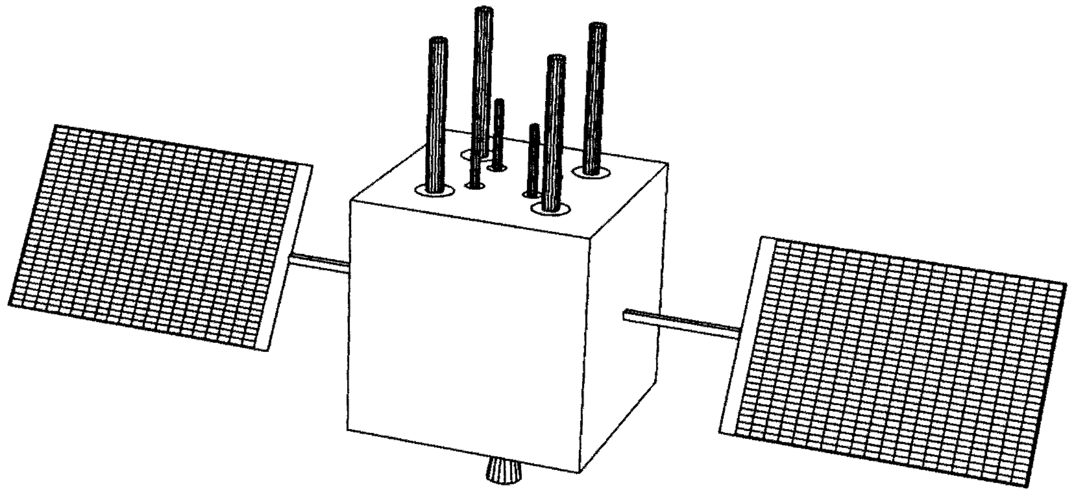


Fig 3--"Two-Cubic-Meter" Phase 3D with deployable and rotatable solar panels. Antennas shown are quad arrays of helical design (per ARRL Handbook) for 24cm and 13m. Size: 1.22m cube; Mass: 250kg; Power: 530W (continuous).

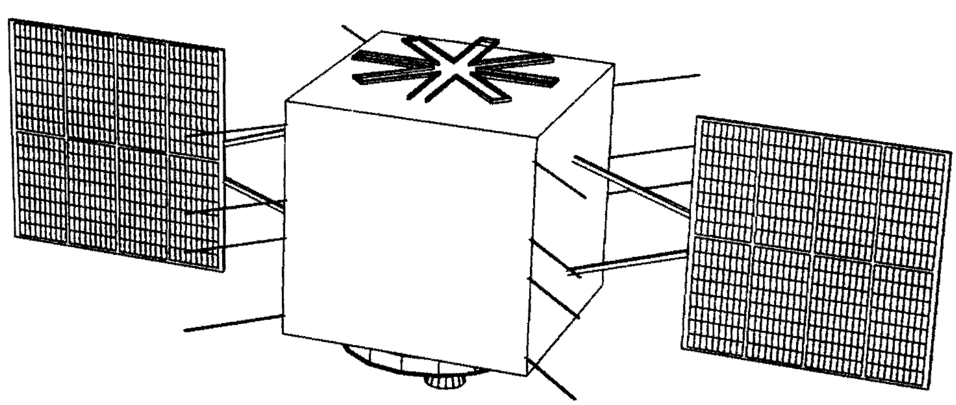


Fig 4--"Two-Cubic-Meter" Phase 3D with deployable fixed solar panels. Antenna shown is a 13dBic "Roederer Cross" for 70cm and 4x4 CP Yagi for 2m. Size: 1.22m cube; Mass: 250kg; Power: 530W (peak).

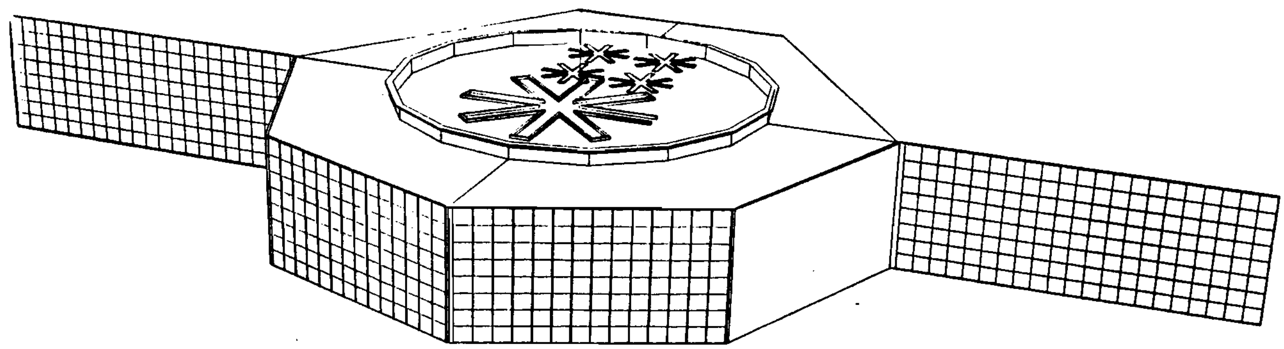


Fig 5--Seven sided Marburg configuration Phase 3D with deployable solar panels. Top Flange is ϕ1920mm end of central launch vehicle cylinder. Antennas are Roederer Cross' for 70cm and 23cm. Diameter: 3.2m; Mass: 500+kg; Power: 668W (peak).

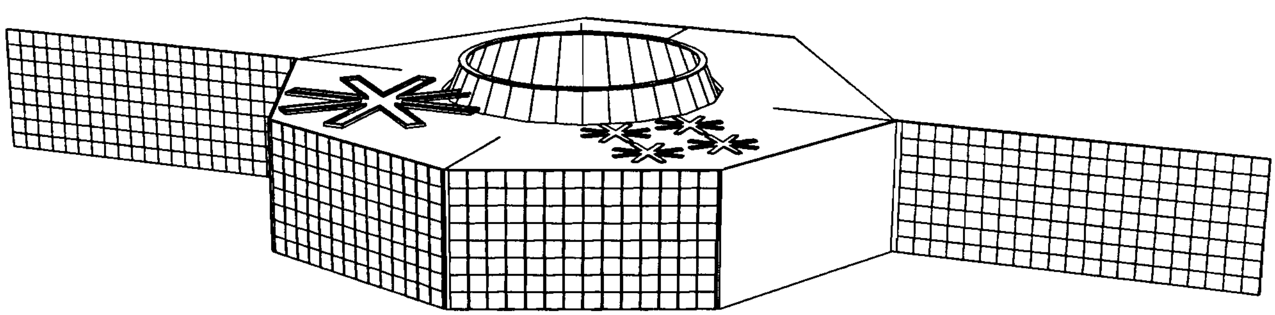
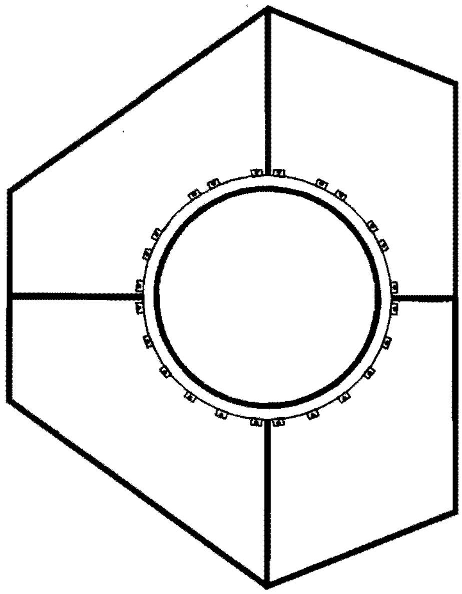
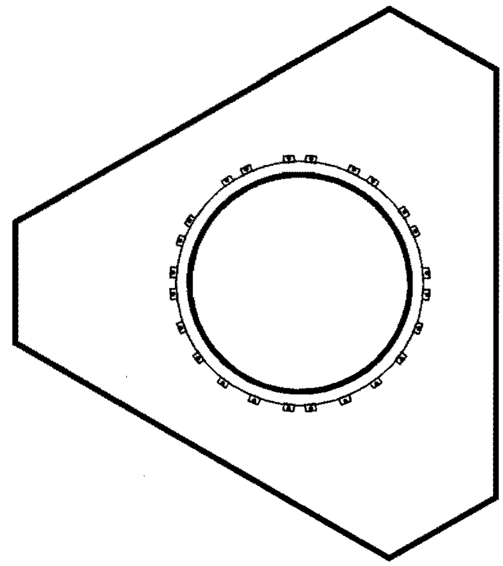
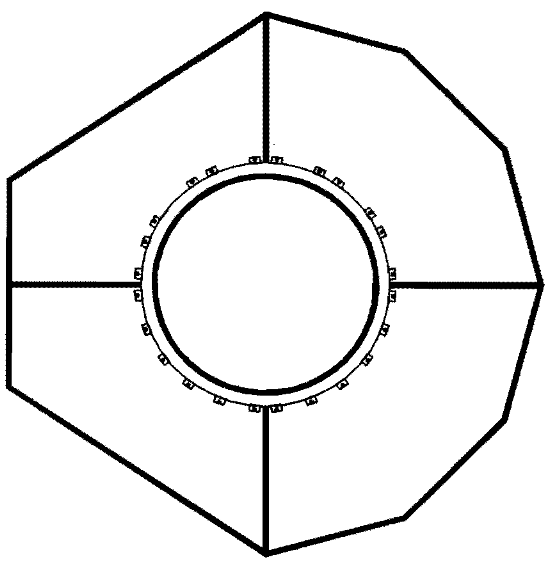
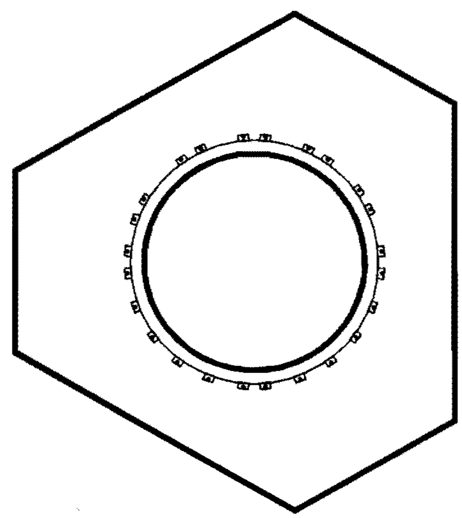


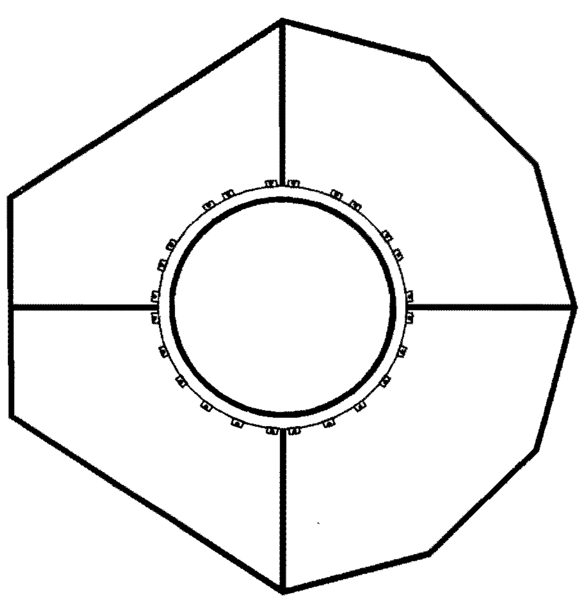
Fig 6--Seven sided Marburg configuration Phase 3D with deployable solar panels. Top Flange is ϕ1215mm end of central launch vehicle Adaptor cone. Antennas are Roederer Cross' for 70cm and 23cm. Diameter: 3.2m; Mass: 500+kg; Power: 668W (peak).











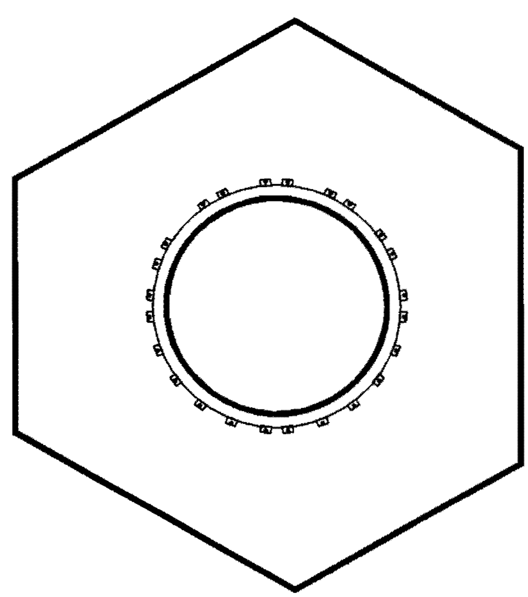


Fig 7--Six variations of spacecraft bus examined for possibilities.

Upper Left: Nine sided version of 1991 Marburg configuration. Diameter: 3.20m; Mass: 600kg; Power: 680W (peak).

Upper Center: Compressed nine sided configuration. Compression limited by the propellant tank size. Diameter: 3.02m; Mass: 500kg; Power: 664W (peak).

Upper Right: "Ugly" six sided configuration. Diameter: 3.20m; Mass: 500+kg; Power: 727W (peak).

Lower Left: Six sided (not hexagonal) configuration. Diameter: 3.20m; Mass: 600kg; Power: 655W (peak).

Lower Center: Compressed six sided configuration. Diameter: 2.82m; Power: 655W (peak).

Lower Right: "Maxi" six sided configuration. Diameter: 3.20m; Mass: 500+kg; Power: 873W (peak).

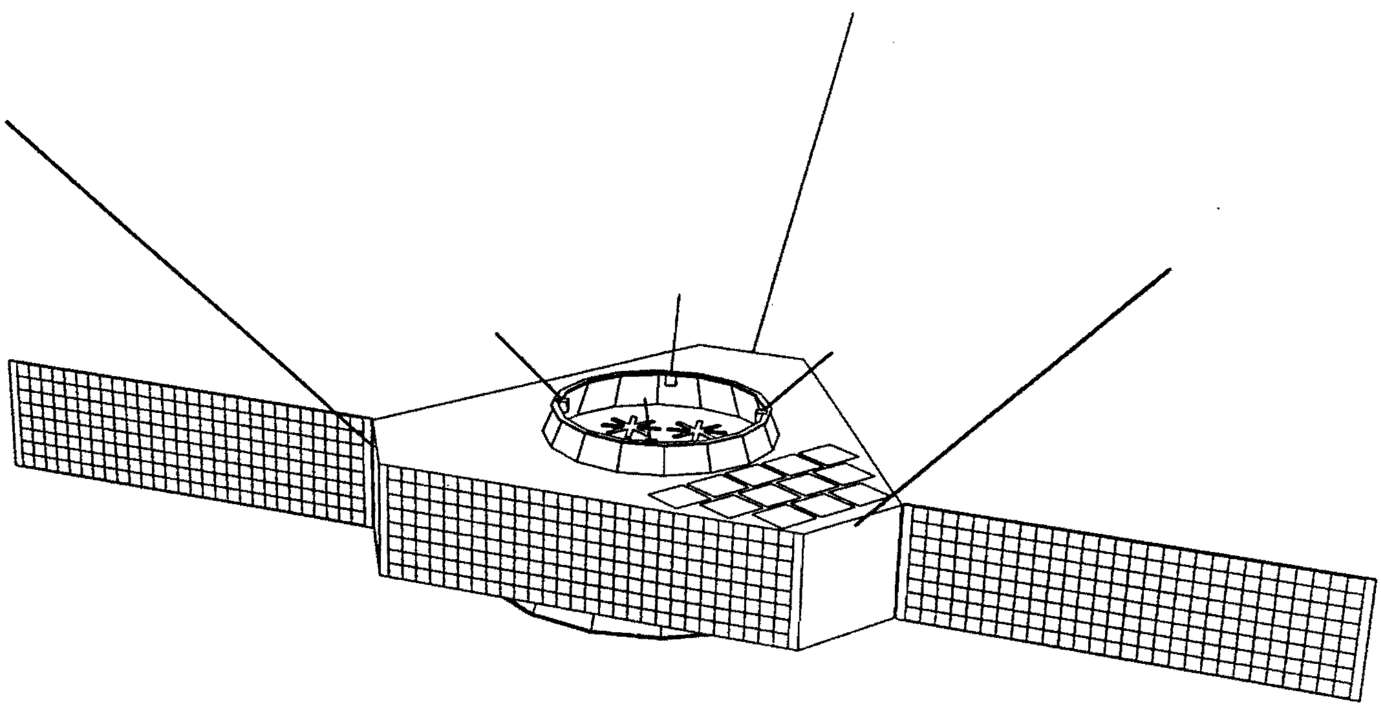


Fig 8--"Falcon" Phase 3D configuration based on the above "Maxi" bus shape, a triangularly symmetrical bus shape.

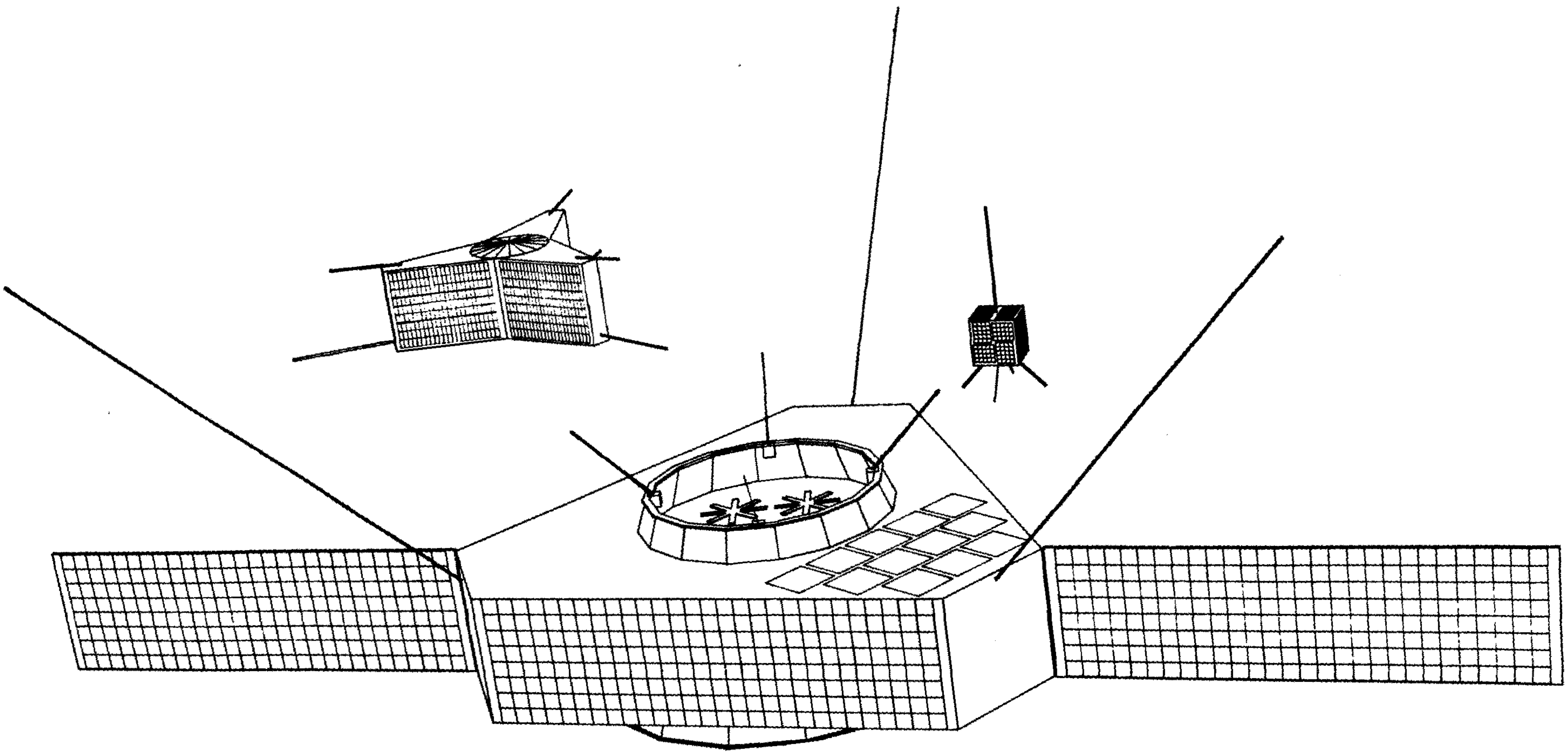


Fig 9--Another view of Falcon, showing the size comparison with OSCAR13 and OSCAR16.

Gateways to the 21st Century

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Abstract

The Amateur Radio Service, about to transition into the next century is facing the loss of sections of its vhf, uhf and microwave bands to commercial services. At present radio amateur use of these bands is somewhat haphazard and uncoordinated. This paper presents an integrated plan for the use of those bands, that has the potential not only to safeguard those frequencies but to revolutionize the whole concept of amateur radio.

This paper discusses how Gateways may be used to integrate amateur radio terrestrial, satellite and interplanetary microwave communications. Such an integrated capability will provide capabilities that don't exist at this time and has the potential to transform amateur radio.

The Problem

The Amateur Radio Service, about to transition into the next century is facing the loss of sections of its vhf, uhf and microwave bands to commercial services. In 1991, the Amateur radio service is still using technology based on that developed in the 1970's, with the sole exception of packet radio.

Recent advances in the state-of-the-art of computers and microwave technology have been ignored by the mainstream of radio amateurs. At present radio amateur use of these bands is somewhat haphazard and uncoordinated.

The Alternatives

There are three alternatives:-

1. Do nothing.

2. Try to increase usage of these bands without providing new services.

3. Identify a new service suited to the properties of the bands, and propose a plan to move communicators into those bands.

Doing nothing will not make the problem go away. The bands are there and 1.2 GHz equipment is available commercially, but few communicators are moving up to that band from the 2 meter and 70 cm bands. This is because there is little incentive to move up to 23 cm. In general the higher the frequency, the more expensive the equipment that uses it. A new technology is rarely adopted unless it provides a new (and is or quickly becomes desired) capability [1].

The third alternative is thus the only choice that stands a chance of increasing the occupancy of those bands. The Gateway Project Proposal is herein identified as one way of providing an incentive to move the general communicators up in frequency. It also addresses several other problematic aspects of amateur radio and provides an integrated solution.

The Gateway Project Proposal

This project identifies Gateways as a mechanism for integrating amateur radio terrestrial, satellite and interplanetary microwave communications. Such an integrated capability will provide capabilities that don't exist at this time and has the potential to transform amateur radio.

The VHF, UHF and Microwave Bands

The microwave bands are allocated to the Radio Amateur Service as secondary allocations. At present radio amateur use of these bands is somewhat haphazard and uncoordinated. Radio amateurs have the use of these frequencies providing they do not cause interference to the primary users. Sections of the 70 cm the 23 cm bands have already been lost in various countries, 220-220 Mhz has been lost in the U.S.A and the prospect of further losses face us today. Our use of the vhf, uhf and microwave bands is twofold; terrestrial and satellite.

Terrestrial Use of Microwave Bands

Random contacts (QSO) on the microwave bands are few and far between. They seem to take place either as the result of a telephone call between the stations involved, or as the result of a scheduled expedition. In the latter case, the two stations involved drive out to different mountain tops, make a contact and write it up for the national magazine. All well and good, but hardly everyday use of the band. The microwave bands are not suited for random QSOs in the same way as the lower frequency bands. Figure 1 shows a typical situation with three stations, each using highly directional antennas. The antennas are so directional that each station cannot hear another. On the other hand, if a repeater was employed as shown in Figure 2, they would be able to QSO easily enough. Repeaters are commonly used on 2 meters and 70 cm, yet they are very rare on the microwave bands. Why? Perhaps it is because microwave users tend to be experimenters, not communicators. From the experimenter's point of view, there is no challenge in repeater QSOs. From the communicator's point of view, a

Figure 1 Microwave usage Scenario

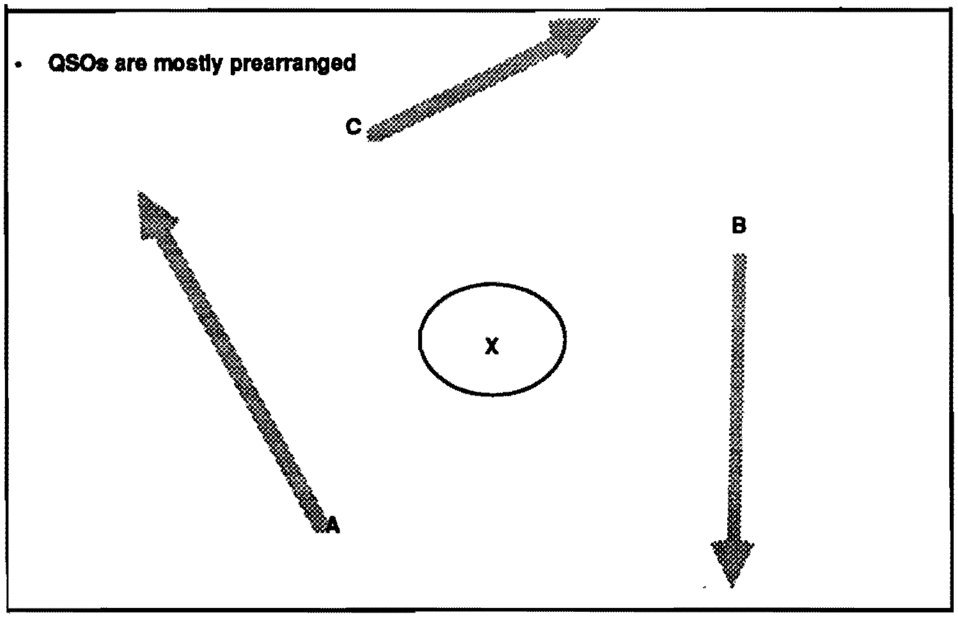
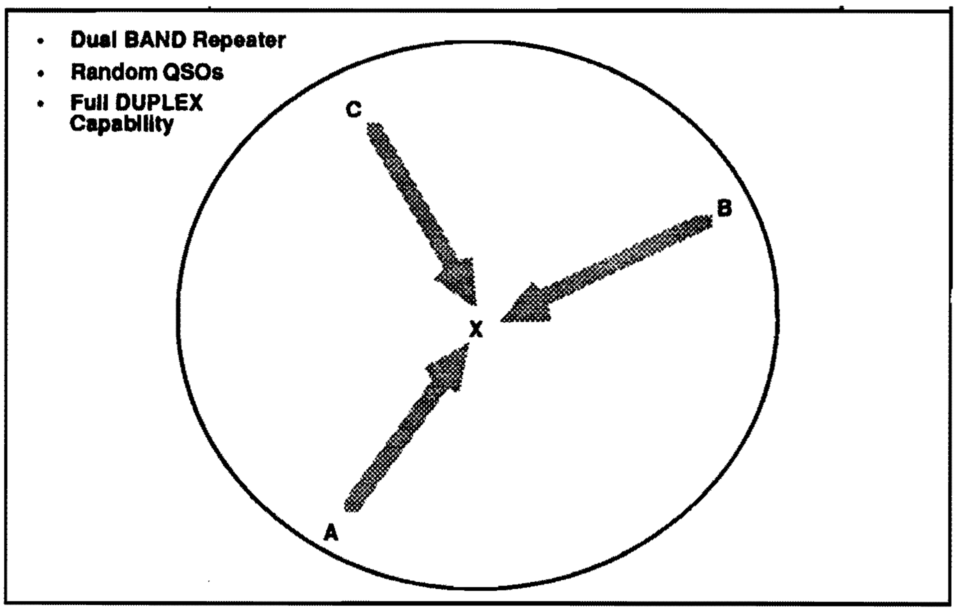


Figure 2 Repeater Usage Scenario



microwave repeater, as a copy of a 2 meter repeater, would not offer anything worthwhile building the equipment to use it. If we are going to make use of the microwave bands for communications, we have to do it in a way that offers something new. One such capability which seems to have been overlooked is full duplex communications.

Satellite Use of the Bands

The 2 meter and 70 cm bands are the most popular of the vhf and uhf bands. The current spacecraft in development for the amateur radio service, shown in Table 1 [2], are still planning to use these bands. The 2 meter band is very crowded in most parts of the world. There is at present already enough interference (QRM) in the satellite section of the 2 meter band. This situation is only going to get worse.

Satellite users vocally want "Mode B" with its 70 cm uplink and 2 meter downlink, yet mode B usage through the AMSAT-OSCAR (AO) 10 and 13 spacecraft is minimal. On the other hand, mode B on AO-21 is used by the same number of stations. If the users really wanted mode B, AO-10 and AO-13, with their intercontinental range and long access times, should used by more stations than those using AO-21. It seems though that they are not. Since AO-21 is in low earth orbit, it is much easier to get a stronger signal into and out of (albeit for shorter time periods) than AO-10 and AO-13. OSCAR users who are vocally demanding "Mode B" seem to be stating the problem in terms of a specific solution. **What really they seem to be demanding is "Easy Access to communications satellites"**. They are stating it in terms of the current capability of AO-21, and their remembered capability of Mode B from AO-7.

Spacecraft Requirements

In the late 1970's, Karl Meinzer, DJ4ZC and AMSAT-DL studied the problem of providing worldwide amateur radio communications service with a single spacecraft [3]. These requirements were summarized as shown below [4].

1. All users want to get as much daily communications (operating) time as possible.

2. All users want to be able to work anybody they can (DX or local) taking advantage of the propagation characteristics of the medium (no skip zones).

3. At least 90% of the amateur radio population of the globe are located in the northern hemisphere.

4. The radio amateur population is distributed evenly over all geographic longitudes.

The optimal orbit to meet these requirements is the highly elliptical orbit, as used by the Molniya satellites. These spacecraft provide the desired

Table 3 Amateur Radio Spacecraft Currently Under Development

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

communications capacity to the Soviet Union with much the same population distribution. Unfortunately, this orbit when used to provide Mode B communications suffers from marginal links due to the spacecraft on board antenna and power limitations.

Let's now add the following observation to those above.

5 The majority of radio amateurs live

in urban areas.

By introducing a Gateway into the communications path, users have easy access with good signal levels and do not have to worry about tracking the spacecraft. Satellite builders can build microwave communications systems. A new group can pick up the challenge of building both the gateways and designing the user equipment for accessing the Gateway. The state-of-the-art has changed.

A block diagram of the conceptual gateway is shown in Figure 4. The gateway is modular in construction. It consists of a wide band terrestrial receiver and transmitter using frequencies selected by the local gateway group. The satellite up and down link frequencies are determined by the satellite builders (in conjunction with the gateway community). The gateway is built to comply with (to be developed) International Amateur Radio Gateway Standards. The gateway also contains a terrestrial beacon which can be used to provide local news bulletins, spacecraft schedules, educational and housekeeping telemetry, etc. The gateway uses different terrestrial bands (or spacing) so that all users can receive their own transmissions.

The Conceptual Gateway

Satellite Gateways were proposed and described by this writer in 1978 [5][6]. In the 1970's the technology to use gateways was not practical, in the 1990's it is. Consider how the gateway would work. Figure 3 shows a typical satellite usage scenario at some particular instant of time. In Figure 3A, stations A, B, C and G can access the satellite to work each other or any DX that is about. Station A is blocked by the hill that station G lives on. If a gateway is located atop the hill together with station G as shown in Figure 3B, then A, B, C and G all have equal access to the spacecraft. The gateway acts as a second transponder in series with the spacecraft and decouples the user interface to the spacecraft. Note that the gateway does not preclude individual access to the spacecraft by any station.

Conceptual User Equipment

User equipment is also modular. The example discussed in this section uses 1.2 GHz as the user transmit frequency and the 2.4 GHz band as the user receive frequency. This frequency pair has been chosen because 1.2 GHz transmit is used as the Mode L uplink and 2.4 GHz is the Mode S downlink. A non rotatable microwave antenna is aimed at the gateway. This antenna may be placed on a mast, roof or balcony. Attached to it are the up/down converters which convert the gateway signals to those used by the 2 meter and 70 cm equipment in the radio shack. This gives the user Mode B in the shack and minimizes the radio frequency (rf) attenuation in the cables between the antennas and the radios. DX can be worked without towers and beams. The equipment also contains a

Figure 3 A Typical Satellite Usage Scenario

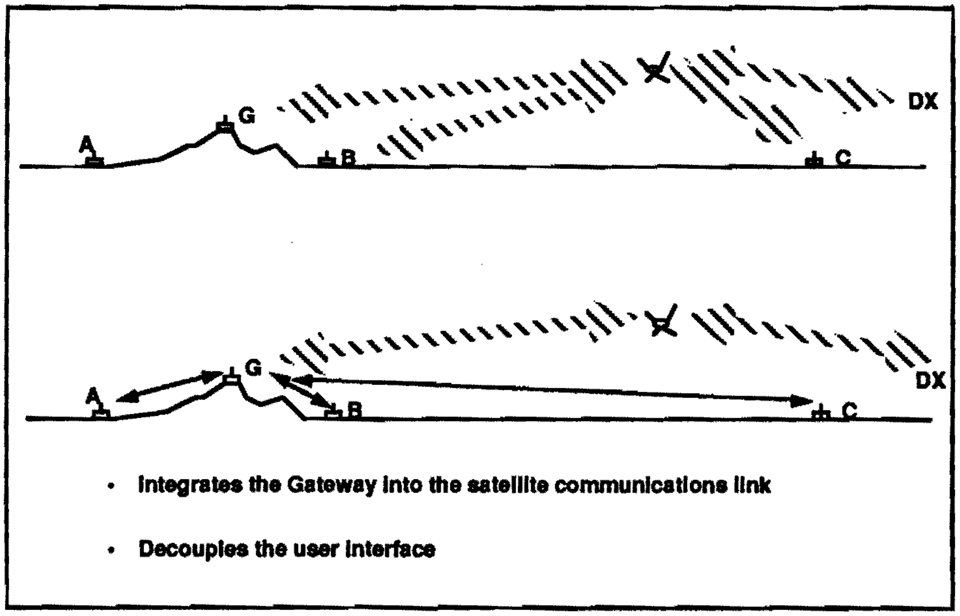
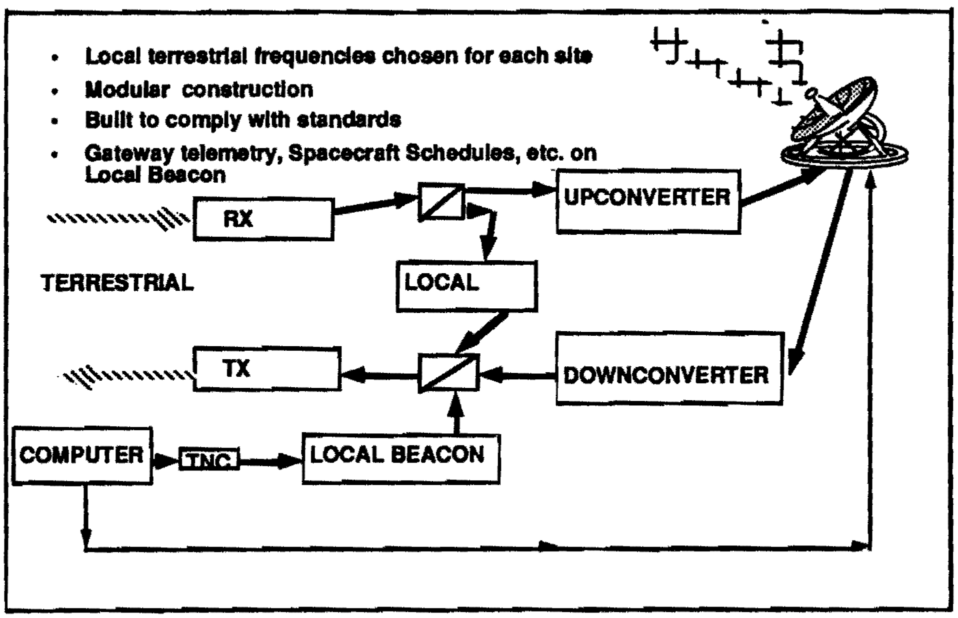


Figure 4 The Conceptual Gateway



simple self monitoring capability to allow the user to verify that the equipment is operational. The equipment can provide digital or analog communications or a mixture. Real-time video is also a possibility. Suitable low cost equipment for users at these frequencies has already been described in the literature. [7][8].

Linking Gateways.

When wide band gateways are established in urban areas, there is no reason why links should not be set up between gateways in neighboring areas, much in the same way that nodes link packet radio local area networks (LAN). A conceptual linkage along the east coast of the U.S.A is shown in Figure 5. From the user's point of view, there is no difference if the gateways are linked by terrestrial or satellite nodes. The actual inter gateway links would also use a pair of microwave bands. The conceptual gateway link node is shown in Figure 6. It is a conventional design and uses modular construction. It is also built to standards. The same block diagram can be applied to a satellite or to a terrestrial node. One way of using linked gateways is by frequency division. This approach is similar in concept to the UK 2 meter band geographical band-plan of the 1960-70 timeframe [9]. Figure 7 illustrates the passband of a gateway with two terrestrial links and one satellite link. Users would chose which link they wish to access by transmitting in the relevant part of the passband.

Advantages of the Gateway

Gateways have several advantages, some of which are described below.

* <u>Gateways do not preclude individual radio amateurs from access to spacecraft.</u>

* <u>Gateways provide easy user access</u>. Antennas can be fixed in position. User tracking problems do not exist.

* <u>Gateways provide controlled access to spacecraft</u>. The effects of high power users are only felt by the other users of the same gateway. These irate users may be able to deal with their high power users according to local customs.

* <u>Gateways can provide full duplex communications capacity</u>. This capacity is lacking from most present day amateur radio contacts.

* <u>Gateways allow spacecraft to be simpler</u>. Spacecraft will not have to contain a number of transmitters and receivers for the different modes. Users will no longer have to remember operating schedules for when particular modes will be useable.

* <u>Gateways allow spacecraft builders to tackle higher frequencies</u>. Spacecraft for amateur radio are built by volunteers for the challenge. They are interested in pioneering new techniques and new frequencies.

Gateways would decouple the majority of the users from these new

Figure 5 Linked Gateways

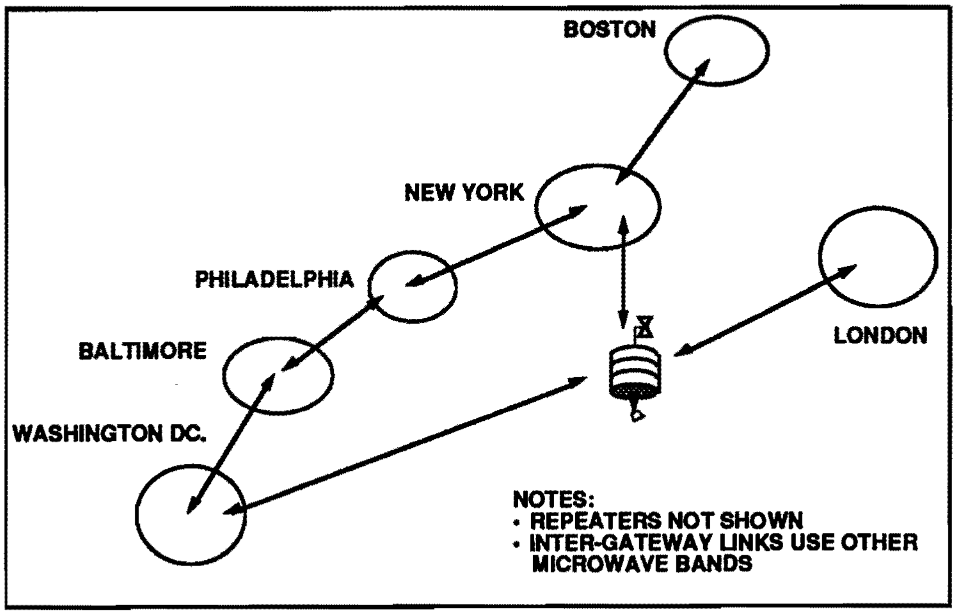
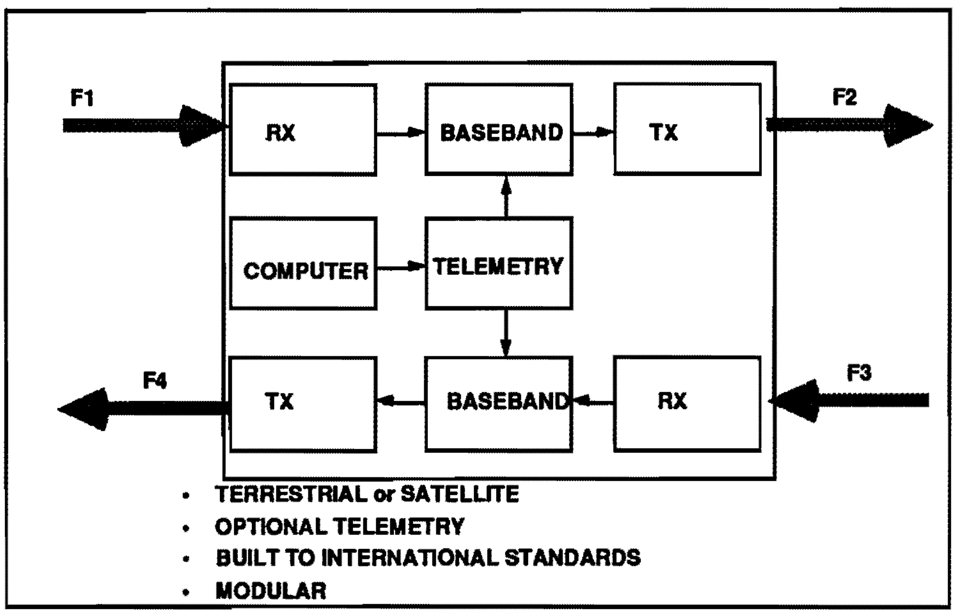


Figure 6 The Conceptual Gateway Repeater or Node



frequencies. The same set of user equipment could then be used for several different spacecraft, each operating with different microwave uplinks and downlinks.

* Ground nodes allow hands on performance measuring and tests of proposed future flight hardware. If the difference between a terrestrial transponder and a ground transponder on a node is only the environment, several versions of proposed hardware and software can be ground tested by real users in different parts of the world before flight. Non viable designs would be discarded without incurring the cost of the launch and the embarrassment of the users finding out how unsuitable the hardware really was. On the other hand, suitable techniques that fail to become active in orbit may be demonstrated and become widely adopted on the ground.

* Gateways provide a training ground for developing new technical talent for the radio amateur space hardware development program. Up to now, amateur spacecraft are built to order. A launch date is obtained, and the team strives mightily to meet that date. So far they have all succeeded in that the hardware has been aboard the rocket when it lifted off. This pressure is real because rocket payloads have to be balanced. If a date is missed, the launch agency might never allow amateurs another chance, and there are very few launch agencies. The project team have to allocate the work to people whose performance capabilities are known. They cannot take a chance on an untried person, and cannot take the time to give that volunteer a chance. New volunteers are caught in a Catch-22 situation when trying to join existing teams.

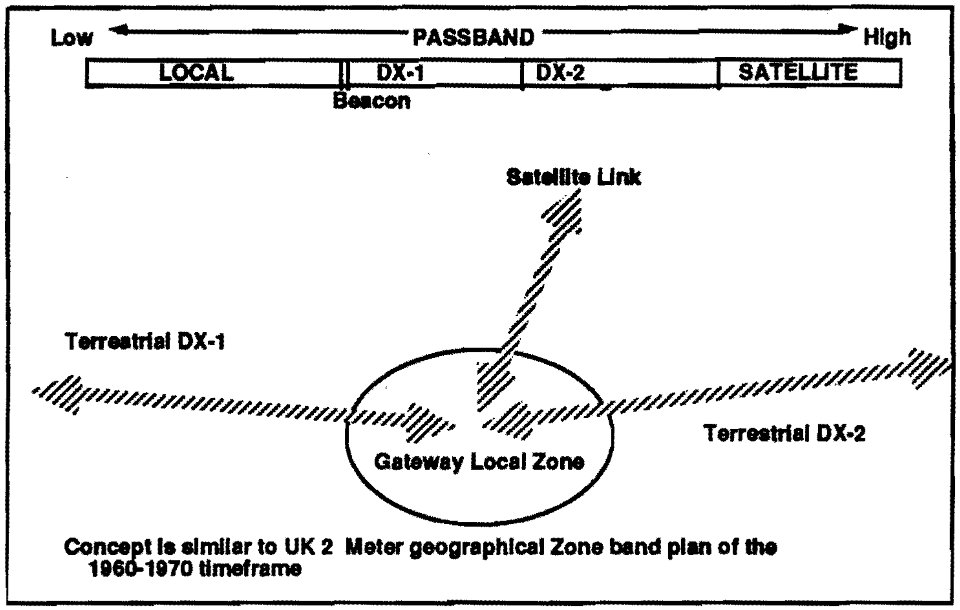
New groups on the other hand can develop their own spacecraft, but to form a group, a particular nucleus has to exist. Ground nodes on the other hand can be built by clubs, technical schools and other starting groups. They can take the time to do it right. They don't have a tight launch date to meet.

* Gateways can also reduce the cost of accessing satellites for the individual users. They can use the same equipment they use for terrestrial QSOs for spacecraft access. In fact, gateways make the communications link transparent. If the terrestrial gateways get to be linked in a manner similar to the packet radio network of today, the only way users may know that they are communicating via a satellite is by the time delay on the signals.

Path Attributes

Consider the path loss and noise attributes of the microwave link. The goal of the transmitting station is to put a useable signal into the antenna socket of the distant receiver. For any given path between two stations. The received signal strength is a function of the gain of the antennas and the cable losses at each end of the link as well as the attenuation over the distance of the link. These factors have been worked

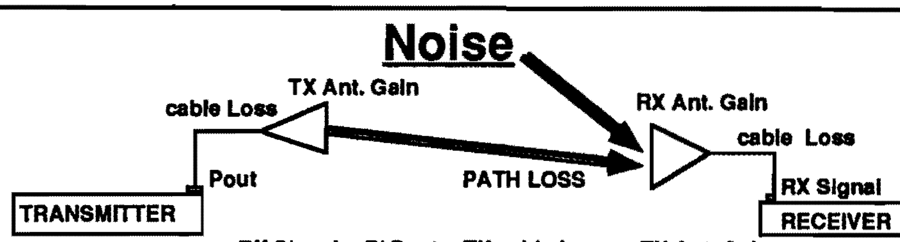
Figure 7 Conceptual Gateway Spectrum Use



out and the received signal levels at various frequencies for different link parameters can be readily predicted. The second major factor to impact microwave communications is noise. Atmospheric noise is both natural and man made. Most radio amateurs living in urban environments suffer from the effects of man made noise. Noise is also present in the front end of receivers. Any communications link design such as that shown in Figure 8 has to take noise into account. Adding transponders or gateways in series will add noise to the link, a phenomenon which will have to be accounted for. A typical example of the communications capacity of a link using a 100 Watt morse code transmitter, with identical dish antennas at each end of the link, in a 100 Hz bandwidth is shown in Figure 9.

The limiting factor seems to be distance. A 1 meter dish provides communications capabilities out to 450,000,000 km at 24 GHz. A 2 meter dish will provide QSOs at 1.2 GHz out as far as 100,000,000 km. Given that the moon is at a mean distance of 384,399.1 km from the earth, why does moonbounce require a lot of power? Well in moonbounce, much of the power is lost at the moon because it only reflects a minuscule percentage of the incident power. The earth transmitter has to uplink sufficient power to overcome that loss and provide a signal leaving the moon that is powerful enough to overcome the return path loss. A one way link does not have to worry about what happens to the signal once it arrives at the destination providing it is strong enough to be received.

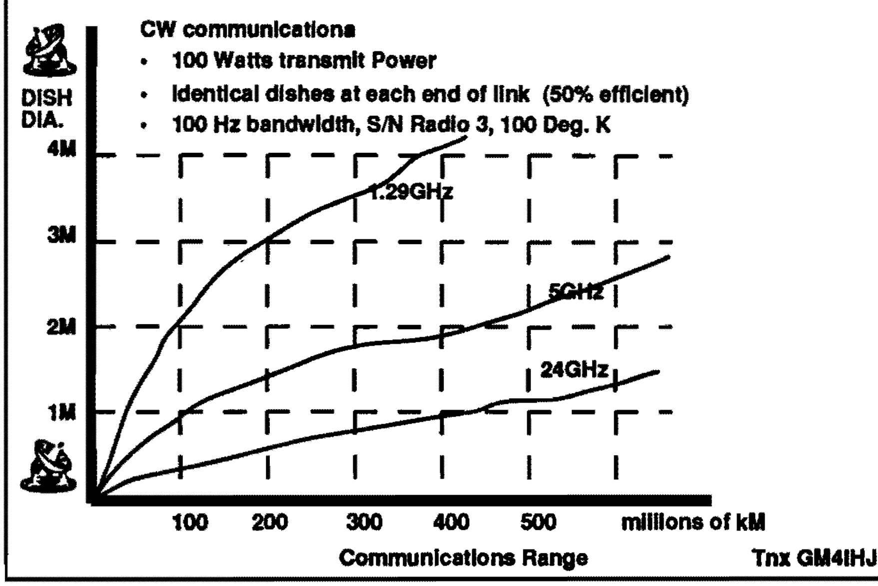
Figure 8 Path Attributes



RX Signal = F(Pout - TX cable Loss + TX Ant. Gain
- PATH LOSS
+ RX Ant. Gain - RX cable Loss)
+ NOISE

PATH LOSS	LOSS
TERRESTRIAL	distance
UP LINK	distance
MOON BOUNCE	distance + Reflection coefficient + distance
E-M (1 Way)	distance

Figure 9 Communications Ranges



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Interplanetary Communications

A range of 100,000,000 km provides communications capabilities with future bases on the moon or Mars. The distance between the Earth and Mars varies between about 80,000,000 and 230,000,000 km depending on the positions of the planets as they travel along their own orbits around the sun. Overcoming the path loss is only one problem that has to be faced by the radio amateur configuring for interplanetary communications. The major problem will be the time delay. The one way travel time for a signal between the Earth and Mars varies between about 4 minutes when Mars is only 80,000,000 km distant, and 20 minutes when Mars is 220,000,000 km. If you've ever listened to a pile up on 20 meters, think about what it would be like if it took up to 80 minutes or so to get an acknowledgement of the first call. Interplanetary amateur radio QSOs will not be real time voice links in the same format as intraplanetary QSOs. *Nobody ever said that a QSO had to take place in real time.* Apart from the path loss and the time delay, both planets are rotating, so there will be Doppler shift on the signals. For any station on the amateur radio station located on the surface of the Earth (earthstation), Mars will only be above the horizon for a few hours each day. There is no guarantee that when Mars is viewable by an earthstation, Mars base will be able to see the Earth let alone the same earthstation. These problems are not insurmountable, PCs can handle all the math involved, but they do tend to make direct interplanetary communications difficult. If suitable spacecraft were in orbit about both planets they could make interplanetary communications much easier. However, getting these spacecraft built and into suitable orbits may be difficult. The concept of direct and indirect interplanetary communication is shown in Figure 10.

Perhaps, radio amateurs will need not build their interplanetary relay satellites. Amateur radio seems to be in space to stay. It is an important part of MIR daily activities [10]. It has flown on the Space Shuttle and amateur radio may even be manifested as personal equipment belonging to the astronauts. If that happens, any flight carrying an astronaut who is a radio amateur will have some amateur radio activity. Operations from the shuttle suffer from the lack of an outdoor antenna [11]. Bulkhead fittings are present on the vehicles so the only technical problem preventing the attachment of suitable antennas in the payload bay is the cost of the paperwork required to document the changes. The National Aeronautics and Space Administration (NASA) is currently planning for upgrades to the NASA Communications Network, Space Station support and the new Customer Data Operations System (CDOS). Amateur radio needs to get their inputs into the system now while it is in the planning stage. If they are in from the beginning, they are in at minimal cost. A conceptual integrated approach is shown in Figure 11.

Figure 10 Direct and Indirect Interplanetary Communication

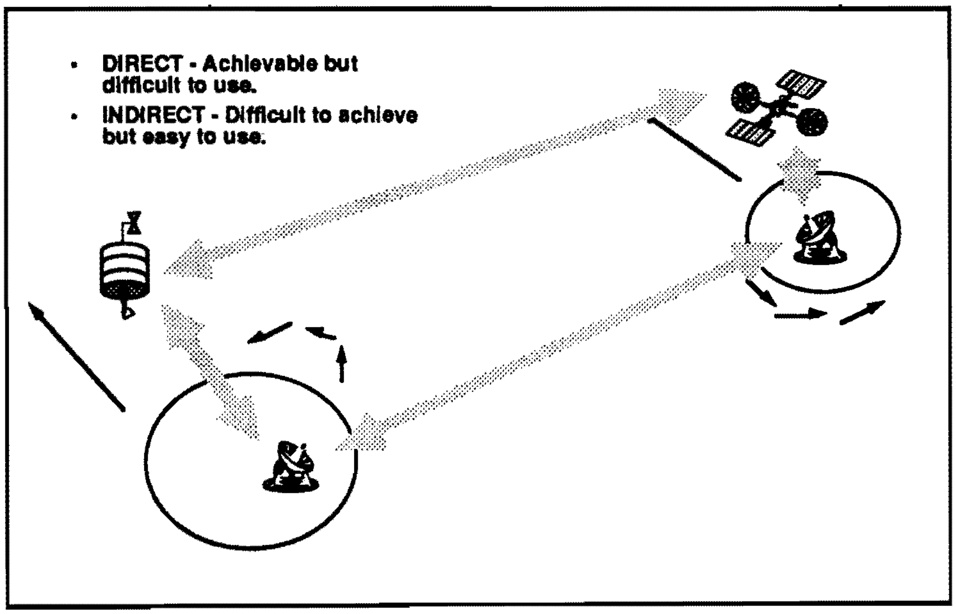
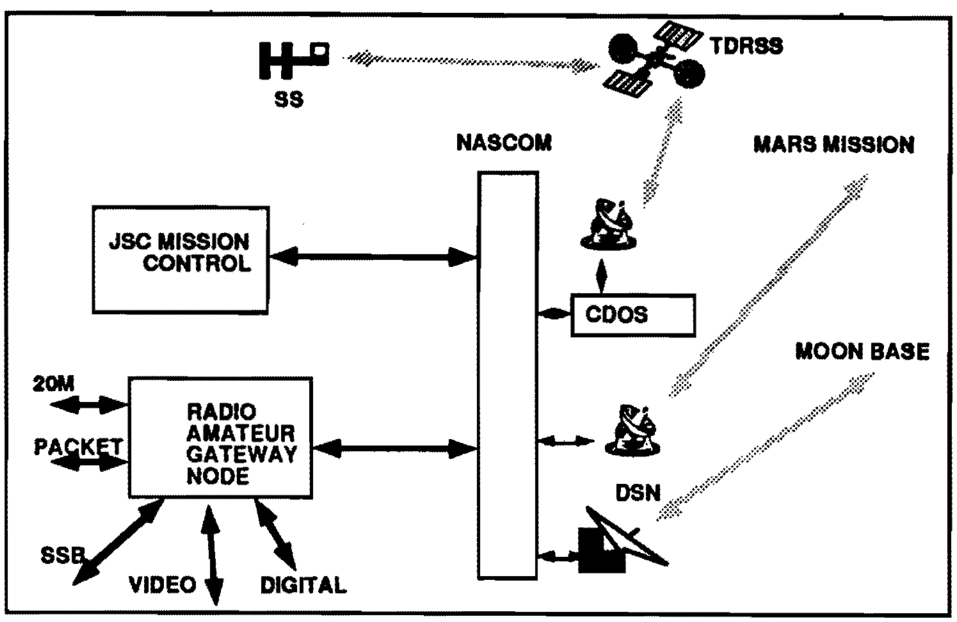


Figure 11 Conceptual Integration of Amateur Radio into Space Communications Links



Summary

Gateways of the future can radically change amateur radio as we know it today. A Plan for an integrated terrestrial and satellite radio amateur communications network is a plan for the future of our microwave bands.

Gateways of the future will be full duplex to provide new capabilities to attract the communicators. They will provide both intraplanetary and interplanetary communications capability. They will provide high speed audio, video and digital communications. They will not inhibit individual access to the microwave bands.

Gateways of the future are feasible and can be built using 1991 technology. A well equipped high frequency (HF) packet radio Bulletin Board System (BBS) contains about $5,000 of equipment, a packet radio Node, about $500. Gateways should cost less than $5,000.

Gateways of the future need standards and imagination. They should be designed in a top down manner and implemented from the bottom up. Let's not repeat the haphazard implementation of the packet radio mess we have today by providing standards, guidance and education **up front**.

Gateways of the future provide something for everybody. Users get easy access to satellite and DX communications and a host of new services. Satellite builders get to play with higher frequencies. *Best of all, they provide a plan for the use of the microwave bands in a manner for which the bands are best suited.* Such a plan may also tend to safeguard those bands for the Amateur Radio Service.

In the past radio amateurs have acquired boxes and asked themselves the question "How can I use them ?" This paper has presented a vision of the future. Perhaps the question should be posed differently. "I have a vision of the future, how can I get the black boxes to implement the vision" ?

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Glossary

AO	AMSAT-OSCAR
AMSAT	The Radio Amateur Satellite Corporation
BBS	Bulletin Board System
CDOS	Customer Data Operations System
DX	Distant transmission
HF	High Frequency (Short waves)
LAN	local area network
NASA	National Aeronautics and Space Administration
OSCAR	Orbiting Satellite Carrying Amateur Radio
QSO	Contact between two radio amateur stations
rf	radio frequency
vhf	very high frequency
uhf	ultra high frequency

Telemetry: Past, Present and Future

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Abstract

Each time an Orbiting Satellite Carrying Amateur Radio (OSCAR) has been launched the spacecraft designers have developed their own telemetry systems. The result has been a different downlink data format for each spacecraft. As a consequence, the developers had to re-invent the data transfer process and the users were faced with the problem of capturing and processing data in different formats. With the anticipated launch of between five and ten more spacecraft within the next five years, should they also use different formats, life will get very complicated for ground stations planning to acquire and process telemetry.

This paper examines the telemetry from the existing satellites, discusses telemetry from a systems perspective and looks at requirements for all parts of the system including spacecraft builders, telemetry users and ground station software developers. The paper then introduces two proposed amateur telemetry standards, the first for downlinking of data, the second for interchanging data between different computers and long term archival of the data.

Spacecraft in Orbit

The earliest of the amateur spacecraft designed to downlink digital telemetry was the first Phase 3A satellite, built by the Radio Amateur Satellite Corporation (AMSAT), which was designed in the middle 1970's. At that time personal computers were not on the market. Anyone who wanted one had to build it from scratch or from the few kits such as the AMSAT-GOLEM-80 Project [1][2] that did exist. Most radio amateurs who were interested in digital communications used mechanical (noisy) teleprinters; a very few lucky ones had cathode ray tube (CRT) terminals.

The AMSAT Phase 3A satellite failed to achieve orbit because the Ariane launch vehicle malfunctioned a minute or so after leaving the ground and the range safety officer activated the self destruct procedure [3]. Subsequent Phase 3 satellites, AMSAT-OSCAR (AO) 10 and AO-13, launched in 1983 and 1988 respectively, used the same data formats and downlinked 50 baud

BAUDOT and 400 baud ASCII telemetry. The downlink format was somewhat similar to the fixed frames of morse code telemetry generated by AO-6, AO-7 and AO-8. The 50 baud telemetry used standard amateur radio teletypewriter (RTTY) frequency shift keyed (FSK) formats so that any radio amateur suitably equipped could receive the data. The received data display shown in Figure 1a is simple and reception errors can be readily identified. The 400 baud telemetry was mainly intended for use by the command stations and used phase shift keying (PSK) to provide what was then (1975-1980) high speed data over long distance radio links [4]. The 400 baud data downlink format of blocks (similar to packets) was designed to be displayed on home made personal computers (PC) using crt displays having 16 lines of 64 characters per line.

The satellites built at the University of Surrey, England increased the downlink telemetry rate to 1200 baud. UoSAT-1 (UO-1), launched on 1981 and UoSAT-2 (UO-2) launched in 1983 sent back 1200 baud ASCII telemetry in a number of formats. A basic received real-time ASCII telemetry frame is shown in Figure 1b. This format is more complex than the Phase 3 BAUDOT format and reception errors are not as readily identified. Consequently, the UoSATs were the first to introduce a checksum into the telemetry data to allow the receiver to verify that the data was good.

Terrestrial amateur packet radio experiments began in 1980 and an international network grew rapidly once an amateur adaptation of the X.25 standard (AX.25) was adopted [5]. The Japanese AMSAT built Fuji-OSCAR 12 (FO-12) (launched in 1986) was the first amateur satellite to incorporate packet radio. FO-12 and FO-20 (launched in 1990), while using packet radio also used a fixed format as shown in Figure 1c. No checksum was needed in the data, because the checking was done by the link protocol. All good packets received, were error free by definition.

In 1990 AMSAT achieved an impressive milestone with the launch of six spacecraft as secondary payloads on an Ariane vehicle. With one stroke, two more UoSATs and four digital satellites were launched (UO-3 and UO-4, OSCARs 16, 17, 18 and 19). Each downlinked telemetry using packet radio. UO-4 malfunctioned soon after launch and has not been heard from since. UO-3 swiftly changed its downlink format to 9600 baud binary.

AMSAT's microsats, AO-16, DOVE-OSCAR 17 (DO-17), Weber-OSCAR 18 (WO-18) and Lusat-OSCAR 19 (LO-19), downlinked telemetry at 1200 baud in an ASCII format using packet radio. DO-17's signals can be received by anyone who has a 2 meter packet radio system. A typical example is shown in Figure 2a. This format uses a number of transfer frames to downlink a source frame of data and mixes ASCII text and hexadecimal data.

Figure 1 Examples of Data Received from Various Satellites

Figure 1a. AO-13 RTTY Z Block Transfer Frames

```
Z HI. THIS IS AMSAT OSCAR 13
 05.02.54 8661
.0086 .0000 .07B9

64 6 0 1 16 218 1


193 170 158 143 181 144 147 140 200 7
147 7   7   7   165 29  100 7   149 7
10  7   145 115  34 7   153 129 122 180

152 73  7   145 137 55  7   183 136 151
7   154 137 169 211 142 127 100 9   140
161 7   173 149 150 154 14  131 127 210
HI THIS IS AMSAT OSCAR 13 08SEP90
NEW AO13 SCHEDULE FROM 17OCT90 AFTER MOVE TO LON 180 LAT 0
MODE B  MA 000 TO 095
MODE JL MA 095 TO 125
MODE LS MA 125 TO 130
MODE S  MA 130 TO 135
MODE BS MA 135 TO MA 140
MODE B  MA 140 TO 256
```

Figure 1b UoSAT-2 ASCII Telemetry Data Transfer Frame

```
00519D01413702676503614004046605;4 6019E07045608040C08036C
10519C112983120003130561140 69A15529A!6188;17545218590519505 8
20519F21220322662223000124001725000726093E27541528564D294681
30519E31041732287C33568B340070352172842 6B39455E
40649F41117242647343061044162545000146000247444748454949422x
50456251108D52634653284p54663215000056p00357451258447A59460E
60826A615FC1625F4A633341644402651604661742677006 68000E69000F
UOSAT-2        9101281004625
```

Note : Errors due to noise.

Figure 1c FO-20 Telemetry Data Transfer Frame

```
05-Jun-91 09:43:35 8J1JBS*>BEACON:
JAS1b RA 91/06/05 09:39:58
493 481 688 691 854 839 850 833 002 746
615 000 418 453 457 448 451 454 651 000
683 681 745 713 999 643 874 385 1BE 000
010 111 011 000 111 100 001 100 111 000
```

The major improvement introduced by the microsats is twofold. All four satellites used the same downlink data format allowing a single table driven data acquisition, decode and display program to be used in the ground station. Their telemetry channel information is transmitted together with the data, and this format provides a great deal of flexibility. For the first time, the potential to change the order of data on the downlink came into existence. For example, the same channel or a particular group of channels could be sampled more often. The fact would be obvious to anyone watching the downlink. This technique if stretched just a little further could do away with the need for special format whole orbit data (WOD) dumps. The projected display of Figure 2b could conceptually be a part of a WOD dump of channel 00 if a secondary header was present in the packet. The concept of a secondary header will be addressed in a later section of this paper.

AO-16, WO-18 and LO-19, the micro-sats with downlinks in the 437 MHz band switched to an unpublished binary downlink format a month or so after UO-4 with little prior notice. More than a year after the event, AMSAT still have not published this binary downlink format.

AMSAT's Philosophy

In its earliest days, AMSAT had a policy of advancing the state-of-the-art while at the same time trying not to obsolete ground station equipment [6]. Each of the satellites provided a downlink using technology compatible to that existing in amateur radio stations at that time, and also introduced something new. Thus the Phase 3 satellites carried 50 baud BAUDOT RTTY even as late as 1988 to allow reception by amateurs equipped for RTTY.

The UoSAT downlinks were designed to be compatible with a terrestrial audio cassette data storage standard [7]. This use of a standard allowed radio amateurs having suitable devices to connect them to their radio receivers and display the data received from the spacecraft. The advent of low cost floppy disk drives provided random access off-line data storage and effectively killed the tape standard as a storage approach before it came into very widespread use. SARA-OSCAR 23's (O-23) downlink telemetry modulation complies with the same audio standard. A similar approach of using a USSR tape data storage standard was adopted for the digital PSK telemetry of AO-21 built in the Soviet Union and launched as an attached secondary payload to a USSR geological research satellite in 1992 [8].

FO-12 and FO-20 carried packet radio, but required the prospective user to obtain a PSK modem to be able to receive the digital signals. The user however was still able to use the basic AX.25 software in the terminal node controller (TNC). The AMSAT micro-

Figure 2 DO-17 Telemetry Data Transfer Frames

Figure 2a Received DO-17 Telemetry Data Transfer Frames

```
23-Jan-91 02:49:23 DOVE-1*>TIME-1:
PHT: uptime is 173/00:36:26. Time is Wed Jan 23 02:47:30 1991

23-Jan-91 02:49:26 DOVE-1*>TLM:
00:59 01:59 02:87 03:31 04:59 05:5A 06:6E 07:52 08:6D 09:72 0A:A2
0B:DC 0C:E9 0D:D8 0E:02 0F:26 10:CC 11:A8 12:01 13:04 14:AD 15:94
16:98 17:94 18:96 19:98 1A:94 1B:91 1C:9B 1D:98 1E:25 1F:5F 20:BA

23-Jan-91 02:49:27 DOVE-1*>TLM:
21:95 22:82 23:24 24:1E 25:2A 26:01 27:02 28:02 29:01 2A:02 2B:02
2C:01 2D:29 2E:02 2F:9E 30:CA 31:9E 32:11 33:CE 34:C4 35:9A 36:A8
37:A6 38:B6

23-Jan-91 02:49:28 DOVE-1*>STATUS:
 80 00 00 8F 00 18 CC 02 00 B0 00 00 0C 0E 3C 05 0B 00 04 04

23-Jan-91 02:49:28 DOVE-1*>LSTAT:
I P:0x3000 o:0 l:13081 f:13081, d:0

23-Jan-91 02:49:28 DOVE-1*>WASH:
wash addr:0680:0000, edac=0xd6
```

Figure 2b Modified DO-17 Frame showing position of proposed Secondary Header

```
23-Jan-91 02:49:26 DOVE-1*>TLM:
SECONDARYHEADER   00:59 00:58 00:57 00:56 00:55 00:54 00:53 00:52
00:51 00:50 00:50 00:51 00:52 00:53 00:54 00:55 00:55 00:56 00:57
00:58 00:59 00:60 00:59 00:58 00:57 00:56 00:55 00:54 00:53 00:52
00:51 00:50 00:51
```

sats also used 1200 baud PSK compatible to FO-12 and FO-20.

Telemetry Terminology

The spacecraft on-board computer (OBC) sequentially measures spacecraft housekeeping and payload voltages, currents and temperatures at various points in the spacecraft and arranges the data in a frame in a predefined format. The housekeeping information is used to maintain the health and safety of the spacecraft. This information pertains to the battery voltage, solar array currents and internal temperatures. The payload information may be the science data obtained from on-board experiments or communications transponder and other payload data.

The data are transmitted to earth through the weak signal, noisy space channel as a serial, synchronous symbol stream on the telemetry beacon downlink. Fixed length data frames are used to allow for simple, robust and reliable frame synchronization processes at the receiving ends. The frame boundaries are indicated using Synchronization Markers. These synchronization techniques have performed reliably in virtually hundreds of professional as well as all amateur space mission applications. The received telemetry data frames are then stored in ground station computers. Telemetry that is downlinked within seconds of being collected is known as real-time telemetry.

Historically, the lack of standards has resulted in the builders of each spacecraft having to develop a unique set of ground processing equipment to perform telemetry processing functions, though the functions themselves are basically identical. A major benefit of implementing standards is the development of ground data-handling facilities that can be rapidly reconfigured (using look-up tables) to meet the requirements of additional terrestrial and orbiting missions.

The Future

Table 1 contains a list of spacecraft announced at the AMSAT-UK Space Symposium in July 1991. This list does not include the proposed SEDS experiment [9] and the Lunar Solar Sail project [10] also scheduled for launch in the 1992-1993 timeframe. Some of these spacecraft, notably ARSENE, are finished and in the testing stage, others are still under development and time may still permit programming their OBCs to make their telemetry conform to a downlink telemetry standard.

Source Data Frames

When the OBC performs a set of measurements, it stores the results in source data frames. A source data frame may be a telemetry collection sequence, a set of WOD, a data file or a picture taken by an onboard camera.

Transfer Frames

The source data frame is transmitted to earth in transfer frames on the downlink. There does not have to be a 1:1 correspondence between the source data frame and the transfer frame. For example, if the 'Q' Blocks of PSK telemetry from AO-13 are thought of as being transfer frames containing source data frames with a 1:1 correspondence, the 'Z' blocks of RTTY telemetry are transfer frames containing a subset of the source data frame. Each UO-2 and FO-20 transfer frame contain a single source data frame. Large source data frames can be split up into a number of segments and downlinked in transfer frames. DO-17 uses several transfer frames to downlink segments of the source data frame. WO-18 downlinks

WOD and pictures in a number of transfer frames.

Acquisition Sessions

An individual ground station receives telemetry during an acquisition session. Once the data is captured by the ground station it is stored in the computer. An acquisition session begins when the first frame of data is captured and ends following the capturing of the last frame of data. These times correspond somewhat to acquisition of signals (AOS) and loss of signals (LOS).

Types of Telemetry

There are two types of telemetry, public and private. Public telemetry is available to anyone who has the equipment to either capture the data during an acquisition session, or read data files produced by other ground stations. Public telemetry consists of all the data that the spacecraft builders make the decoding information readily available. It is most of the housekeeping and much of the science data.

Private telemetry on the other hand consists of command acknowledgements, temporary telemetry data only downlinked during specific tests and any other information not available to the general public. Private telemetry is normally used by the command stations, spacecraft support personnel and other authorized people.

Whole Orbit Data (WOD)

Not all telemetry is downlinked in real-time. Low earth orbiting satellites are out of range of any single command station for most of the time. In order to obtain data collected over a whole orbit, the command station has to instruct the spacecraft to record data measurements as well as downlinking them on the telemetry beacon. The recorded data are then played back when the spacecraft passes in range of the command station. The National Aeronautics and Space Administration's (NASA) spacecraft record data measurements using magnetic tape recorders. When a tape playback is commanded, the machine is rewound and the data are read from the tape and downlinked at the same time. This playback data is thus both downlinked at a higher speed than the real-time data and is reversed. *The UOSATs pioneered an alternative approach in the OSCAR program by storing measured data (for a few selected channels) in the solid state memory in the OBC.* The stored data now named WOD, are later downlinked in forward order using a special WOD format.

Virtual Channels

Packetized telemetry shares the physical downlink channel with other types of packets. For example the FO-20 telemetry shares the channel with the Bulletin Board System (BBS) downlink. The AO-16 and LO-19 telemetry share the channel with files, messages and announcements. This

Table 1 Amateur Radio Spacecraft Currently Under Development

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

physical channel sharing concept can be expressed as providing each service with a virtual channel on the same physical channel. Ground station software distinguishes between the virtual channels by means of the packet headers. In the future, it is possible that several spacecraft may share the same downlink frequency for packet telemetry and the virtual channel concept will come into its own. Note that at present, UO-2 (ASCII), DO-17 (AX.25) and AO-21 (CW) share 145.825 Mhz.

Data Products

Telemetry data can be considered in three categories, Real-time, Quick Look and Archive. Real-time data are produced by a spacecraft and received by a ground station during an acquisition session. The purpose of real-time data is mainly to check the spacecraft; verify the health and welfare of the on-board equipment and monitor trends. Ground stations produce Quick Look and Archive data. Quick look data are ground station playbacks of the real-time data, used shortly after an acquisition session to reexamine something. Archive data are used days, weeks or even years later in some long term correlation or other kind of analysis. Today's radio amateurs do not normally exchange data after an acquisition session, so there is no perceived difference between Quick Look and Archive data.

Typical Receiving Systems

A systems view of a typical ground station is shown in Figure 3. From this perspective, there are effectively two types of signal being received simultaneously. The wanted transfer frames and the unwanted noise. The noise may be internal system noise in the receiver's front end or external noise which is either man made or natural. The transfer frames are not the only "signal" inputs to the system. The system also needs to know when the acquisition sessions will take place and needs the telemetry decoding information for each spacecraft.

The effects of noise on the captured data can be readily seen on ASCII and BAUDOT data where they show up visually on the screen as "bad data". However on packet radio downlinks the effects are not normally noticed because the TNC filters out bad received packets. For example, consider DO-17 which generates a number of different types of packets as shown in figure 2. In the absence of noise, since the spacecraft generates twice as many TLM packets as WASH packets, the ratio of received TLM to WASH packets is 2.0. In the real world, when noise interferes with the downlink, the ratio is somewhat less. Figure 4 contains summaries of packet counts from DO-17 data captured by a number of different ground stations. The program used to generate the packet header counts [11] has no provision for separately summing the different TLM segments, but visual observations while the analysis was running showed that more second segment transfer packets were copied than first segment ones. The second segment transfer packet has a byte count of 148; the first of 204. As there is no other information about the types of antenna used at the ground stations and their local noise environment, all that can be said is that the data shows that the longer the packet, the fewer the number received. This axiom should not be forgotten when designing telemetry links and tends to show that a packed binary telemetry packet is more desirable from a link performance point of view.

Figure 3 Systems View of a Typical Ground Station.

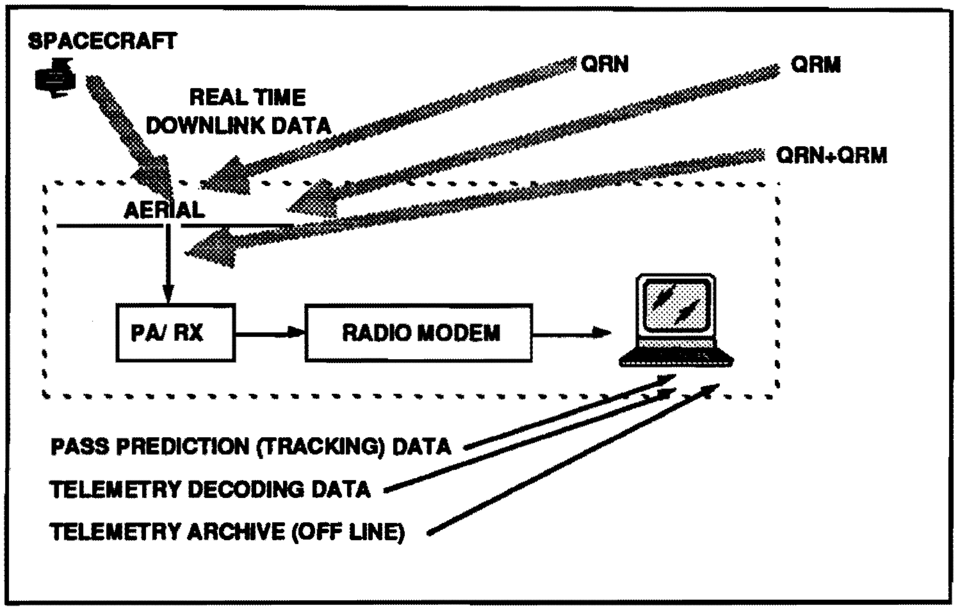

Figure 4 DO-17 Received Transfer Frame Summaries.

CALL	WASH	STATUS	TIME	TLM	TLM / WASH
(Bytes)	30	60	63	148/ 204	
G3ULS	1085	956	1028	1767	1.63
GM4IHJ	883	759	817	1343	1.52
KB3FN	273	220	228	363	1.33
NC5Y	168	133	134	259	1.54
VE3BRO	939	711	798	993	1.06
W3/G3ZCZ	2409	2075	2128	3072	1.27
WD0GML	3870	3540	3715	6499	1.68
ZL1ACO	2480	2110	2246	3350	1.35
ZS6BMN	370	340	377	669	1.81

The thrill of receiving a signal from space soon fades however if the data cannot be understood. The user in general is interested in seeing an engineering unit display in real time, not binary garbage or ASCII format hexadecimal numbers. A typical real-time display of decoded DO-17 telemetry is shown in Figure 5. However, after a few days, watching the temperatures on-board a spacecraft change as it passes overhead is also of little interest. What can be made interesting however, viewing data acquired over many days or even months and looking for trends and relationships.

Link Intelligence

In designing telemetry links the goal is to get the data from the spacecraft down to the ground station in a usable format. From a system's point of view the spacecraft and ground station can be viewed as a distributed micro-computer system as shown in Figure 6. Given a computer at each end of a telemetry link, there is a tradeoff as to what is processed in which micro-computer. Data appearing on a CRT at a ground station can be downlinked from a spacecraft as ASCII or as binary if intercepted, filtered and reformatted in the ground station software before appearing on the screen. There is computing power on the spacecraft (the OBC). There is computing power in the TNC, in the PC and in many instances in the radio receiver. *Just because computing power or memory capacity exists at more than one point in the system does not mean that it has to be used.* Given the mixture of computing power, the telemetry link can be optimized to make best use of the distributed characteristics.

The software which makes the measurements has to be in the OBC. The software which converts the measured data to engineering units can be either in the OBC or in the ground station. The software that displays the data at the ground station has to be in the ground station PC. Until now, the UoSATs and microsats have split the decode function between the spacecraft and the ground station. This is as it should be because the casual radio amateur who tunes in on a spacecraft downlink ought to be able to see something usable.

A typical ASCII received display from UO-2 is shown in Figure 7. Note the effects of link errors. Using a packet format will not eliminate the link errors. The bad packets will just not be displayed, the data they contain will be lost. *The AX.25 technique does not guarantee that all the transmitted data will be received without errors. It just guarantees that all the received data coming out of the TNC will be error free.*

If a telemetry beacon uses a virtual channel on a physical channel shared with the communications payload (the primary mission), as in AO-16, LO-19 and FO-20, then intuitively, the spacecraft should maximize the amount of time that it is downlinking

Figure 5 Sample Decoded Page of DOVE Telemetry

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

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

Figure 6 Link Intelligence.

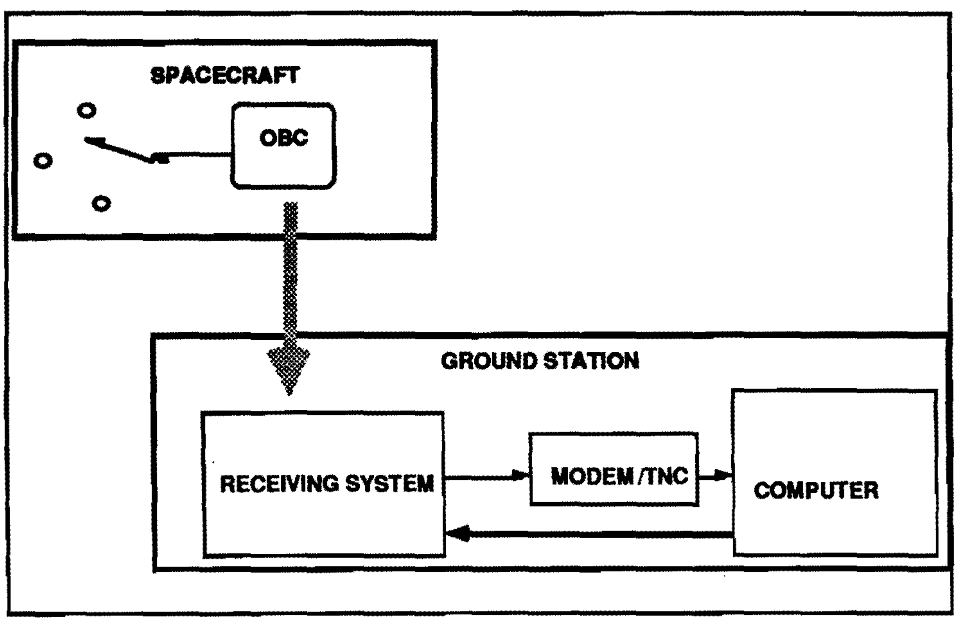

Figure 7 Typical UoSAT 2 Received ASCII Data Display

```
* UOSAT-2 OBC STATUS INFORMATION *

DIARY OPERATING SYSTEM V3.1 SMH MLJM MSH

 Today's date is 14 /5 /91 (Tuesday)
 Time is 1 :26 :50 UTC
 Auto Mode is selecteH
 Spin Period is - 225
 Z Mag firings = 0A
 + SPIN firings = 72
 - SPIN firings = 28
 SEU count  = 1230
 RAM WASH pointer at BCA0
 WOD commE\ced 14 /5 /91 at 0 :0 :9
 with channels 50 ,51 ,52 ,57 ,
 Last cmnd was 109 to 0 , 0
 Attitude control initiated, mode 1
 Data collection in progress
```

communications and minimize the amount of time spent transmitting telemetry. This factor also tends to suggest the use of binary telemetry since more data can be transmitted in a fixed time.

Goals of the Telemetry System

The telemetry system is more than just the spacecraft. It contains the spacecraft, the communications link and the ground station. The goals of the telemetry system are twofold. The first is to provide the information for ensuring the health and welfare of the spacecraft. The second is to provide information that can be used by anyone in an educational manner. To incorporate these spacecraft into educational curricula, information about their capabilities and telemetry must be available well before launch.

The system needs to provide the public with data in a manner in which they can use it, while at the same time, provide the software development people with a means to have temporary, permanent or special data elements. This should also be done with minimum changes to software on the ground and in orbit, and minimal needs for documentation.

Microprocessor and amateur radio capabilities are continually getting better. While a fully automated telemetry capturing system might be expensive today, it will get cheaper as time goes by. Software to be developed in the next few years should look ahead to what can be expected to exist and provide for those capabilities. They may not be implemented initially in every ground station but the capability to upgrade performance and functionality in an incremental manner should be provided.

Today's telemetry decoding and display software are written as a labor of love by interested enthusiasts who want to know what's up in the satellite or as an educational exercise. The easier it is for them to write good software, the more people will be attracted to the spacecraft. The development process should make the work of the ground station software developer as easy as possible.

To meet these goals, a number of requirements have been developed as discussed in the following paragraphs. The requirements have been categorized as discussed below and are summarized in Appendix 1.

Requirements for Spacecraft Builders

Spacecraft builders have to provide users with the capability to capture data automatically, store the data and perform analysis on that data using computerized tools. The user community needs time to prepare for the spacecraft. People should be able to build and test ground station hardware and software a long time before the actual flight takes place. *If people are "ready to go" at launch, there is a greater incentive to monitor the spacecraft and a larger population of potential sources for data during the critical early hours of the flight.*

The groups that build the spacecraft are small. They should be able to use already developed and proven processes as much as possible. They should be able to offload the task of developing and providing ground station software (at least for public use).

Telemetry should be encoded to allow ground station software to use a Table Driven Approach. This is a very powerful technique which allows the users to change the coefficients of an equation, or customize displays without having to change the software itself. For example customization files can be created containing one line for each telemetry channel. A typical line could contain 17 items in the format described below.

TLM_Channel, TLM_Segment_ID, TLM_Description, TLM_Eqn_Type, TLM_C, TLM_B, TLM_A, TLM_Units, TLM_Page, TLM_Row, TLM_Col, TLM_Width, TLM_Dec, TLM_Limit_Check, TLM_Limit_Low, TLM_Limit_High, TLM_Negative_Blank.

Consider each of them in turn.

TLM_Channel:- This is the channel number of the telemetry data in the frame.
TLM_Segment_ID:- This is the segment identifier.
TLM_Description:- This item is the text string or description of the telemetry channel that will be displayed on the screen page. (e.g. '+Z Array Grad.')

TLM_Eqn_Type:- This item tells the program the type of equation to use to decode the telemetry. Typical examples are shown below.

Published Format	Spacecraft	"Type"
Y = A*N^2 + B*N + C	AO-16	1
Y = B*(A+N) + C	AO-13	2
Y = B*(A-N) + C	FO-20	3
Y = B*(N+A)^2 + C	AO-13	4
Y = B*(A-N)^2 + C	AO-13	5

Where A, B and C are coefficients and may be 0.

The Type values have been assigned arbitrarily. Note the Type 2 equation "B*(A+N)+C" can be expanded to "(B*A)+(B*N)+C" which, since A, B and C are constants, can also be written as "0*N^2+B*N+E" where "E = (B*N)+C", which is the same form as the Type 1 equation. Since the computer is doing the computations, people can use the format that looks simpler.

TLM_C:- This item is the equation Coefficient C.
TLM_B:- This item is the equation Coefficient B.
TLM_A:- This item is the equation Coefficient A.
TLM_Units:- This item is the Units text string (e.g. '.C') in the screen display.
TLM_Page:- This item identifies the display page.
TLM_Row:- This item identifies which row in the screen the data element will be displayed.
TLM_Col:- This item identifies which column in the screen the first character of the data will be displayed.
TLM_Width:- This item identifies how many characters wide the display is to be. For example, voltage can be displayed as '1.3' or '1.28567'.
TLM_Dec:- This item defines the number of digits after the decimal point in the display.
TLM_Limit_Check:- This item identifies the kind of limit checking to perform on the telemetry channel data.
TLM_Limit_Low:- This item is the Low limit value (e.g. -4.00).
TLM_Limit_High:- This item is the High limit value (e.g. +10.6).
TLM_Negative_Blank:- This item indicates that computed negative results are to be displayed as a zero. It is used for example, in Solar Cell voltage computations, when negative values are produced because the equation used to convert the data is not valid at low or zero values of light.

ASCII messages should also be seen on the downlink. These messages tend to attract new people who happen to tune into the downlink, provide bulletins on schedules and other events of interest.

There needs to be some parameter in the system to enable the groundstation to detect (and correct) errors induced into the transfer frames due to the effects of noise (QRM and QRN). While noise can readily be seen in ASCII telemetry, it is difficult to detect in binary telemetry. Today's optimal approach to meeting the need to detect errors is to use packet radio AX.25

techniques as the downlink transfer protocol. Error correction schemes are not currently in use.

Requirements For Ground Stations

Ground stations should be optimized for real-time data capture. This requirement is intuitive. The better the antenna and the lower the receiver front end noise, the greater the amount of telemetry that will be captured.

Data captured should be saved for later processing and analysis in a format that can be exchanged between different computers, even if someone doesn't want to do anything with it at the time it is captured. *There is no requirement for the people who analyze the data to be the same people as those who acquired it directly from the satellite.*

Requirements for Ground Station Software

Users should be able to use the same computer capture, decode and display program with each satellite. The remaining requirements developed for ground station software fall into two categories, acquisition and archiving.

Software should provide real-time customizable engineering unit displays for use during acquisition sessions. It is much more interesting to see voltages, temperatures and colors change, than to look a stream of ASCII numbers or binary gibberish. The user should also be able to customize the display to either change the location of a parameter display on the screen, or set up different screens for different sets of channels. Raw telemetry display capability should also be provided to allow the user to validate the decoding configurations by performing calculations by hand to validate the displayed numbers. Audio and visual alarms should be provided for conditions when telemetry channels contain values that exceed, fall below or fall outside preset limit value(s).

Users should be able to configure the software for their particular systems. The user should be able to view the raw data to see non telemetry information such as messages.

The user should have the capability to extract telemetry data to a spreadsheet for further analysis. Each user will want to see different data displays and/or relationships. With this capability, the software developer does not have to anticipate them all.

Requirements for Tracking Capabilities

Users should be able to see when acquisition sessions can be expected. The system should configure the receiver and TNC to the spacecraft beacon frequency and modulation at AOS. The software should provide antenna control capability and compensate for Doppler frequency changes. This requirement is for automated data capture.

Telemetry Standards

Designing amateur satellites requires in-depth knowledge of several fields. In the past spacecraft developers knowledgeable in one or more areas of activity, when needing something from another area have had to develop items from first principles. When these things are viewed by professionals in those fields, the 'sloppiness' is readily apparent. **The word "amateur" is not a synonym for "sloppiness"**. Defining and using standards makes life simpler for everyone and eliminates the need to continuously reinvent the same application due to different non-compatible implementations.

Two standards are herein proposed, one for transfer frames, the second for data archive and interchange. Many of the ideas herein are adapted from the Consultative Committee for Space Data Systems (CCSDS) recommendations for standards [12][13][14][15][16].

Since future radio amateur telemetry links can be expected to use packet radio as the downlink, at least for the next few years, and binary is suitable for computer compatible data, a binary standard is recommended for the downlink telemetry transfer frames. An ASCII format is recommended for the data archive and exchange standard to allow users with minimal knowledge of data access techniques to roll their own software to get at the archived data.

Binary Format Transfer Frame Standard

The proposed standard for Radio Amateur BINARY transfer frames is attached as Appendix 2. The basic assumption is that the transfer frame is encapsulated in an AX.25 packet. The AX.25 link process guarantees that delivered data will be error free. It does not guarantee delivery of every packet. The AX.25 packet contains a header which identifies the source and destination (broadcast address) of the packet. The transfer frame standard inserts a secondary header into the data area prior to the actual data itself. This secondary header provides information about the data that may be used by ground station software both during an acquisition session and for archive data processing.

The term 'octet' represents 8 bits. The rationale for the contents of the secondary header is given in the following paragraphs.

The secondary header should contain the number of bytes ground station software should look for. There is no need for people writing simple telemetry decoding software to have to use the TNC in its KISS mode and have to reinvent AX.25 handlers. The AX.25 firmware in the TNC is debugged and stable. If the first two octets in the secondary header are the number of octets in the data part of the AX.25 packet, life gets simple.

The secondary header should contain the number of channels ground station software should decode and display. Ground station software for public use would not display the private telemetry octets, yet could archive them so they would be available for later analysis. If the ground station software only displays the public octets, and is told to ignore anything after that, most people will never see the engineering octets. Most of those who look at the raw data using a dumb program will probably never count the octets, and those who do, well, we cover that by stating that they are engineering octets, subject to unannounced changes so will not be documented.

The secondary header should contain a packet sequence count that increments for each downlinked telemetry packet. As most ground stations miss a few packets during acquisition sessions, these octets allow data from several ground stations to be merged. For example, AMSAT-NA requested telemetry captured during the 1991 solar eclipse to be sent in for processing. A packet sequence count in the telemetry would have made merging the data produced by different ground stations a relatively simple task. This information also serves as an "up-time" indicator. Rollover of the sequence count should not be a problem due to both the low data rates and the inclusion of the sample time in the secondary header.

The secondary header should contain the time the data sample was made. The format should be UTC time to simplify ground station software as in YYMMDDHHMMSS (not everybody is writing in C).

The secondary header should contain one octet containing the version of the flight software in the OBC. It is updated as needed, but in any event any time a public change is made.

When data are transmitted in more than one octet, the data should be transmitted least significant octet first to comply with the rationale used in defining the Pacsat Protocols [17].

There are several options for the telemetry data formats, a straight run and a tagged run. In the Straight Run, each channel is transmitted in a predefined sequence of data (D) value octets, i.e. D1D2D3. The advantage is fewer octets, the disadvantage is the fixed format, so the OBC software revision must be updated each time a change is made, not forgetting the public announcements (ahead of time).

In the Tagged run, each channel is transmitted as two octets; channel number (C), and then data values (D), i.e. C1D1C2D2C3D3 etc. This is somewhat like the DO-17 ASCII format. The disadvantage is more octets. The big advantage is the flexible format so that the order can be changed without affecting (properly written) ground station software, updating the OBC software revision number, or needing advance public warning. This format allows the OBC to change the downlink packet contents without the world complaining.

The public telemetry data is the mixture of analog and status data, the order should be as published in the radio amateur press. When allocating status data channels, some thought should be given to facilitating manual reading of the data. Status telemetry does not need to use all 8 bits of an octet for different items. For example, if digipeater status was allocated one octet at the start of the data part of the frame with the hex code of 01H for "ON" and 20H for "OFF", anyone looking at the raw binary as displayed on a PC would see a smiling face character when the digipeater was on, and a blank space character when it was off.

The Private Telemetry Data octets contain whatever data are needed for spacecraft command and control. If these octets use the same format as the public octets, command stations don't need special software to set up special screen displays of this 'private' data.

The Standard Formatted Data Unit (SFDU)

The purpose of the Standard Formatted Data Unit (SFDU) is to provide data in a format that can be readily exchanged between users of different types of computers. Data compression is not incorporated, because many different techniques exist for different machines and each file can be separately compressed for storage. The proposed SFDU is not the most efficient for any specific machine, but does allow for data exchange between different home computers. It also allows people with all levels of programming skills to access the data using simple text file read/write software. The proposed SFDU Standard is attached as Appendix 3.

The SFDU header should identify the Spacecraft and the Ground Station that acquired the data. It should identify the times associated with the first data frame in the unit and the last data frame in the unit to simplify automated searches of multiple SFDUs for data between specific times. Requiring this item in the header does mean that generating the SFDU may not be a one pass process.

The SFDU header should contain identification about the data format. Since the existing spacecraft use different modulation schemes and data formats. The time should also be identified as either spacecraft or ground station generated. UO-2, AO-13 and FO-20 each downlink time in the transfer frame. DO-17 downlinks time in one segment of the transfer frames. Since each ground station may not capture all transfer frames, there will be some acquired data that will consist of incomplete source frames and may not contain accurate spacecraft times.

The SFDU header should identify the number of channels of data to assist processing software to quickly scan the stored data. The SFDU header should contain information representing the OBC Software Release value for all the source data frames stored in the unit. This parameter will provide the capability to allow the spacecraft programmers to change channel assignments or inhibit channels from the downlink. For example the assignments of some of the status channels of DO-17 have been changed since its launch.

Converting Captured Telemetry to SFDUs

This section describes how telemetry captured from current spacecraft may be converted into SFDUs. This section also provides examples of the format of the SFDU for use in writing software to produce or recover the data.

UO-2 downlinks decimal and hexadecimal data. It also transmits spacecraft time as the last line in the transfer frame. There are no packet sequence counters, so the four characters following the time are blank. The UO-2 SFDU can be a Type D. The day of week digit in the time is discarded. The data are stored using spacecraft time and there are 70 (00-69) channels of data in the frame. A typical header and part of the first line for the frame shown in Figure 1b is shown in Figure 10a. Note the spaces due to missing/bad data in the captured transfer frame.

AO-13 downlinks blocks of telemetry containing decimal and hexadecimal data. It also transmits spacecraft time in the block (transfer frame). There are no packet sequence counters, so the four characters following the time are blank. The AO-13 SFDU can be a Type D. The channel count will differentiate between the Q and Z blocks. When Z blocks are being stored, channels 0 through 59 shall be stored first, then channels 64 to 70. The frame length shall be 67 for Z RTTY blocks and 128 for the PSK Y blocks and 256 for PSK Q blocks.

AO-16, DO-17, WO-18, and LO-19 downlink hexadecimal data. The DO-17 transfer frames contain ASCII octets, those of the others binary. There are no packet sequence counters, so the four characters following the time are blank. The data from these spacecraft can be either Types D or H SFDUs. Time tagging the data presents a problem because each transfer frame does not contain time information and many ground stations do not enable the TNC time in the packet header. The software producing the SFDU may match the packet header time (generated by the TNC) the information contained in the TIME-1 packets to derive the spacecraft time (S), or just use the packet header time (G). A typical header and part of the first line corresponding to the DO-17 transfer frames shown in Figure 2a is shown in Figure 10b. Note that all microsat frames other than the TLM frames are discarded in this example.

FO-20 downlinks transfer frames of telemetry containing decimal and hexadecimal data and spacecraft time

Figure 10 Examples of SFDU Headers For Different Existing Spacecraft

Figure 10a UO-11

```
UO-11W3/G3ZCZ  910128043000910128045959DS070
910128043000   519413676614046  019045040  51929800056069529...
```

Figure 10b DO-17

```
DO-17W3/G3ZCZ  910123000000910123235959HGnnn
910123024730    59598731595A6E526D72A2DCE9D80226CCA80104AD...
```

Figure 10c FO-20

```
FO-20W3/G3ZCZ  910605000000910605235959DS040
910605093958    4934816886918548398508330027466150004l845..
```

in transfer frame. There are no packet sequence counters, so the four characters following the time are blank. The FO-20 SFDU can be a Type D. A typical header and part of the first line for the FO-20 transfer frame shown in Figure 1c is shown in figure 10c.

File Naming Conventions

There is not much point in having standards for the contents of files without giving some consideration to naming the files. There are two types of files to consider, the one containing the data captured during the acquisition session, and the SFDU. The standard adopted in WHATS-UP [11] for the PC is to name the capture-to-disk files with the date of capture (YYMMDD) and give them a file type corresponding to the spacecraft designator. There is little point in adding minutes and seconds, since most stations do not have clocks that are that accurate. As an example, data captured on 12 September 1991 for different spacecraft are stored in files named as shown below.

AO-10	910912.O10
UO-2	910912.U11
AO-13	910912.O13
AO-16	910912.O16
DO-17	910912.D17
WO-18	910912.W18
LO-19	910912.L19
FO-20	910912.F20
AO-21	910912.A21
SARA	910912.O23
MIR	910912.MIR

The suggestion for the SFDU naming convention is to use a name containing the spacecraft designator describing the spacecraft and the day of year of the first frame of data. The filetype should be SFD for standard format data. As an example, the name for an SFDU containing DO-17 data from January 1, 1991 would be D1791001.SFD.

Summary

This paper has covered a lot of ground in providing an introduction to telemetry. After discussing the telemetry from satellites in orbit, it discussed telemetry concepts and terminology. The telemetry process was described from a Systems point of view looking at the requirements for developers and users. Lastly the rationale for standards was covered. Draft proposed standards are appended to this paper. If we can agree on standards, then telemetry will prosper.

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

Glossary

AMSAT	The Radio Amateur Satellite Corporation
AO	AMSAT-OSCAR
AOS	Acquisition of Signals
ARRL	American Radio Relay League
BBS	Bulletin Board System
CCSDS	Consultative Committee for Space Data Systems
crt	cathode ray tube
CW	continuous wave (morse code)
DO	DOVE-OSCAR
DOVE	Digital Orbiting Voice Encoder
FM	Frequency Modulation
FO	Fuji-OSCAR
FSK	Frequency Shift Keying
HTU	hundreds-tens-units
LO	LUSAT-OSCAR
LOS	Loss of Signals
OSCAR	Orbiting Satellite Carrying Amateur Radio
PC	Personal Computer
PSK	Phase Shift Keying
RTTY	Radio Teletypewriter
SFDU	Standard Formatted Data Unit
THTU	thousands-hundreds-tens-units
TLM	telemetry
TNC	Terminal Node Controller
UO	UoSAT-OSCAR
WO	WEBER-OSCAR
WOD	Whole Orbit Data
YYMMDDHHMMSS	Year-month-day hour-minute-second (2 digits for each)

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Appendix 1. Requirements for Spacecraft Telemetry systems

A.1 Requirements for Spacecraft Builders

The following requirements have been developed for spacecraft builders.

A.1.1.1 Provide computer compatible telemetry conforming to the standard for transfer frames.

A.1.1.2 Provide/publish preliminary telemetry decoding information at least 6 months before launch.

A.1.1.3 Provide tape cassettes of sample data from spacecraft ground testing to national AMSAT organizations for distribution to potential users at least 6 months before launch.

A.1.1.4 Update the preliminary telemetry decoding information as soon as possible after launch (or even before).

A.1.1.5 Provide telemetry for use in real-time.

A.1.1.6 Formulate the telemetry to use generic decoding equations.

A.1.1.7 Provide short ASCII messages as well as computer compatible telemetry.

A.1.1.8 Provide a mechanism for allowing ground stations to detect errors in the received telemetry data induced by the radio transmission link.

A.1.2 Requirements For Ground Stations

The following requirements have been developed for spacecraft ground stations.

A.1.2.1 Optimize the receiving system for real-time data capture.

A.1.2.2 Provide capability for processing archive data.

A.1.2.3 Provide capability to read data archived by other ground stations.

A.1.3 Requirements for Ground Station Software

The requirements developed for ground station software fall into two categories, acquisition and archiving.

A.1.3.1 Provide ONE generic user friendly program for all spacecraft.

A.1.3.2 Provide the capability to decode and display the raw telemetry while it is being captured.

A.1.3.3 Perform automatic capture-to-disk of raw telemetry.

A.1.3.4 Provide link quality measurement capability.

A.1.3.5 Provide several user configurable display screens.

A.1.3.6 Provide for wild card screens (channel shows up on all screens).

A.1.3.7 Provide selectable display of Engineering units or Raw Telemetry data for each display screen.

A.1.3.8 Provide the capability to display raw (unprocessed) data.

A.1.3.9 Provide color change capabilities if a parameter value changed between successive frames.

A.1.3.10 Provide audio and visual alarms if telemetry values exceed, fall below or fall outside preset limit value(s).

A.1.3.11 Provide customizable colors, PC to TNC baud rate, data parity and stop bits.

A.1.3.12 Provide the capability to extract telemetry data to a spreadsheet for further analysis.

A.1.3.13 Provide default configuration files for different spacecraft.

A.1.4 Requirements for Tracking Capabilities

A.1.4.1 Display spacecraft orbital elements and tracking data.

A.1.4.2 Set receiver to spacecraft beacon frequency and modulation at acquisition of signal (AOS).

A.1.4.3 Set the TNC/TU to the correct modulation mode at AOS.

A.1.4.4 Provide audio warning of spacecraft AOS and loss of signal (LOS).

A.1.4.5 Provide antenna control capability.

A.1.4.6 Provide capability to compensate for Doppler frequency changes.

Appendix 2 Transfer Frame Standard

A.2 Introduction

The transfer frame standard describes the downlink standard for BINARY telemetry. The basic assumption is that the transfer frame is encapsulated in an AX.25 packet. The AX.25 packet contains a header which identifies the source and destination (broadcast address) of the packet. The transfer frame standard inserts a secondary header into the data area prior to the data itself as shown in Figure A1. This secondary header provides information about the data that may be used by ground station software both during an acquisition session and for archive data production.

Figure A1 The Transfer Frame

Secondary Header	Data

A.2.1 The Secondary Header.

The contents of the secondary header shall be as listed below in the order listed below.

Octets	Item	Octets
0,1	Total Octet Count	2
2,3	Public Octet Count	2
4,5	Packet Sequence Count	2
6-12	Time of Sample	6
13	Segment Identifier	1
14	Type of Frame	1
15	OBC Software Release	1

A.2.1 Total Octet Count

The secondary header shall contain two binary octets containing the total number of octets in the data section of the transfer frame (public and private).

A.2.2 Public Octet Count

The secondary header shall contain two binary octets containing the number of public data octets in the data section of the transfer frame.

A.2.3 Packet Sequence Count

The secondary header shall contain a packet sequence count in the form of a 16 bit binary number that increments monotonically for each downlinked transfer frame.

A.2.4 Time of Sample

The secondary header shall contain six octets in which the OBC shall tag the data. The format is YYMMDDHHMMSS (UTC). The octets shall each contain two BCD digits. The first octet shall contain the YY information, the last octet the SS information.

A.2.5 Segment Identifier

The secondary header shall contain one binary octet containing the segment identifier. If the transfer frame contains the whole source frame, the segment identifier shall be 0.

A.2.6 Type of Frame

The secondary header shall contain one binary octet identifying the format of the data in the transfer frame. Two options for the telemetry data format are specified herein.

A.2.6.1 Straight run:- Telemetry data shall be transmitted in a predefined sequence of data (D) value octets, i.e., D1D2D3.

A.2.6.2 Tagged run:- Telemetry data shall be transmitted as two octets; channel number (C), and then data (D) value, i.e., C1D1C2D2C3D3 etc.

A straight run shall be identified as a type 0, a tagged run as a type 1.

A.2.7 OBC Software Release

The secondary header shall contain one binary octet containing the version of the flight software in the OBC. This octet shall be updated as needed, but in any event any time a change noticeable by the public is made.

A.2.8 The Data

The data section of the transfer frame shall contain the public telemetry octets followed by the private telemetry octets. Data shall be digital status bits or algebraic analog data according to the formats specified below.

Type	Description
1	One octet (8 bit value) Y = A*N^2 + B*N + C
2	One octet (8 bit value) Y = B*(A+N) + C
3	One octet (8 bit value) Y = B*(A-N) + C
4	One octet (8 bit value) Y = B*(A+N)^2 + C
5	One octet (8 bit value) Y = B*(A-N)^2 + C
11	Two octets (16 bit value) Y = A*N^2 + B*N + C
12	Two octets (16 bit value) Y = B*(A+N) + C
13	Two octets (16 bit value) Y = B*(A-N) + C
14	Two octets (16 bit value) Y = B*(A+N)^2 + C
15	Two octets (16 bit value) Y = B*(A-N)^2 + C
30	Octet contains 8 bit Channel Number (used in tagged formats).
31	one octet of 8 individual status bits.
32	Octet contains two 4 bit data elements.

Where:

A, B and C are coefficients and may be set to 0.
Y is the arithmetic result.
N is the decimal value of the telemetry data.

A.2.8.1 Data requiring more than one octet shall be inserted in the transfer frame least significant octet first.

Appendix 3 The Draft Standard Formatted Data Unit Standard

A.3 Introduction

The purpose of the SFDU storage unit is to facilitate the exchange of data between users of different types of computers. Data compression is not specified, because many different techniques exist for different machines and each file can be separately compressed for storage.

A.3.1 Basic SFDU Requirements

A.3.1.1 Each SFDU shall only contain data from one spacecraft.

A.3.1.2 If a spacecraft source data frame contains an OBC Software Release parameter, SFDUs shall not contain data from more than one release of the OBC Software.

A.3.1.3 The SFDU shall be an ASCII file format comprising a storage header followed by lines of data.

A.3.1.4 Each SFDU shall only contain one header. This header shall provide information about the data and the ground station that captured the data.

A.3.1.5 The SFDU header shall be a standalone line.

A.3.2 The SFDU Header

The contents of the SFDU header shall be as listed below in the order listed below.

Octets	Item	Octets
0-4	Spacecraft ID	5
5-15	Ground Station ID	10
16-27	Start Time of Data	6
28-40	End Time of Data	6
41	Data Format ID	1
42	Time ID	1
43-45	Frame length	3
46	OBC Software Release	1

A.3.2.1 Spacecraft ID.

The SFDU header shall contain five octets to identify the spacecraft in ASCII. The format shall be a two letter identifier, a hyphen and a two number identifier (AA-NN), as illustrated by the following examples UO-02, AO-13, AO-16, DO-17, and FO-20. When OSCAR 100 is launched, the hyphen shall be replaced by the digit '1'.

A.3.2.2 Ground Station ID.

The SFDU header shall contain ten ASCII octets which shall contain the callsign or other identification of the ground station that captured the data. The first octet shall contain the first character of the ground station ID. Blank characters shall be used following the callsign to build the string up to 10 characters.

A.3.2.3 Start Time of Data

The SFDU header shall contain twelve octets which shall contain the ASCII string of the time associated with the first data frame in the unit. The format is UTC time as in YYMMDDHHMMSS. The first octet shall contain the higher digit of the YY information, the last octet the lower half of the SS information.

A.3.2.4 End Time of Data

The SFDU unit header shall contain twelve octets which shall contain the ASCII string of the time associated with the last data frame in the unit. The format is UTC time as in YYMMDDHHMMSS. The first octet shall contain the higher digit of the YY information, the last octet the lower half of the SS information.

A.3.2.5 Data Format ID.

The SFDU header shall contain a one digit ASCII identification about the data format. Since the existing spacecraft use different modulation schemes and data formats, several storage unit data formats are specified, each optimized for specific spacecraft. Two data formats are currently specified.

A.3.2.5.1 Type "D" Storage Format :- ASCII Decimal/Octal Format

The data elements are stored as three digits (hundreds-tens-units [HTU]) in a sequential line. There are no spaces between data elements. Channel numbers are not included. If the transfer frame was not AX.25 packet, or a segment was lost, erroneous or missing, that data shall be replaced by space characters.

A.3.2.5.2 Type "H" Storage Format :- ASCII Hexadecimal Format

The data are stored in a sequential line as two hexadecimal digits. There are no spaces between data elements. Channel numbers are not incorporated. If a segment was lost, erroneous or missing, that data shall be replaced by space characters.

As a goal, if the all data elements in a frame never contain a value greater than 255, the Type H format should be used to minimize the length of the SFDU.

A.3.2.6 Time ID.

The SFDU header shall contain one octet which shall identify the times as spacecraft or ground station generated. The octet shall contain a single ASCII character. An "S" shall define spacecraft time, a "G" shall define ground station time.

A.3.2.7 Frame Length

The SFDU header shall contain three octets which shall contain a three digit ASCII text string (HTU) representing the count of the number of channels of data (not the number of octets) in a single frame of data.

A.3.2.8 OBC Software Release

The SFDU header shall contain two octets which shall contain a two digit ASCII text string representing the OBC Software Release value for all the source data frames stored in the unit. This item shall only be present on the header if the spacecraft telemetry contains the parameter.

A.3.3 The Data Lines

A.3.3.1 Each frame of data shall make up one line of data in the storage unit.

A.3.3.2 Data frames shall be stored in ascending time order.

A.3.3.3 A carriage return/line feed combination shall separate the header and each of the frames.

A.3.3.4 The first 12 characters of the data frame shall be the time identification associated with the frame in YYMMDDHHMMSS format.

A.3.3.5 The next four digits shall be the packet sequence count as a hexadecimal ASCII text string (thousands-hundreds-tens-units [THTU]). If the spacecraft telemetry does not contain a packet sequence count, these four digits shall be filled by space characters.

A.3.3.6 The remainder of the frame shall be the data stored according to the specification for the type parameter.

ORBIT SELECTION CONSIDERATIONS FOR FOURTH GENERATION AMSAT SPACECRAFT

Jan A. King, W3GEY and Stephan Eckart, DL2MDL

All of us are now familiar with the intended characteristics of the Phase-3 orbit. Those who live in the northern hemisphere are currently being treated to the protracted periods of time the spacecraft seems to hang in the sky at high elevation angles and the amazing amount of the world that is in view during these times. Finally, to the relief of the designers of the system, users are required to point their antennas to the north. This is clearly a dream come true. As we are now painfully aware, however, AMSAT-OSCAR 13 will come to an end in 1996 almost as certainly and as suddenly as it was launched in June of 1988.

This paper discusses the efforts of the Phase-3D study team to identify improvements in orbits for international, high earth orbiting amateur spacecraft and methods of assuring that they do not meet the fate now sealed for our current operational satellite.

INTRODUCTION

Clearly, all users of the current Phase-3 satellites would agree they are a great improvement in availability time per day and DX capability when compared to low earth orbiting satellites. AO-13 is now nearing its optimum communications position and is truly behaving like the Molniya orbiting spacecraft we had intended back in 1975 when the design of Phase-3 began. Nonetheless, the orbit selected does have some shortcomings and improvements are in order.

Certainly, the largest complaint of all users of Phase-3 has been the signal levels received from the spacecraft. Let's face it, with average single Yagi up/down user systems, signals are just plain weak! Please remember, however, that its a long way to apogee and 35 watts only goes so far when you divide it among 40 to 50 users in the passband. It is our intention to fix this problem in the follow-on system in a BIG way but, that's not the subject of this particular paper. When it comes to orbits, the largest complaint that has been heard relates to the drift in time-of-day that the apogee occurs. The apogee drifts in time such that during certain periods the best performance of the spacecraft from a given location occurs during the middle of the night. Arguably, this "bad time of day" continuously changes for all users in the world so that it is approximately equally distributed for everyone concerned, when averaged over time. While most of us in the northern hemisphere are enjoying the performance of the AO-13 for more than 14 hours per day, the southern hemisphere is certainly not able to share in the fun. A second item needing change is the way the orbit divides the available communications time between the northern and southern hemisphere of the earth. Finally, means must be found to deal with the inherent instability of highly elliptical, high earth orbits. As will be seen, the lifetime of our orbit is governed by the initial right ascension of ascending nodes value which is directly related to launch time and the time and position of our kick motor firing. Beyond our ability to adjust these two parameters, only the use of on-board propellant to accomplish occasional delta-V maneuvers will meet our needs to maintain the orbital elements within acceptable limits.

INTRODUCTION TO M/N RESONANT ORBITS

AO-13 is in an orbit with a period of slightly less than 12 hours. The mean motion value is approximately 2.097 rev/day and is neither synchronized with the sidereal nor the solar day. If the mean motion were adjusted to 2.000 rev/day for a spacecraft in an orbit like AO-13, the orbit becomes locked to the earth. Further, if the inclination is adjusted to 63.43 degrees, the satellite follows the same ground track day after day and there is no shift in the apogee position as we now see with AO-13. Such an orbit is known as a resonant orbit. The Molniya orbit has very nice properties; many that we have been exploiting during the Phase-3 program. A true resonant orbit, however, has been intentionally avoided. As a consequence, the apogee will "walk" around the earth resulting in considerable variety in the coverage pattern of the satellites from one day to the next.

Resonant orbits have both good and bad attributes. For communications systems that require regular communications conditions, resonant orbits offer the opportunity to use even fixed beam antennas so that the satellite will fly into the directed fixed antenna beam at least once per cycle. The bad news is that the orbit flies over exactly the same geophysical features of the earth each day and gravitational irregularities of the earth tend to badly pump the orbit and cause changes in the orbital elements. As V. Kudielka, OE1VKW and T. Clark W3IWI have shown, the gravitational effects of the earth, sun and moon on high earth orbiting objects result in changes to the Keplarian elements that are described as mathematically "chaotic." Changes in one particular parameter cannot be expected to provide insight as to how changes to the orbit will occur in the future. Subtle changes in inclination and R.A.A.N. for instance, interact strongly and guessing the outcome of these changes cannot be inductively accomplished. It is an interesting fact of this type of mathematics that given an initial set of orbital elements (and a suitable 386 or 486 machine), it is possible to determine with good precision, what will happen to the orbit in the future. T. Clark has noticed, however, that the inverse process is truly impossible to predict. That is, given an end state in the orbit (say at the end of the lifetime of Phase-3D) that one wishes to achieve, it is not possible to work the problem backward and identify the starting elements that will be slowly perturbed into the final desired set of elements. The orbit perturbations that occur act on all orbits. Highly elliptical orbits suffer significantly from these effects, but resonant orbits are the most effected because they tend to integrate the same gravitational effects day after day and the orbit becomes maximally influenced by the earth.

The good news about all of this is, with the advent of powerful PC's available to the amateur satellite enthusiast, the ability to model such effects has gone from a few NASA and ESA experts to the masses. Never again will we have to depend on a favor from a space agency to "run our case" on their super computer. Solving the problem, in this case, is primarily the ability to model the future and a small amount of extra station keeping propellant.

The Phase-3D design team has now recognized that the Molniya resonant orbit, which executes exactly 2 orbits per sidereal day is but one orbit in a family of orbits. Consider a class of orbits that:

1) Executes M Integer Orbits

IN

2) N Integer Sidereal or Solar Days

If the period is truly synchronous with the sidereal day, then the orbit is fully resonant with the earth's geopotential. However, synchronism with the solar day (i.e. the clock) is perhaps, to amateur satellite enthusiasts, a more useful property. A satellite that is synchronized to the solar day will have apogees that occur at the same time every day but, the apogee positions will very slowly drift in longitude. A useful way to discuss the family of resonant orbits is to talk of the ratio of M to N or M/N. Table 1 shows the family of orbits that could be practically achieved by our future spacecraft given the possible delta-V available, which is not likely to exceed 2.0 km/sec.

TABLE 1

M (Orbits)	N (Days)	M/N	PERIOD (Minutes)	SEMI-MAJOR AXIS	APOGEE HT. (KM)	ECCENTRICITY
3	1	3	480	20307.459	23858.586	0.488948076
5	2	2.5	576	22932.061	29107.79	0.547438584
7	3	2.333	617.143	24011.461	31266.588	0.567782801
2	1	2	720	26610.299	36464.266	0.609994386
5	3	1.666	864	30049.501	43342.67	0.654631004
8	5	1.6	900	30878.517	45000.702	0.663903354
3	2	1.5	960	32236.082	47715.832	0.678057464
7	5	1.4	1028.571	33753.416	50750.501	0.692529906

The orbits shown have periods synchronous with the solar day and have some properties in common. To wit:

1) Perigee Height = 4000 km

2) Inclination = 63.43 degrees

3) Argument of Perigee = 270 degrees

The apogee has been set high because it was expected from the onset that this orbit type would be less stable than other elliptical orbits as discussed above. This has been borne out as will be seen later in this paper. Figures 1-8 show what the repeating ground track looks like for the orbits studied using GrafTrack II. If one were to allow each of the orbits to continue to propagate for several days the slow drift in longitude becomes apparent. The plots shown are for only one cycle (N days).

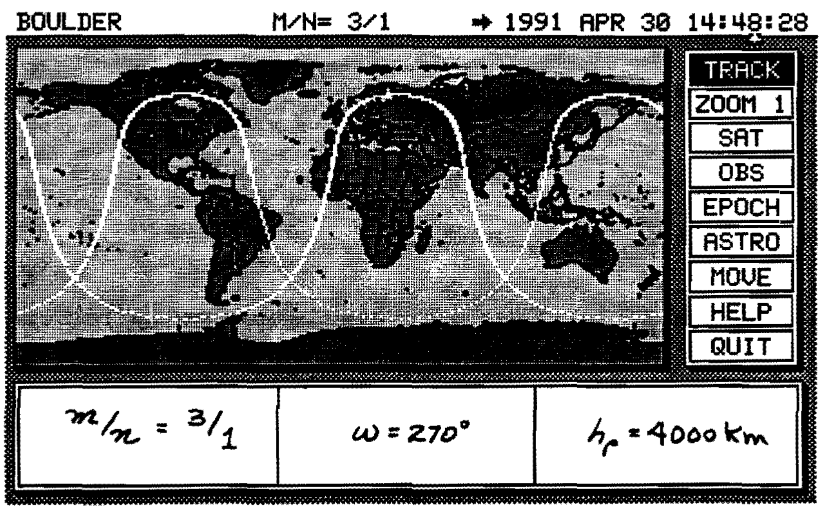

FIGURE 1: M/N = 3.0

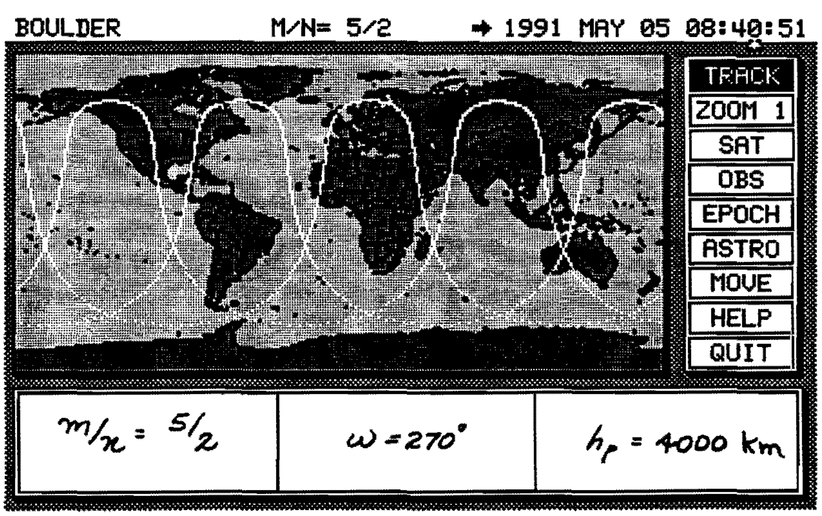

FIGURE 2: M/N = 2.5

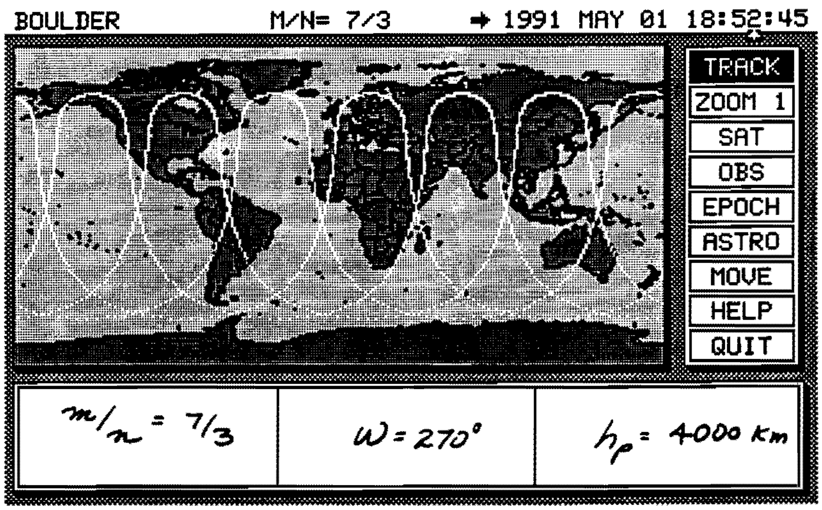

FIGURE 3: M/N = 2.33

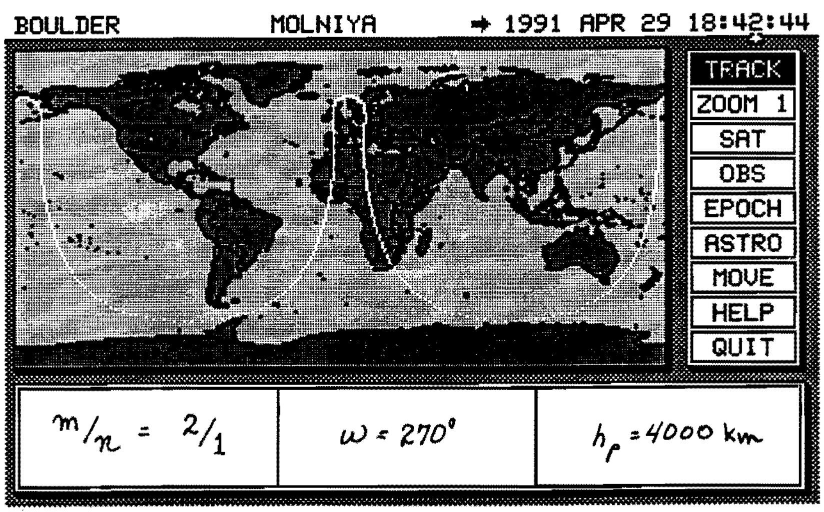

FIGURE 4: M/N = 2.0 OR MOLNIYA

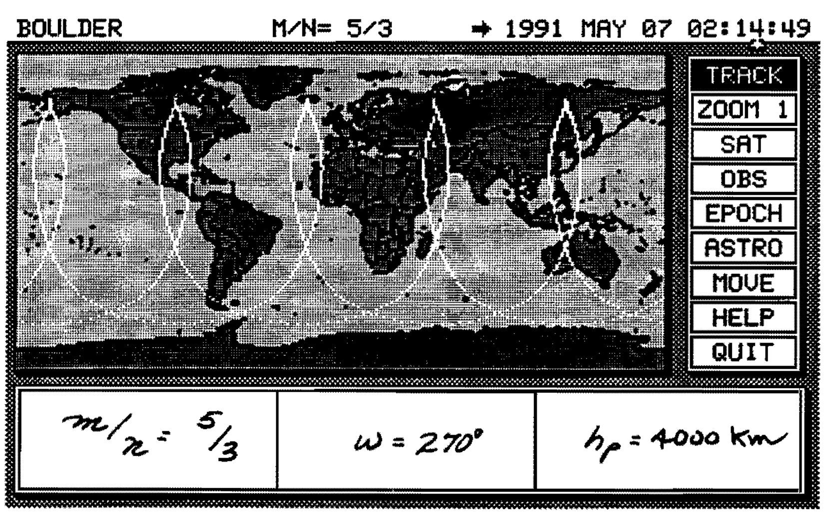

FIGURE 5: M/N = 1.66

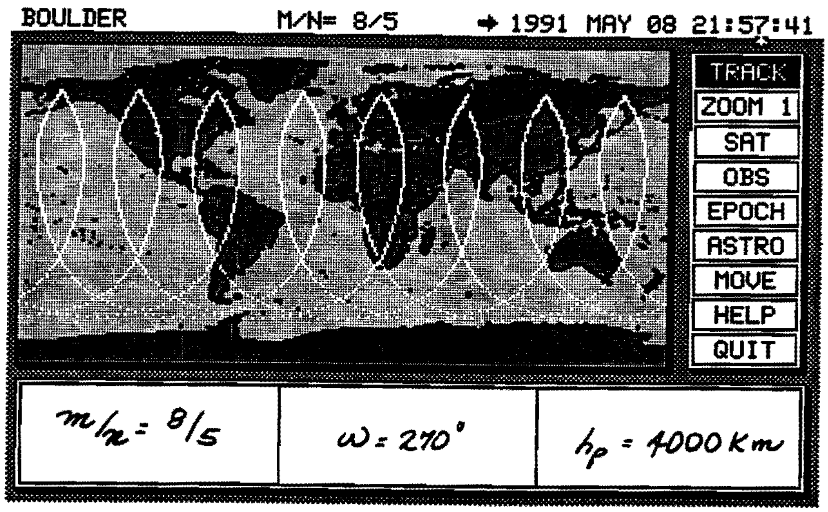

FIGURE 6: M/N = 1.60

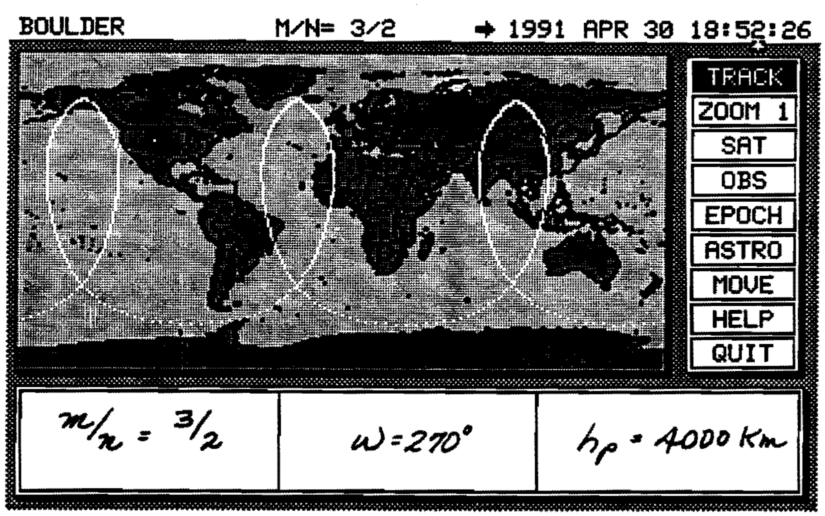

FIGURE 7: M/N = 1.50

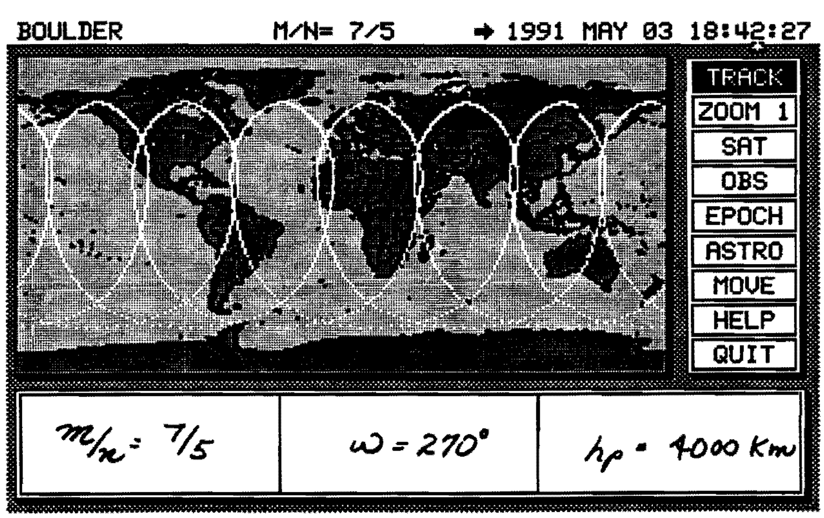

FIGURE 8: M/N = 1.40

Higher M/N values correspond to lower energy orbits with less dwell time at the apogee and lower apogee altitudes. They are also inherently more stable. Lower M/N values have long apogee dwell times and some, like the Molniya have a very tightly focus ground track around the apogee value. Unfortunately these orbits are less stable and will require some delta-V if the long term properties of the orbit are to be realized. In other words, it takes energy to keep the orbit put where we want it. At about the Molniya orbit value where M/N = 2.0, the orbit ground track begins to fold back on itself. Actually, the Molniya can be made to be an "open" or "closed" loop ground track depending on the perigee altitude (value of the eccentricity) selected. Given these choices which make reasonable sense from an energetic point of view, one begins to note the desirable properties and to do trade-offs among them.

THE DISCOVERY OF M/N = 3/2

During this past year two equivalent observations were made on opposite sides of the Atlantic ocean. Karl Meinzer, DJ4ZC noted that the prime times for amateurs to use satellites is on either side of the normal work period (which is typically 8 hours long AND that the work periods around the world have peak values separated by 8 hours. Jan King, W3GEY independently noted, using a simple cartesian world map, that there are three primary population centers in the world and that the mean longitudinal differences between the three is equal and therefor, spaced by 120 degrees. These two observations are equivalent because 120 degrees in longitude corresponds to 8 hours of rotation of the earth. This suggests that if the spacecraft of the next generation can have a period that is 8 hours, or a multiple thereof, then all three population centers can be served AND during the time periods most likely to be of use to the average amateur. Even for people who rotate their work and sleep periods (e.g. "graveyard shift"), since these are multiples of 8 hours, the satellite should be of maximum use to them as well.

An orbit with a period of 8 hours is a bit too low to have a well focused apogee ground track and the dwell time at apogee is a little short. Further, this orbit spends all of its time in fairly intense radiation (apogee altitude = 23,900 km) and that can be a killer as we learned from AO-10. The n0ext choice at M/N = 1.5 or more specifically 3/2 (3 orbits in 2 days) looked good since it can have an apogee located directly over each of the three population centers but, until it was studied in more detail, just how special this orbit is, was not revealed. The only drawback when compared with the 8 hour period M/N = 3/1 is that the user may have the most desirable apogee period occur once every two days instead of once every day. It will, however, occur at exactly the same time and very nearly in the same location as the previous cycle two days earlier. In order to achieve the most useful aspects of the orbit it must be synchronized (i.e. set the first time) with the correct local time. This places a constraint on the apogee picked for the orbit transfer. This constraint, may or may not be consistent with an apogee firing choice that also optimizes orbit stability. The remainder of this paper examines the useful features of the M/N = 3/2 orbit.

TEMPORAL COVERAGE

Figure 9 shows the 16 hour period orbit ground track adjusted so that the three apogees are centered in the major population zones of the northern hemisphere. It is hard not to notice how closely the apogees come to the center of North America, the center of Europe and the region north of the Pacific Rim countries. If the time of one of the apogees is adjusted for any one location (say within the time zone of the apogee longitude) it will be correctly set for all other locations. For instance, suppose the North American apogee is set for 0800 local time (e.g. CST). The next orbit apogee will occur at 0000 CST (midnight) and the apogee will be over Northern Europe. The third apogee will be north of Japan and will occur at 1600 CST the following day. The local times in the time zones containing the other apogees will be the same set of times (0800, 0000, 1600) but, shifted by eight hours in each location. All three apogees are visible from mid latitudes in the Northern Hemisphere. If you live one time zone away from one of the apogees then, of course, your time would be shifted by one hour. This is of little consequence since the two "poor apogees" are visible for 10 hours around apogee and the good apogee lasts as long as 15 hours! Note that the poorest time zones (those that lie 4 hours plus or minus from an apogee) are primarily located in the middle of the oceans. The single exception is central Asia which is between two of the apogees.

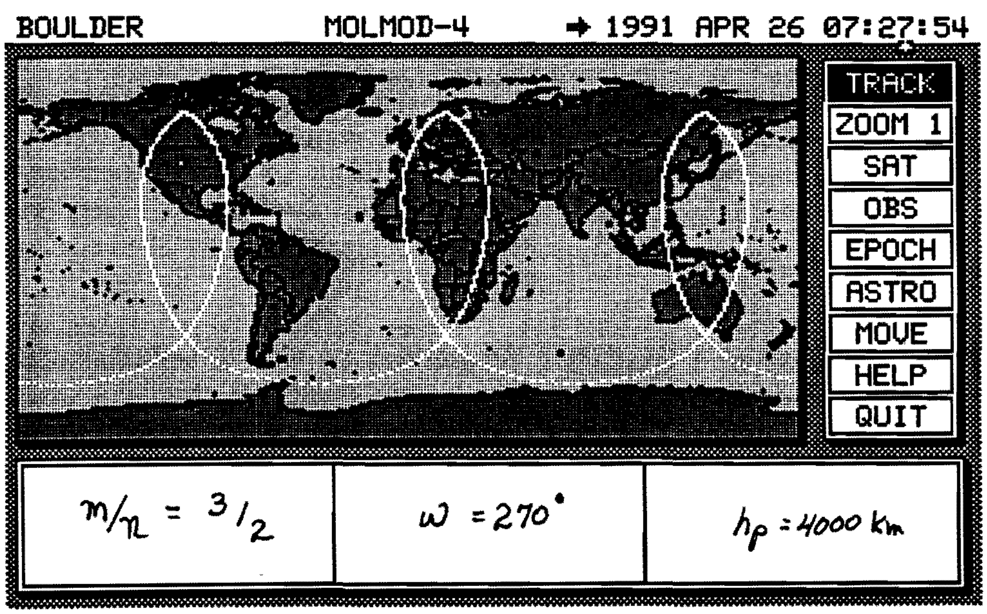

FIGURE 9

SPATIAL COVERAGE

For the time being lets assume that the M/N = 3/2 is set for true resonance, i.e. synchronized with the sidereal day and locked to the ground track shown in Figure 9. Table 2 gives the orbital elements for this particular case. Figures 10 through 12 show

TABLE 2

ORBITAL ELEMENTS

M/N = 3/2; SYNCHRONOUS WITH SIDEREAL DAY

```
Satellite Database Editor    V3.00    Copyright (C) 1985-1989 Silicon Solutions
file: P3D                                          edited: 21 Apr 1991 19:05
title:                                         satellites:  4  observers:  7

  satellite name     Molmod-4                   command:

element set desc     TEST-1; m/n=3/2                          object:  5
      epoch year     1991
       epoch day     80                                       E   - edit
     inclination     63.4349      degrees                     S   - satellite
      r. a. a. n.    225.00       degrees                     O   - observer
    eccentricity     .677437757                               N   - next
  arg of perigee     270          degrees                     P   - previous
    mean anomaly     0.00         degrees                    .nn  - object 01-16
     mean motion                  orbits/day                  C   - clear entry
   decay (ndot2)                  orbits/day**2               R   - read entry
     use decay?      0            0=no, 1=yes                 W   - write entry
    orbit number     1                                        G   - get data
      orbit base     0            0=perigee, 1=equator        U   - roll up
 semi-major axis     32174.15     km                          T   - edit title
beacon frequency     2400.00      MHz                         X   - exit (update)
  blat or nddot6                  degrees or orbits/day**3    Q   - quit (abort)
    blon or drag                  degrees or bstar            Esc - to this menu
     orbit model     0            0=SSI, 1=Bahn, 2=SGP, 3=SGP4/SDP4
```

the visibility from orbit apogees 1, 2 and 3 (numbering system arbitrary but started at the prime meridian and proceeding to the east). As can be seen, the coverage from the northern hemisphere is exceptional on all apogees. At this point it becomes useful to determine how good a performer the orbit is as seen from various points around the earth. If the ground track is fixed then the visibility time is the same for every cycle. We can therefor define a **Visibility Factor** which is a constant for every location on earth. The visibility factor is just:

$$\textbf{Visibility Factor} = \frac{\textbf{Visibility Time / N Days}}{\textbf{N Days}}$$

The results are given in Table 3 for various key locations in both hemispheres. It is important to note that percent coverage factors are high BOTH because of the superior properties of the orbit AND because we have located the apogees strategically. This is not particularly true for the southern hemisphere. An alternative analysis technique used by M. Davidoff, K2UBC when applied to this orbit shows that if the orbit is allowed to drift in apogee position then, on average, the coverage will be slightly better than that given for the southern hemisphere locations listed in Table 3. The northern hemisphere, however, benefits still further from having apogees fixed and strategically located over the major population zones. Not surprisingly, coverage in the southern hemisphere benefits most from a reduction in the argument of perigee value away from 270 degrees. For this orbit, however, once the argument of

TABLE 3

Visibility Factor for M/N = 3/2

Various Locations and Argument of Perigee Values

Location:	$\omega = 270°$:	$\omega = 235°$:	$\omega = 210°$:
Frankfurt	0.776	0.734	0.641
Tokyo	0.703	0.568	0.505
Boulder	0.734	0.708	0.526
Cape Town	0.120	0.203	0.328
Buenos Aires	0.073	0.141	0.229
Melbourne	0.120	0.182	0.307

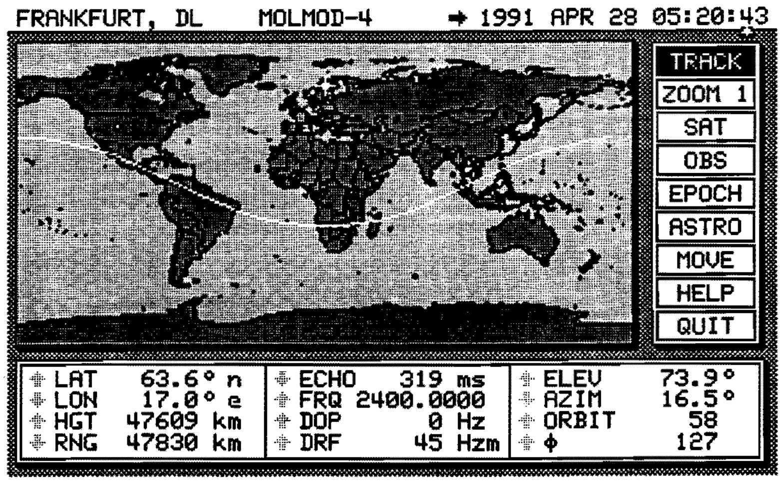

FIGURE 10: APOGEE NO. 1

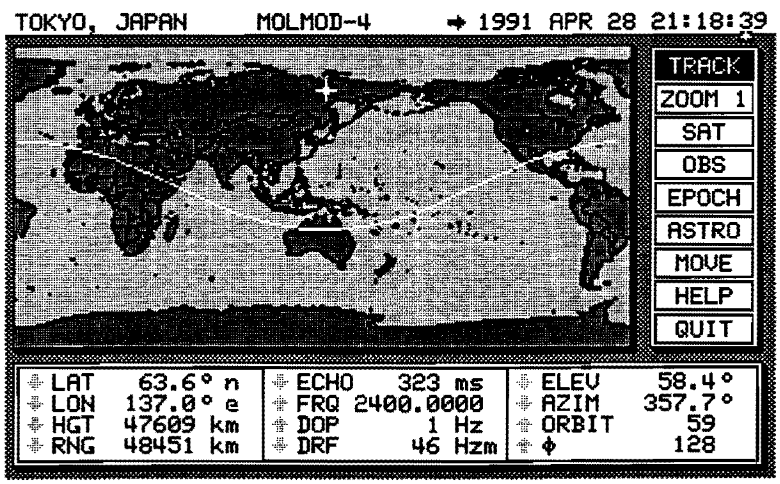

FIGURE 11: APOGEE NO. 2

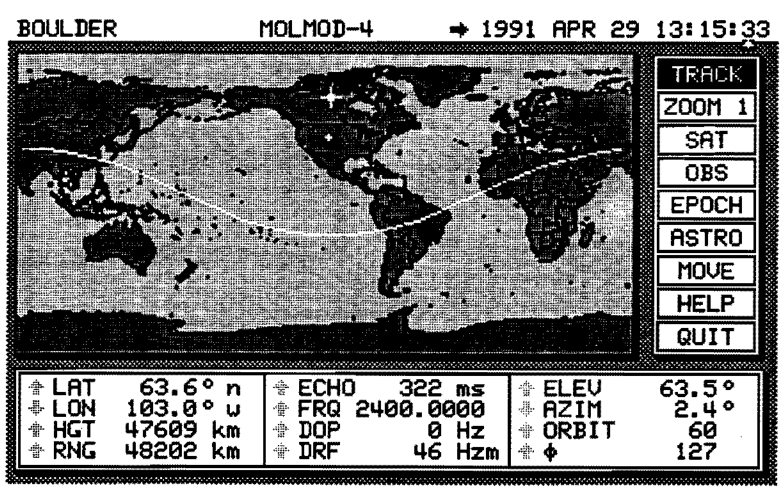

FIGURE 12: APOGEE NO. 3

perigee has been selected, it will not change with time, provided that the inclination is kept at an average value of 63.43 degrees (the orbit perturbations also affect the inclination). By selecting an argument of perigee value in the range around 220 to 230 the visibility factor for mid-latitude stations in the southern hemisphere will average about 0.25. The peak value if the orbit apogees drift may be as high as 0.35.

EFFECTS OF ARGUMENT OF PERIGEE VALUE FOR M/N = 3/2

The investigation of the argument of perigee for M/N = 3/2 was a real sleeper! Typically, for other resonant orbits of this class, as the argument of perigee is reduced from 270 degrees, the tight focus of the ground track around apogee breaks up rapidly and the ground track opens widely on either side of the apogee. This orbit instead, begins to fold back on itself and forms a double loop ground track. The principle axis of the loops begins to rotate (north end to the west). The cusp of the orbit (top loop) remains well formed until the argument of perigee is at 200 degrees where the loop finally opens up. This is an excellent property as will be seen when the tracking characteristics are discussed. Figures 13 through 22 show the properties of the orbit ground track with decreasing values of argument of perigee.

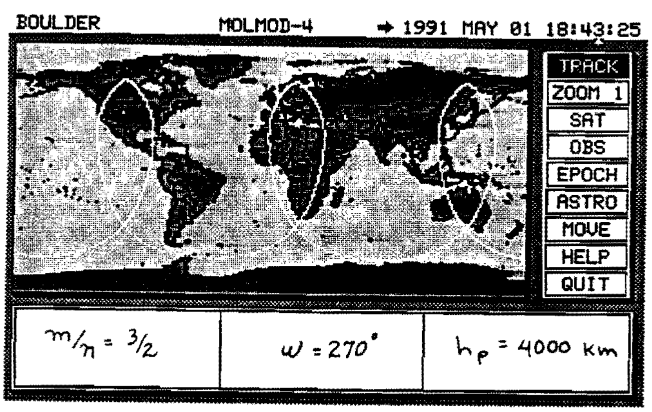

FIGURE 13

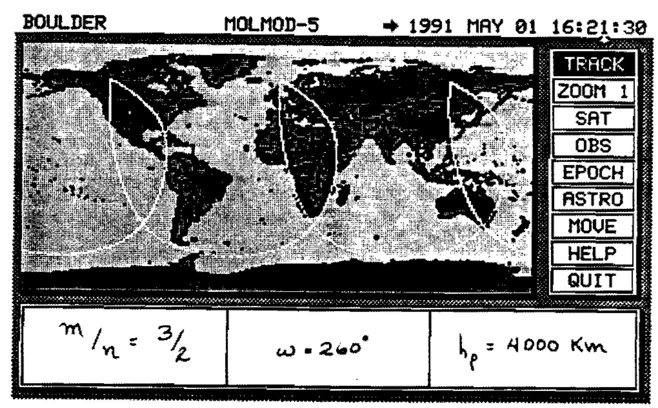

FIGURE 14

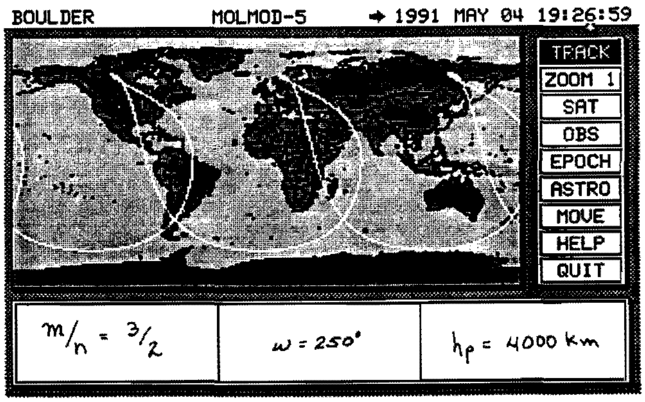

FIGURE 15

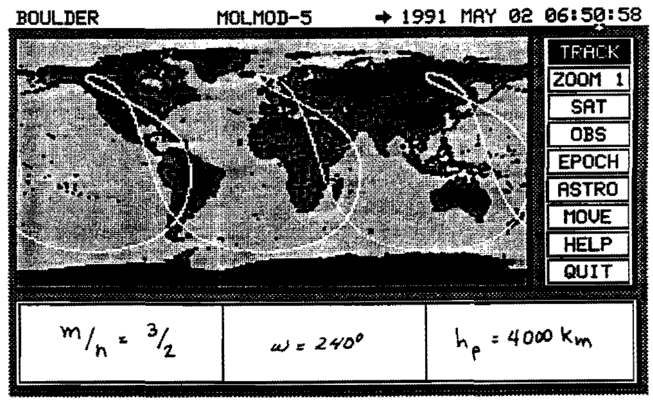

FIGURE 16

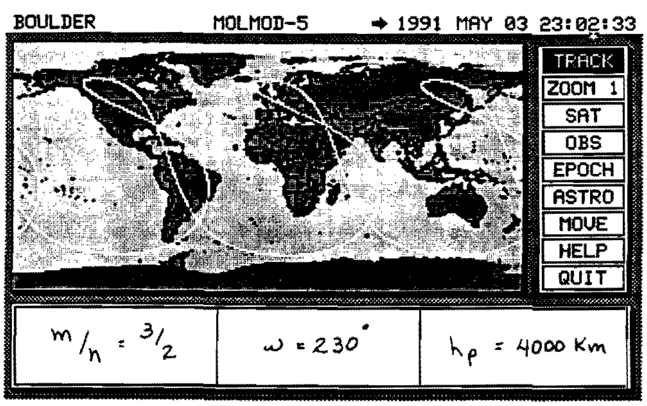

FIGURE 17

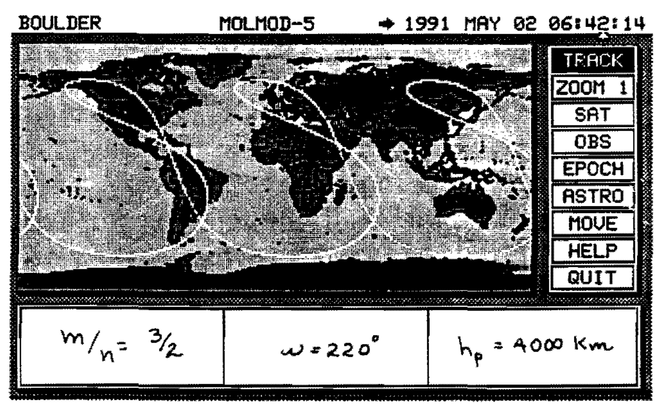

FIGURE 18

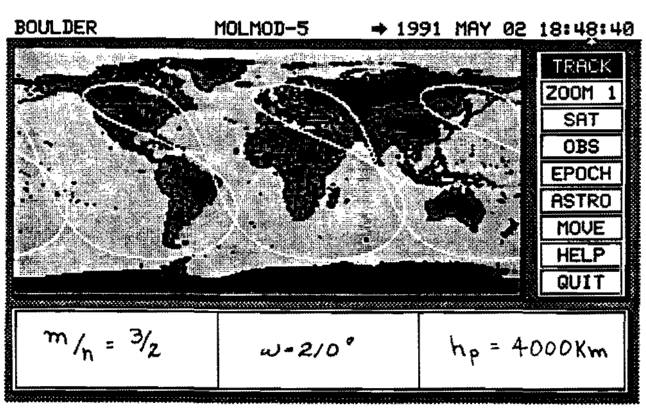

FIGURE 19

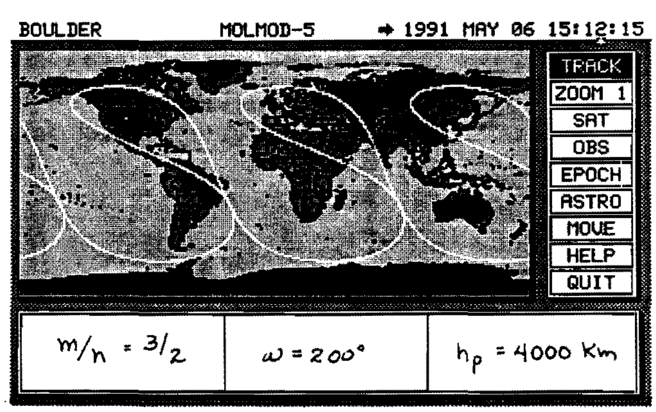

FIGURE 20

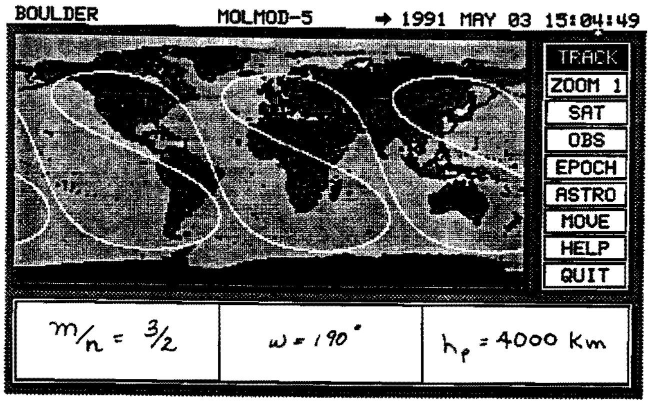

FIGURE 21

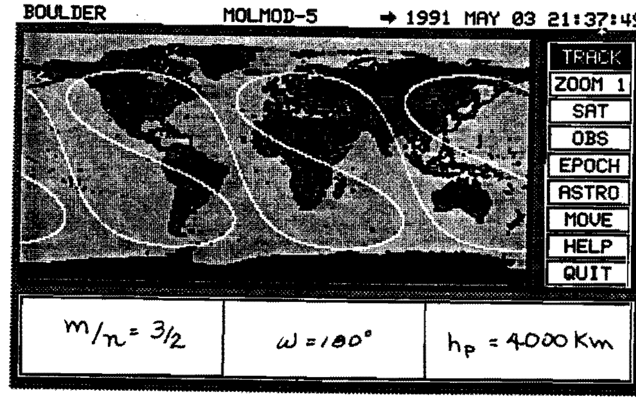

FIGURE 22

By adjusting the R.A.A.N. value of the orbit, the double loop ground track can be placed over land masses. For example, notice how nicely the double loop can be caused to overlay North and South America for argument of perigee values between 220 and 250 degrees. One must continue to remember, however, that if the orbit is synchronized with the solar day the double loop pattern will slowly drift westward each cycle. This motion can be stopped to provide the ground tracks shown but, at the expense of a slip in the time apogee occurs each day. Judging from the characteristics of the double loop and the increased southern hemisphere coverage provided by a lower argument of perigee, a value of 225 degrees appears to be close to an optimum value for the Phase-3D mission.

TRACKING REQUIREMENTS FOR M/N = 3/2 ORBIT

Another surprise awaited the investigation of the tracking characteristics of the M/N = 3/2 orbit. The sidereally synchronized orbit with an argument of perigee equal to 270 degrees was first investigated. This is the case shown in Figure 9. Ground tracks were generated for three locations: Boulder, Colorado (central USA), Frankfurt, Germany (central Europe) and Tokyo, Japan. These locations are in the same time zonesas the apogee longitudes. Not surprisingly, the ground tracks from each location looked similar but, they are phased differently, given the geometry of the locations selected.

As seen in Figures 23 through 25 two of the passes from each location are tightly focused, much more so than the current Phase-3 orbits. In fact, the position in the sky where the satellite "resides" is sufficiently small that a fixed antenna can be used to track the satellite, even at the lower microwave frequencies. Remember once again, a fixed antenna would only work if the orbit were sidereally synchronized. If solar synchronized, a quasi fixed antenna could be used. The pattern would drift and change shape very slowly such that a user could "pre-steer" his antenna for a pass to occur later in the day. The fixed antenna could then remain in this position for several days until the apogee drift caused another pre-steering session to take place.

The third orbit in the cycle is truly incredible! The spacecraft rises rapidly above the horizon and reaches an elevation angle greater than 60 degrees in just about one hour. It then stays there circling around the user QTH zenith position for more than 12 hours! It then sets just as rapidly, not to return in this mode for two days. This characteristic is absolutely ideal for mobile satellite communications and anyone else at a fixed location where space is a problem. The user simply points antennas for the frequencies of interest with the directive end straight up. The gain of these antennas can be as high as 16 dBiC and the spacecraft will remain within the beam any time it is above 60 degrees elevation angle. Somewhat lower user antenna gain will increase the communications time. The communications transponders on board will be designed to accommodate users operating with low power and using this mode of communications. More than likely, 16 dB of antenna gain will be far more than sufficient for a user mobile antenna, however, the 16 dB figure shows how much gain can be used without significantly reducing communications time and without steering.

For users located away from the apogee longitude, the Az/El plots here are skewed somewhat but, the effect is fairly small since the spacecraft slant range is very large (about 50,000 km at apogee).

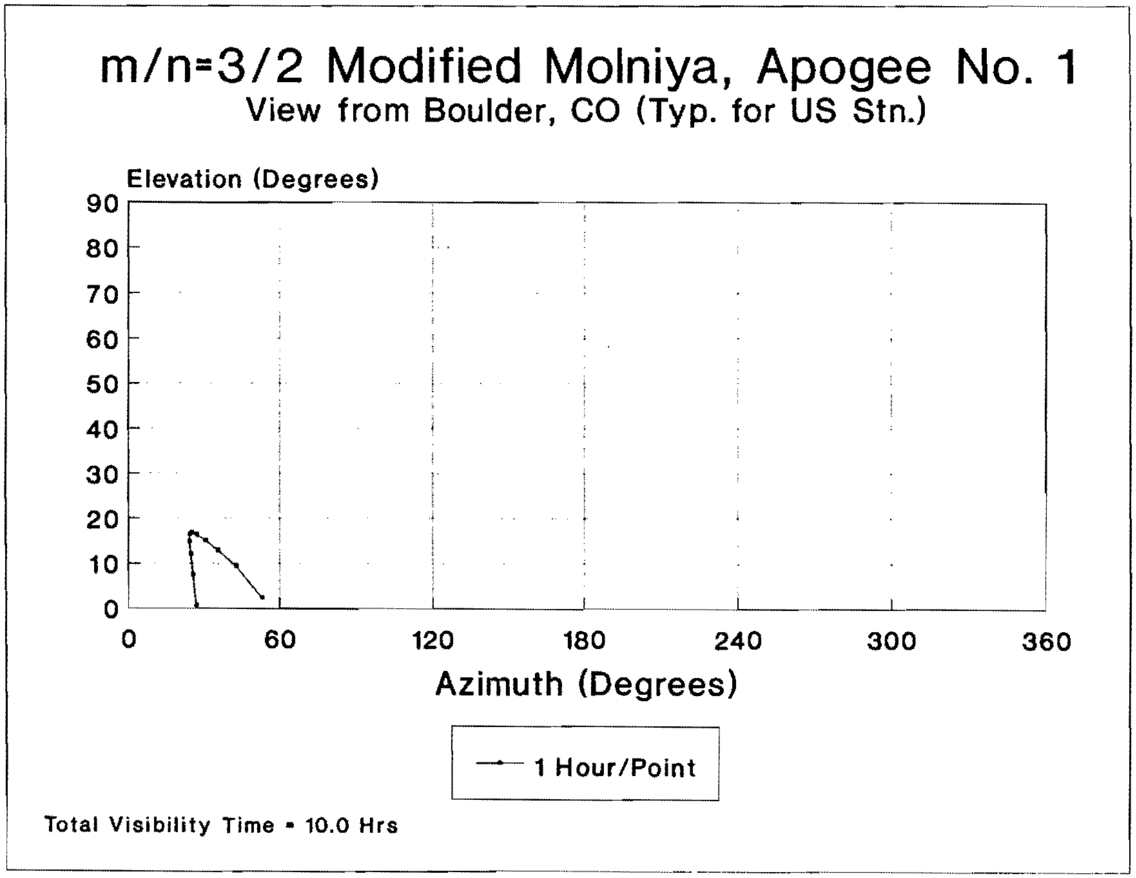

FIGURE 23

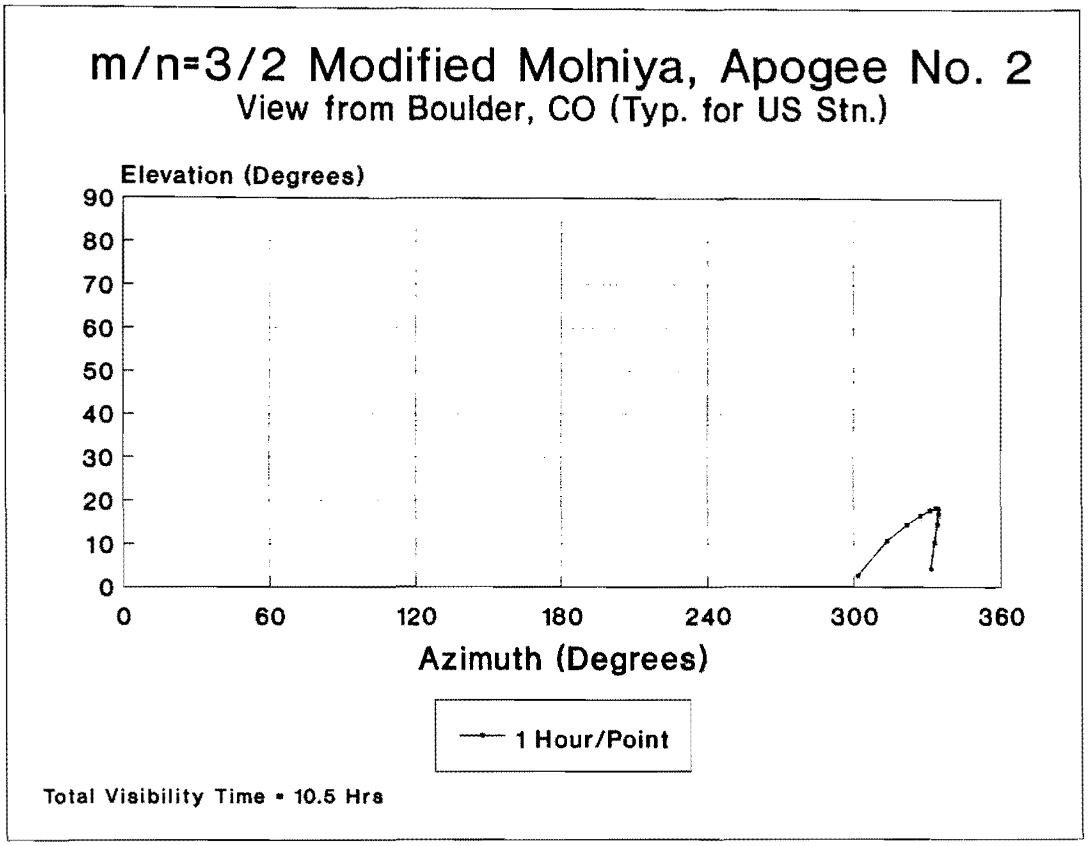

FIGURE 24

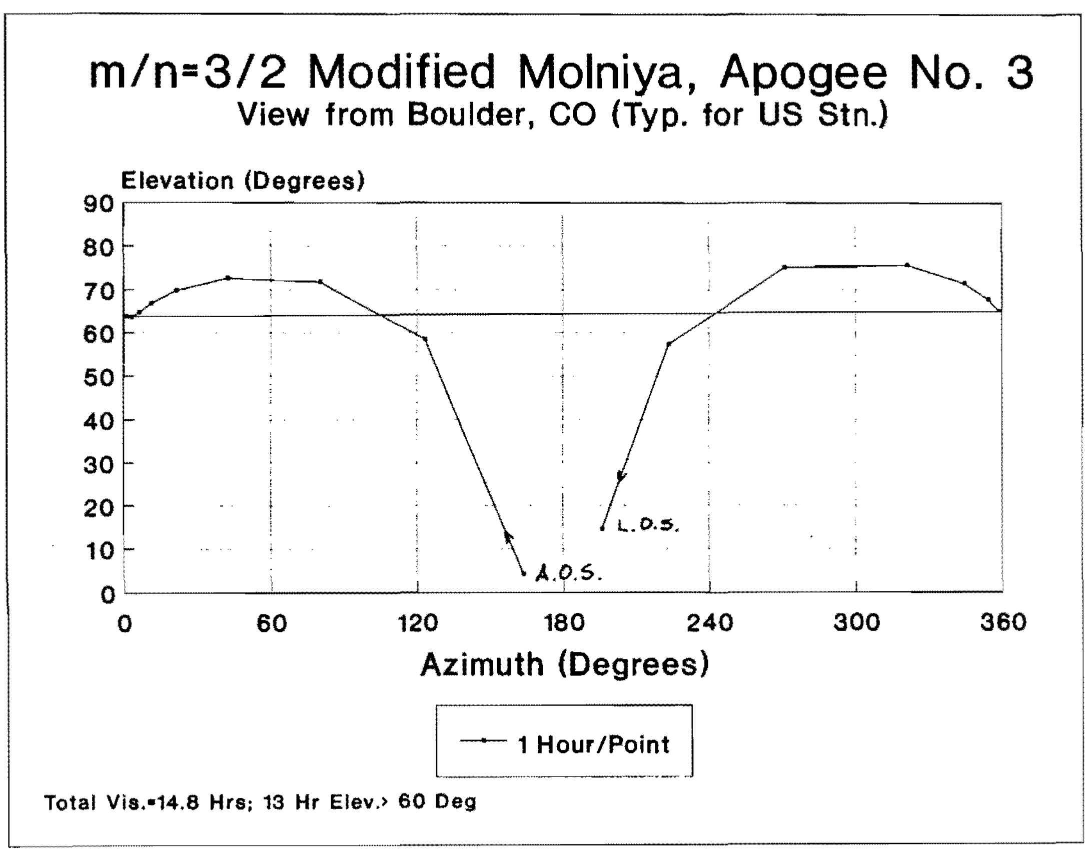

FIGURE 25

The argument of perigee has an effect on the coverage characteristics of the orbit but, not as much as one might think. There has not been enough time to investigate the coverage for a large number of argument of perigee cases, however, a brief look has been taken at values around 220 degrees. For stations at mid-latitudes in the northern hemisphere, there are three types of passes. One becomes a mobile satellite pass (albeit not with the super-high elevation characteristics of the former orbit), the second pass has a fairly focused apogee Az/El plot (call it a DX pass) and the third pass is a horizon skimmer. It rises just above the horizon and moves slowly in azimuth along the horizon and then sets. The quality of the third pass will be a strong function of the users latitude. The horizon skimmer may be the best DX orbit of all however, since coverage dips far into the southern hemisphere on the opposite side of the earth from the user in the northern hemisphere.

SIDEREAL VS SOLAR DAY SYNCHRONIZATION

Throughout this paper the issue of sidereal vs solar synchronization keeps arising and has been discussed. Both approaches have advantages. Solar synchronization allows users to have a satellite system that is available during the times of the day that are likely to be most useful (i.e. greatly improved availability). The walking apogee that results is viewed by many to be an advantage since this condition provides variety to the orbit coverage. On the other hand, sidereal synchronization freezes the ground track and allows up to two orbits per cycle where fixed directive antennas could be used. More importantly, perhaps, the "mobile satellite pass" can be optimized for the three northern hemisphere populations zones. Clearly, the mobile possibilities are not as good with a walking apogee. For certain values of argument of perigee, sidereal synchronization will improve southern hemisphere coverage for many locations, however, it will be reduced at other locations in comparison to the solar sync. solution. The problem with this particular parameter: you have to pick one or the other even though, at various times, both choices would be nice. Table 4 summarizes the two choices.

TABLE 4

Three Orbits Per Two Solar Days:

- Period = 960.0000 Minutes
- a = 32,236.082 km
- e = 0.678057464
- Apogee Time Drift = -497 seconds/cycle

Three Orbits Per Two Siderial Days:

- Period = 957.2348 Minutes
- a = 32,174.150 km
- e = 0.677437757
- Logitudinal Drift = -2.1 Deg./Cycle (West)

ORBIT STABILITY ISSUES

It seldom happens in an engineering environment that the same mistake is repeated twice. To be sure, however, mistakes do happen. All AMSAT users can rest easily that the orbit stability problem that will eventually cause the demise of AO-13 will not happen again. Before it is over, in fact, it is likely that this issue will be studied to death on the Phase-3D program. To start the process off, one of the authors, Stephan Eckart, DL2MDL has developed an orbit propagation model that includes higher order terms in the earth geopotential as well as the gravitational effects of the sun and moon. In order to minimize the errors in propagating the effects of the orbit forward in time, a sophisticated integration method has been employed. In order to check the validity of the software model it has been compared against other models predicting the behavior of the AO-13 orbit. Figures 26A, B and C show the long term prediction for AO-13 perigee altitude, argument of perigee value and inclination. These predictions are in good agreement with the work of others and track quite well the actual data for the orbit as determined by NORAD.

The model was then turned to the evaluation of the stability of the M/N orbits. In addition to the Molniya orbit, two additional orbits had looked promising. These were M/N = 5/3 and M/N = 3/2. Both of these were investigated using the model. Figures 27 A, B and C show the predicted results for the M/N = 3/2 case. Stephan used a somewhat lower starting perigee than has been assumed in investigating the general characteristics of the orbit. Since the perigee altitude would reasonably be picked, in part, as a result of running such an analysis, the initial starting point is quite arbitrary. The parameter used in the data is R.A.A.N. It is clear from even a quick look at the data, that the orbit is quite unstable. Note particularly, that the perigee altitude falls like a rock for values of RAAN around 270 degrees while values around 180 degrees are more or less stable for the first 10 years. Ultimately, however, the perigee becomes unstable and increases to an unacceptably high value.

The model clearly shows that if any of the nice properties of a resonant orbit are to be accomplished, delta-V maneuvers will have to be performed and perhaps quite frequently. The amount of propellant needed to maintain the orbit period and argument of perigee nearly constant and the optimum means of using such propellant will be the subject of a most amazing study in the future! This is all the more true because of the chaotic nature of the orbital mechanics involved.

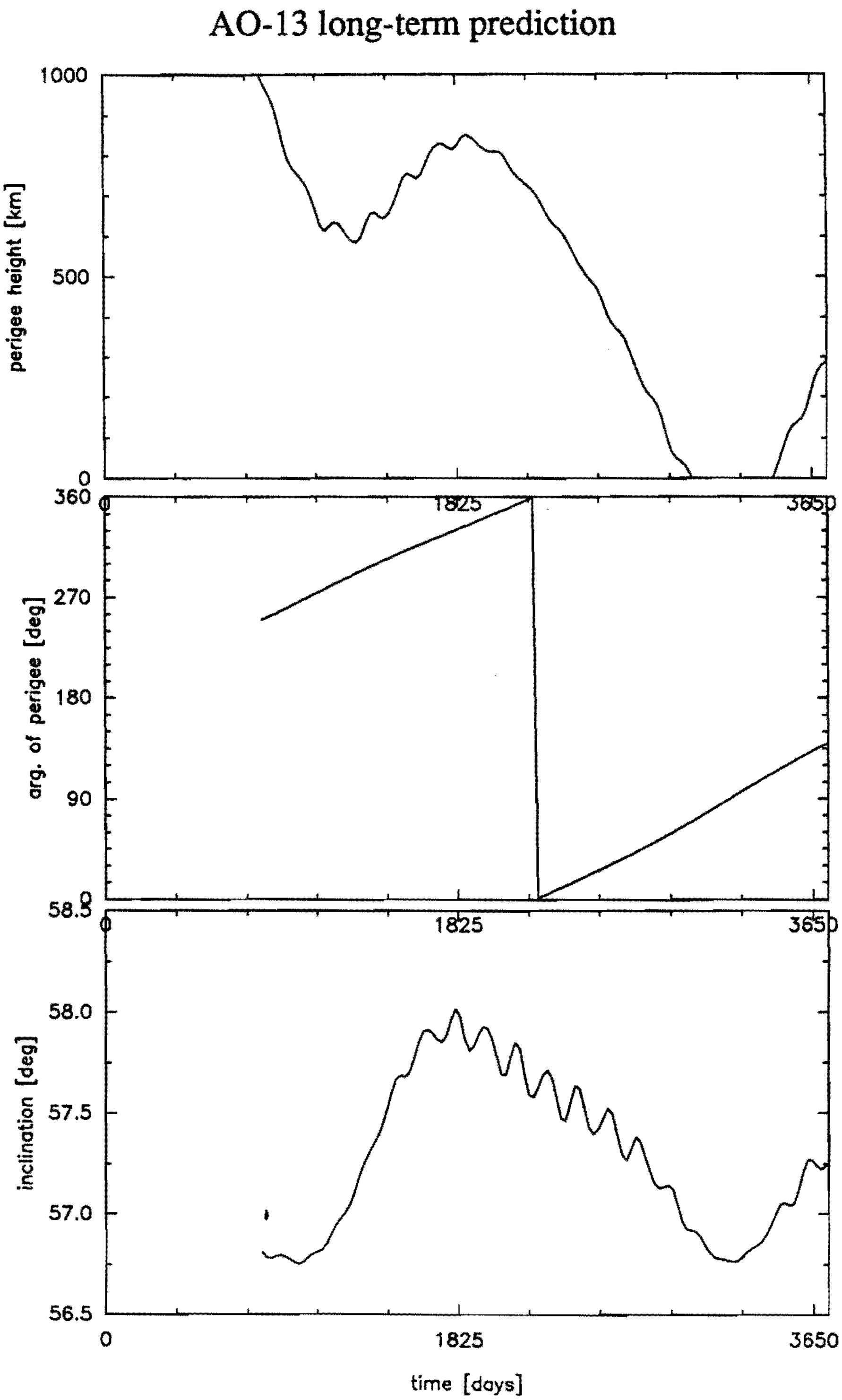

FIGURE 26 A, B, C

3/2 orbit, i=60 deg, h=2500 km

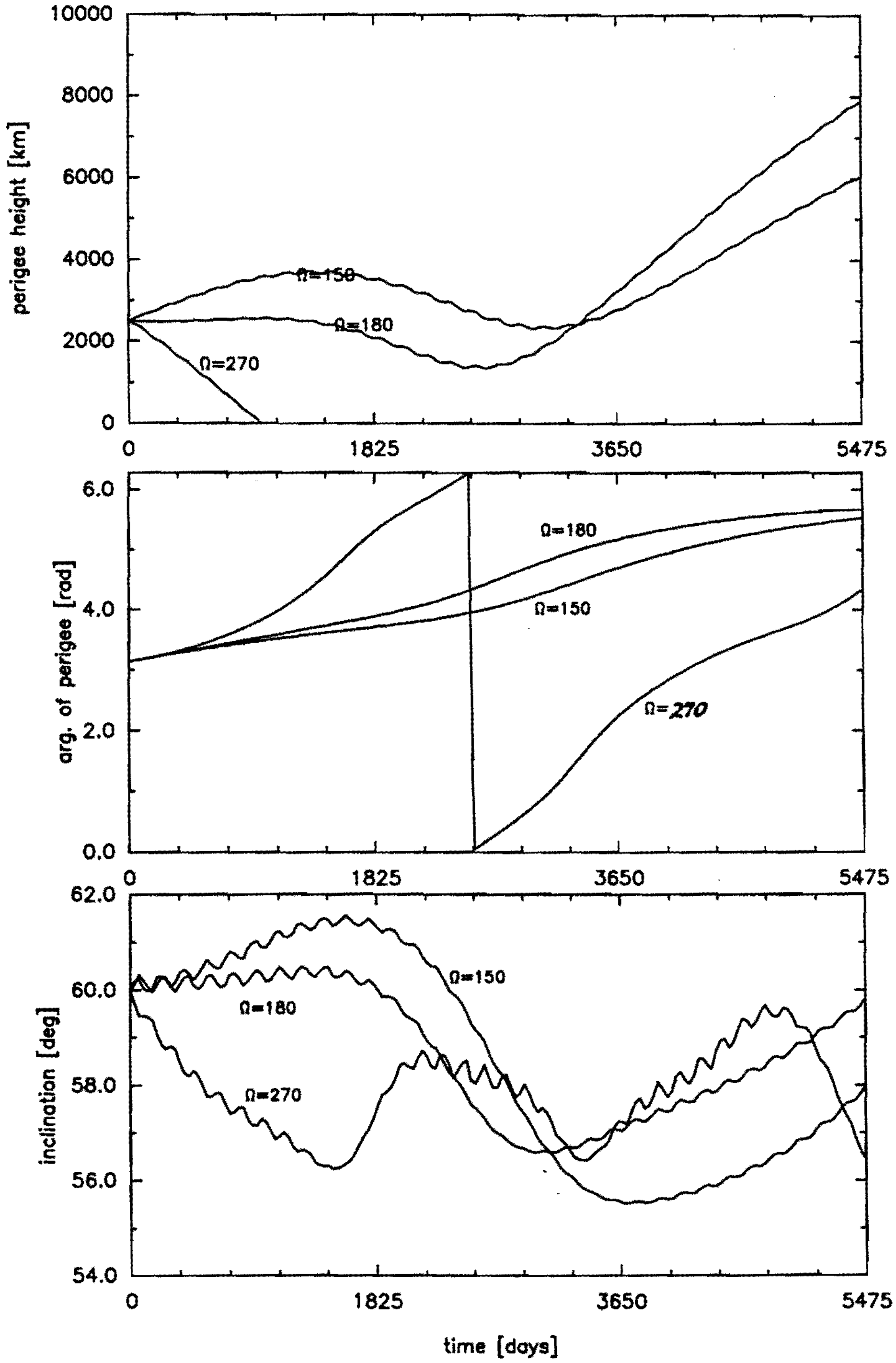

FIGURE 27 A, B, C

PRELIMINARY DECISION OF THE PHASE-3D DESIGN TEAM

After considerable discussion at the Marburg Phase-3D design meeting in 1991 it was tentatively decided that the orbit to be chosen should have the following properties:

- o Resonant Orbit With 3 Orbits Per 2 Solar Days
- o Orbit Period of 960.0 Minutes
- o Apogee Altitude of About 48,000 km
- o Perigee Altitude Between 2500 and 8000 km Depending on Outcome of Further Studies
- o Inclination of 63.4 Degrees
- o Argument of Perigee Between 200 and 225 Degrees Depending upon User Response
- o R.A.A.N. to Optimize Orbit Stability / Lifetime

All AMSAT members are encouraged to provide comments regarding the orbit selection. It is hoped that this paper has placed the thoughts of the Phase-3D design team in perspective and that everyone will have a better understand of the orbit options.

ACKNOWLEDGEMENTS

Our thanks to the Phase-3D design team for their active participation and constructive help in reaching a consensus on the orbit choice. Our thanks to Silicon Solutions, creaters of GrafTrack and Silicon Ephemeris. This program was particularly useful in completing our analysis.

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"S Band" : Principles and Practice

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On Oct 4, 1989, I had the good fortune of being in Denver on business at the same time that the Microsats had returned. A call to the AMSAT lab brought an invitation to come and see the birds- in person. Jan King and Jeff Zerr gave me a guided tour of the facility and the satellites themselves. The most striking characteristic about them is how small and compact they are- barely 9 inches on a side. Even their antennas are tiny. And the tiniest antenna was for the uncharted regions known as "S BAND". Jan King said a suitable ground station S band antenna would be a 1 to 2 foot long helix. And that stuck with me.

Having had my curiosity peaked by the thought of effective amateur communications requiring such small antennas, I pursued the "Principles" or what and why and the "Practice", or how of S band communications. What started out as a seemingly insurmountable project (after all, mode L had been rather challenging to become homebrew QRV on) turned out to be surprisingly easy and straightforward. Following is the mechanical engineer's "no magic" approach to becoming active on S band.

First, the What. The nomenclature "S Band" comes from an old but still much used radar-based designation system that identifies frequency ranges by letters. For example, "L-band" refers to a range from 390 to 1550 MHz. In amateur satellite usage, Mode L refers to a full duplex communications mode that uplinks on 1269 MHz and downlinks on 435 MHz. "S-Band" covers 1550 to 5200 MHz. Currently, S band is used in two different implementations on 3 active satellites. The Microsats AO16 Pacsat and DO17 DOVE are LEO (Low Earth Orbit) birds with 2401 MHz PSK downlinks as alternates to their normal 435 MHz digital downlinks. AO13 is a high elliptical orbit machine sporting a full featured analog transponder. It uplinks on 435 MHz and downlinks on 2401 MHz.

Just defining "S" brings up the second question: Why? And why do satellite designers keep going higher and higher in frequency? Well, S-Band has some real values and benefits, among them:

1) Small antennas. High frequencies allow high gain with physically small antennas. The Microsats are a classic case where there is just not much antenna mounting real estate available. So, a 13cm transmitter allowed a whole different experimenters mode to be included and only required an antenna a few inches long. On the ground, antennas are compact and unobtrusive. As Jan King predicted, a 2 foot long helix antenna is adequate to hear the Microsats. Even the high flying AO13 can be worked with an antenna less than 8 feet long and 2 inches in diameter.

2) It's quiet up there. Sky temperature and galactic noise levels are low, causing little background noise. Manmade noise is low (no 13cm FM handhelds), too, meaning stringent

receive filtering is not necessary. Remember that, in certain areas of the world (Japan), the 2 meter band is so congested that it is almost unusable for weak signal work.

3) The wide open spaces. Our spectrum allocation on 13cm is huge. The amateur satellite portion alone is as wide as all HF bands together, with 6 meters thrown in! Remember, on 2 meters, satellites only get 200 kHz. Lots of room means more chance to accommodate more people and modes with less QRM. And that means more reliable communications.

4) Use it or loose it! Commercial concerns are always looking for space to expand. The best way to keep our amateur allocations is to use them. Look what just happened to 220 MHz. With WARC 1992 looming ahead, having high usage birds already on 13cm will greatly enhance Amateur Radio's argument that this band belongs to hams.

5) Fairly inexpensive. 13cm is no longer the lofty perch of wealthy techno-freaks. Technology has brought the costs of really high performance transistors down to earth. A $9 GaAsFET will get you a preamp with <1 db noise figure.

6) Easy. Mode S requires a 13cm DOWNLINK. This is significant. It is much easier and cheaper to receive UHF signals than it is to generate substantial transmit power up there. AO13's mode S is actually easier to implement than mode L.

7) Fun. It's new and different and populated by a friendly crowd, always glad to see newcomers and eager to help. G2BFO has almost 100 initials on AO13 mode S, so there really are people to talk to up there. Bill McCaa KØRZ maintains a worldwide list of known AO13 stations.

Now that everyone is convinced they must become active on mode S, the question is How. How do you become active on a band for which no integrated commercial gear is available?

Both the 13cm schemes used on current satellites share the same basic requirement- the ability to receive on 2401 MHz. Since the most common mode of satellite operation is mode B on AO13, most satellite users already own the expensive parts of the ground station. You need only add an external frequency converter and antenna in front of your existing mode B (2 meter) receiver. AO13's Mode S transponder uses a 70cm uplink, which is also the same as mode B. This is a pretty cost effective arrangement. Since Pacsat's S band downlink is an alternate to its normal mode J (70cm downlink) arrangement, a 2 meter PSK uplink is required.

So far, so good, but to select the proper equipment, we must look at some of the characteristics of the satellites we intend to hear.

The Microsat's S band transmitters provide strong and loud PSK beacons, though not enough so to allow use of omni-directional antennas. So, it is necessary to use gain antennas and some method of tracking. Tracking techniques are the same as those required for any LEO bird. Medium gain antennas are desirable. High gain antennas have narrow beamwidths and make manual tracking more difficult. Computerized antenna control would be ideal, but is not necessary. The biggest difference that will be noted in the reception of the Microsats is the little aggravation called Doppler Shift. As much as 110 kHz of it on a good pass. This hasn't proven a big problem, but does take some getting used too. Both G3RUH and TAPR PSK modems have autotune functions, so once the modem is locked on the beacon, the receiver will follow the Doppler automatically. Microsats also have rotation induced fades. Pacsat's beacon is on periodically (typically Wednesdays) on an experimental basis and works well. DOVE's beacon is frequently on, but a failure in the modulator makes it not possible to demodulate the data.

AO13, on the other hand, moves slow and easy. It is easy to track and has relatively little Doppler. '13's mode S antennas are quite directional, so operation is scheduled around when the antennas are pointed directly at the earth (nadir pointing). Even so, its signals are rather weak. The best part is that, except for periods of unusual satellite attitude, mode S is available during every orbit.

Receiving 2401 MHz takes the same basic steps required on any other band. Put up and antenna, run a feedline to the shack, plug it into the converter and off you go. Well, almost.

A variety of antennas are commonly used. Note that the antenna selected should match or be a reasonable compromise based on the intended usage. The longer the antenna, the higher the gain and the stronger the received signal. But the narrower the beamwidth and the more precise tracking required. The 2 foot long helix I mentioned earlier is fine as a demo for hearing the Microsats, but I have found it a little light for reliable reception. And you won't even hear AO13 with it.

Many AO13 ops use 4 foot diameter and larger dishes pirated from TVRO downlinks. Like all dish antennas, they offer good performance and are easy to feed, but present complicated pointing and retention problems.

A better solution for most of us is the loop yagi antenna. These devices are similar to the more common Yagi antennas, but replace the yagi's 1/2 wave straight elements with near full wave closed loops. They are easy to feed, requiring no matching device or balun. And best of all, they are very light and unobtrusive. Loop Yagis are available ready made or in kit form from Down East Microwave. They are also reasonable homebrew projects.

A single 45 to 52 element loop yagi cut for 2401 MHz is a good compromise antenna. It will be really loud on the Microsats and usually adequate for SSB on AO13. Since loop yagis are small and easy to mount, they are also easy to stack if more signal strength is desired. Stacking frames and splitters are commercially available. For AO13, a stacked pair would be excellent, but manually tracking the fast moving Microsats would be rather challenging. Start with one yagi, get it working properly and evaluate its performance against your desires. This is an experimenters mode.

After you have a suitable antenna, S band reception requires attention to one main area: system noise. Noise comes from various sources. Galactic and man-made noise are both low up here. Of more significance is noise generated by the receiving system itself.

While modern technology has brought us extremely low noise preamplifiers, they are of little value if we precede them with noise generating devices. The most common noise maker: the feedline! Coaxial cables, which serve so admirably at lower frequencies, are incredibly lossy on 13cm. Feedline loss is indistinguishable from noise, so even a very low noise amplifier mounted after a long run of feedline will not result in satisfactory overall receive performance. The solution- get rid of the lossy cable. And since this is a receive only mode, forget about T/R relays, too. Mount a low noise preamplifier as close to the antenna feedpoint as possible. I've had quite satisfactory performance by mounting homebrewed preamps directly on the antenna boom, less than 6 inches from the driven element. Preamps are available from several sources, both ready made and in kit form. The kits, available from Down East Microwave, are built around the Al Ward WB5LUA "Simple Low-Noise Microwave Preamplifiers" designs as shown in QST, May 1989. They are amazingly easy to build and offer excellent performance with no test equipment. For the less adventurous, ready made preamps are available in various forms from both DEM and SSB Electronic.

Although system noise figure is mostly determined by the preamp, don't skimp on the feedline to the converter. While RG213 is adequate for short runs, 9913 is better and hardline is better yet. If you have a really long run between the preamp and the shack, either add a second, tower mounted preamp or remote mount the entire receive converter. Just put it in a weatherproof box and hang it up on the pole! Then bring the converter's 2 meter output down to the shack with ordinary coax.

Receive converters are available both complete and as kits. The kits (available from Down East Microwave) are the absolutely amazing "no tune" designs of Jim Davey WA8NLC and Rick Campbell KK7B. Use of printed hairpin filters and MMIC's means only one adjustment is required, and that is in the LO. These kits are more like a magazine article and a bag of parts. The boards are easy to build, but do require patience and care. As with preamps, DEM also supplies ready-made versions.

K3MKZ imports ready-made S band converters from SSB Electronic of Germany. Internally, these use GaAsFET RF and mixer stages and conventional tuned strip filters. On on-board LO is included. I have used and tested several converters from each manufacturer and have found all quite satisfactory.

Both downconverters use a 2 meter IF (Intermediate Frequency). For those of us who don't have a 2 meter multi-mode box, it is a simple matter to connect the S Band converter to a 2 meter converter feeding an HF rig. My own setup for AO13 routes the converter into a 2 transistor 2 meter to 10 meter converter which feeds a 20 year old Drake (vacuum tubes!) receiver. Works fine. On the Microsats, substitute the 13cm downlink arrangement and a suitable receiver for your normal (mode J) 70cm downlink equipment.

A word of caution to those using 2 meter multi-mode rigs. Some brands are known to transmit a brief pulse when initially powered up. Since transmitting into the back end of a converter may be the last signal it ever hears, it is best to power up the multi-mode rig before connecting the converter.

That's all there is to the "practice" of S band, hardware-wise. These higher frequency bands are the wave of the future. And are surprisingly easy to become active on.

Sources:

Down East Microwave (Bill Olson W3HQT)
Box 2310 RR1
Troy, Maine 04987
(207) 948-3741

Preamplifiers, converters and loop yagi antennas (kits and built)

SSB Electronic (U.S. rep Jerry Rodski K3MKZ)
124 Cherrywood Drive
Mountaintop, PA 18707
(717) 868-5643

Preamplifiers and converters. (All ready to use)

VITA Operations Using UOSAT-3

by

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and

Gary Garriott, WA9FMQ, Director, Informatics, VITA

I. Introduction to VITA

Volunteers in Technical Assistance is a not-for-profit organization dedicated to providing technical and project assistance to developing countries. For more than thirty years VITA has provided by-mail as well as on-site assistance through its Inquiry Service and long-term overseas programs. A small central staff headquartered in Rosslyn, Virginia, is supplemented by field personnel in eight countries as well as a volunteer roster of over 5000 highly skilled technicians and engineers. VITA has published over 200 technical papers and books dealing with a wide range of development applications from agriculture to water supply, generally emphasizing low- or medium- cost technologies that can be locally produced and maintained in rural settings.

II. History of VITASAT Program

In 1980 VITA began to experiment with alternatives to the by-mail diffusion of technical information. At that time, about 25 two-way real-time audio teleconferences were held over the PEACESAT network. PEACESAT was made up of user groups throughout Oceania and the South Pacific using relatively low-cost terminals on the ATS-3 NASA satellite. While this experience revealed the power of interaction between users and VITA volunteers, it also pointed out the difficulties in effective real-time links over many time zones and the possible advantages of asynchronous communication. VITA also began doing semi-regular broadcasts over the Voice of America on technology overviews at this time.

In 1983 VITA contracted with the Radio Amateur Satellite Corporation (AMSAT) to develop a technical specification and design definition for a LEO PACSAT mission. This activity culminated in a meeting held at Wang Laboratories late in 1983 at which the University of Surrey offered to make its UOSAT-2 bus available for a "Digital Communications Experiment" package if it could be readied in time. Over the next six months AMSAT and VITA volunteers, coordinated by a VITA-paid consultant, managed to complete the DCE and integrated it into UOSAT-2. It was subsequently launched by NASA in March of 1984 and continues to function to this day. VITA's amateur DCE station was established in May 1986 and has been used for occasional demonstrations and training sessions.

The DCE was, however, inappropriate for regular communication regarding VITA's development "business." Subsequently, an effort was undertaken to acquire an experimental license on "non-amateur" frequencies to be able to take advantage of upgraded technology as well as to introduce store-and-forward communications to a limited number of demonstration stations in developing countries. Funding was also acquired from a variety of US government and non-government sources to support the design of the "PACSAT Communications Experiment" providing in-orbit testing as well as two "production" PCE-type payloads for a future operational, dedicated satellite. VITA also purchased satellite transmitters and receivers using the experimental frequencies.

The PCE on UOSAT-3 was subsequently developed by Surrey Satellite Technology, Ltd., and successfully launched by Arianespace in January 1990. It was commissioned early in 1991 and has provided over 100 amateurs from almost 30 countries with many exciting moments and fairly reliable communications to boot! Recently, operations on the experimental frequencies were initiated.

VITA's goal is to use the experience gained from PCE operations to develop the corporate track record and infrastructure to support a fully-dedicated satellite for launch sometime in 1993 (VITASAT-A) which could support at least 500 ground stations worldwide. A second satellite (VITASAT-B) could increase this figure to as much as 1000 with a spare on the ground. To this end, VITA has initiated a difficult (and expensive) process to get FCC authorizations and rules created to support a non-profit LEO store-and-forward satellite service, while simultaneously working to promote adoption of similar allocations at the World Administrative Radio Conference to be held in Spain in early 1992. Table I lists those frequencies proposed to be used by VITA on both the PCE and VITASAT-A/B. VITA was invited to participate in the launch of UOSAT-F, but with the exception of a back-up capability negotiated with the primary US customer (SatelLife), opted instead to pursue the operational phase with its available resources (VITASAT A/B).

III. Objectives of the PCE phase, VITASAT Program

As noted, VITA hopes to gain useful experience from the PCE and its utility in real-life development and relief situations in Third World countries. To this end, it is negotiating Memoranda of Understanding with sponsors who are other non-profit organizations, educational institutions, government bodies and development agencies responsible for acquisition of licenses/authoriza-tions as well as operations. VITA plans to use its staff and volunteers--all radio amateurs--to perform on-site installations while simultaneously conduct-ing operator training. Software is being independently developed and constantly upgraded and evaluated. Initial software development was through a contract with the Virginia Polytechnic Institute (Blacksburg, Virginia).

The first tier of installations will be made using the "fixed station" equipment complement as noted elsewhere in this paper. A "portable station" is also under development which will be deployed in selected disaster response and mitigation sites, such as refugee camps and AIDS epidemiology work in Africa.

VITA expects that 30-40 PCE demonstration stations will be established throughout Asia, Africa and Latin America with perhaps 50% of these in Africa. General topical areas are education, energy/environment and health.

Performance of ground stations in this demonstration phase will be evaluated by VITA using both technical and sociological criteria.

IV. Overview of VITA Field Sites

Besides providing for other organizations to use the PCE, VITA will also be using the system for at least two of its own projects.

One will be based in Peshawar, Pakistan, where VITA provides cross-border assistance to increase agricultural production in Afghanistan. The present objective is to restore the Afghan agricultural infrastructure, which has been badly damaged by more than a decade of war and enforced neglect. Primary attention in this project is given to the repair of irrigation systems essential to the production of wheat and other crops needed to feed the people and of the roads and bridges making it possible to bring farm produce to market and deliver improved seed, fertilizer, and other farm inputs to the villages. The ground station will be jointly operated by VITA and the United Nations High Commission on Refugees.

Another project is located in Djibouti, a small country on the Horn of Africa, where VITA has been working since 1982 with the National Institute for Higher Scientific and Technical Research. The goal in this project is to help the government reduce the country's dependency on imported fossil fuels. VITA has introduced conservation techniques and renewable energy technologies and helped develop a long-term national energy strategy. VITA also helped set up a permanent National Energy Council, revise building codes, and conduct a publicity campaign promoting energy conservation.

We expect to install these stations in October and November, 1991.

VITA is not the only non-profit organization planning a series of installations for its projects. An arrangement supporting other multiple installations has been made on a case-by-case basis with other organizations. One of these is SatelLife. While a newcomer to the international development arena, SatelLife has been notably successful to date in its goals to promote LEO satellites for the exchange of health information. SatelLife expects to install PCE ground stations in a number of East African countries linking medical schools in the "ESANET" countries which at this date include Kenya, Tanzania, Uganda, Zambia, Zimbabwe and Mozambique. SatelLife's Memorandum of Understanding with VITA includes a "non-interference" provision between the PCE and UOSAT-5 on which SatelLife intends to be a major user. VITA and SatelLife are attempting to coordinate many of their activities since the similarity of their goals and use of the same satellite bus can provide system redundancy if and when required.

V. PLAN International Installation - Sierra Leone

PLAN International (formerly Foster Parents Plan) had originally proposed setting up a ground station at their regional headquarters in Dakar, Senegal, and in Conakry, Guinea. In both instances, the local PTT's refused to grant permission. While Sierra Leone had been the third choice for PLAN, it was a fortuitous one for VITA, as the communications infrastructure in this, the poorest of African countries, is virtually non-existent.

For one who has not travelled to Sierra Leone, it is difficult to understand the degree to which PLAN's Freetown office is cut-off not only from its International Headquarters in Rhode Island, but too, the two offices it operates up-country in Makeni and Moyamba.

After years of providing intermittent commercial mains power in Freetown, none has been produced since mid-February. Those that want or need electricity and all it provides (pumping of water and sewage, refrigeration and air-conditioning) must generate it themselves. To that end, PLAN has two diesel generators, one
25 kva and a backup of 7.5 kva. The generators are only run during business hours.

The telephone system is at best erratic. Messages between the three PLAN offices are relayed by courier or HF [voice] radio. To originate international telephone calls -- and thereby send faxes or telexes, PLAN is at the mercy of SLET, the Sierra Leone External Telecommunications Company. A call is placed to the overseas operator, who is given a list of the overseas numbers to be called. Later in the day, the operator calls PLAN's office with the connection(s).

As can be imagined, this method of calling overseas is not terribly reliable. Fax and telex service are especially poor, the former dependent upon high quality telephone circuits, while the later is dependent on another set of operators who re-key the message and send it out of the country.

To overcome these difficulties, PLAN's Country Representative in Sierra Leone, Mohan J Thazhathu, took it upon himself to secure the proper licensing necessary to establish a VITASAT station in Freetown. With UO-14 and later with VITASAT-A & B, Mohan envisions a time in the not-to-distant future when he can send his monthly reports, financial statements, and other administrative materials via satellite to PLAN's International Headquarters.

In addition to establishing the VITASAT ground station, PLAN also purchased three PK-232 terminal node controllers to further connect the offices in Sierra Leone.

As with any project overseas, a great deal of preparation went into the establishment of this station. Equipment from a variety of manufacturers had to be evaluated, and bid specifications prepared. Once a decision was made to go with a particular piece, it had to be integrated into the system. One particular problem we've run into is the difficulty in obtaining the Kenwood TS-790A transceivers. For unknown reasons, this radio has become particularly hard to obtain.

[A listing of the equipment we use for our installations is included in Table II.].

As required, the equipment was modified by a vendor in Washington, DC. This included the installation of a buffer/summing amplifier (designed by John Musson, WD8MQN, at Virginia Polytechnic Institute) between the varactor and FSK input, expanding the transmit and receive range of the radio, setting the deviation, and tapping the discriminator for the audio output.

Documentation for the installation of the hardware and use of the software had to be written, edited, proofed, (re-written) and collated.

The equipment was then inventoried and packed in two footlockers and two boxes for transport with Eric Rosenberg to Freetown. This was easier said than done. Flying on two different carriers -- one American, one Dutch -- subjected him to two different sets of rules for overweight baggage. After a false start which sent him back to re-distribute the weight of the footlockers, the overweight baggage tariffs were paid and Eric was off to Freetown.

Eighteen hours and three flights later, Eric arrived in Sierra Leone. The equipment arrived intact, and unscathed. His suitcase, on the other hand, did not appear for another eight days.

Installation of the antennas and related equipment was straight-forward. While the pace was slower than what he might have expected in the USA, no difficulties were encountered. Bringing everything from electrical tape to feedline and almost everything in-between kept the project close to schedule.

While the antennas and roof tower were going together outside, inside the office PLAN personnel set about hooking up the radio and installing the software on a NEC Powermate computer. PLAN has made a sizeable investment in computers in the Freetown office, and its staff is quite knowledgeable in their use. Installing the software and training the staff to run the station turned out to be a relatively easy task, with PLAN's staff as eager and intelligent students.

In preparing for this and future installations, we had decided that the initial check-out of the ground station would take place on the amateur bands. This would allow us to check out the equipment and give the individual installing the equipment an opportunity to use his free time to give out a 'new one' on the satellites.

On his arrival in Freetown, and with the intervention of Dave Heil, 9L1US, Communications Officer at the US Embassy, Eric was given permission to operate on the amateur bands as 9L1/WD3Q.

The Officer in Charge of Frequency Management for the Sierra Leone National Telecommunications Corporation is Cassandra Davies. Mrs. Davies, in addition to passing judgement on the viability of this project, is 9L1YL -- and President of the Sierra Leone Amateur Radio Society. During his time in Sierra Leone, Eric went to the Radio Society's monthly meeting and gave a short talk about amateur satellites, VITASAT, and the PLAN project in Freetown. In addition, the extra feedline from the PLAN installation was donated to the Society for it's newly established club station.

To say that the station worked on the amateur bands would understate the point. This location stands alone in the satellite's footprint for the entire pass. A large number of transactions can and did occur between the satellite and the ground station.

Based on our experience at the VITA HQ station in Washington, Eric brought a 2 meter amplifier for the uplink. This proved to be unnecessary. What he was not prepared for was an extreme amount of interference on the VITA [429 Mhz] downlink. In a country that has no monitoring service, and without another radio capable of receiving in the UHF frequency range, Eric was unsuccessful in tacking down the source of the interference. However, Mark Oppenheim, KD6KQ, returned to Freetown in early September and was successful in identifying the interference as a T-carrier (wideband, multi-channel telephone link). He subsequently traced it to SLET, the national telephone company, which is using the link for telephone traffic between Freetown and the airport area, 15 miles to the north. It is hoped that the licensing authorities will be able to convince SLET to move the offending signal carrier.

VI. Expectations of the PCE

It is our hope that a viable communications network will be established among development agencies and organizations. To that end, we hope to establish as many as 20 ground stations in sub-Saharan Africa, Asia, Oceania and Latin America by the end of this calendar year. The next stations to go on line will be at VITA projects in northern Pakistan and Djibouti. Soon thereafter, we expect other stations to be established in West Africa.

The PCE on UO-14 is a service shared by amateurs and non-amateurs. Increased use of the non-amateur piece of the will, naturally effect the amateur side. Based on the present activity on the PCE, one may assume that the UO-14 user community in northern Europe, and North America could see little differences in the operation of the satellite. However, as the requests for the non-amateur use of the PCE grow, this may change. Considering that some of the files being up- and downloaded could be as large as 100 kbytes, the satellite may not always be available when an individual wants to access it.

At the present time, the satellite's transmitter switches over to the VITA downlink frequency for between 250 milliseconds to five (5) seconds out of every twenty-five (25). This may increase over eastern North America as we interact with the satellite from our station in Washington. As the satellite will accommodate two users at any one given time, regardless of where the user comes in, we will be subject to the **FULL** flag as much as anyone else.

VITA software is under continuous evolution and development. The current version allows the user to create a list of transactions (uploads, downloads, directories) to be attempted in the connected (FTL0) mode during the next pass. As with PG, it waits for the "Open:" flag before attempting to connect to the satellite. Additionally, users can select files to list or download by source, destination, type and upload date.

Future versions of the software will automatically request downloads of files over a certain size (most likely 8 kbytes) as broadcasts and not in the connected mode. Likewise, uploaded files over a specified size (most likely 4 kbytes) will automatically be compressed prior to uploading. Again, as we are in the demonstration phase of this project, we expect to modify the software to suit the actual, real-world needs presented by our user base.

VII. How Individuals Can Cooperate with VITA

No low-earth orbiting satellite can exist without the help of the amateur satellite community. As we discovered in Sierra Leone, the local amateur radio community can be of assistance in supporting this project. Those of us working on this project have been involved in the satellite community and active on other amateur satellites for years.

But we cannot do it alone. VITA is an organization that runs on volunteer power. We are always looking for qualified individuals to work with us on our various projects, in this instance setting up ground stations in the developing world. If you have experience installing and operating a UoSAT-14 station, and are interested in travelling to the developing world to set up similar stations, we would like to speak with you!

VIII. The Future -- VITASAT Program

While VITA is currently in Phase Two of its three-phase program, we have continued to look forward to Phase Three -- construction and launch of a fully dedicated and operational store-and-forward satellite system (VITASAT-A/B), perhaps beginning as early as 1993. The approach taken by VITA's Board of Directors is to participate as fully as possible in domestic and international proceedings creating the service structure and frequency allocations necessary to make VITASAT a reality. Once at least a temporary construction authorization from the FCC has been acquired, negotiations will begin in earnest for a suitable launch opportunity. Such an authorization may be forthcoming within the next few months.

To date VITA has filed an "Application for Authority to Construct a Non-Profit International Low-Earth Orbit Satellite System" and a companion "Petition to Establish a Non-Profit International Low-Earth Orbit Satellite Service" with the FCC. In addition, VITA has participated as much as possible in proceedings leading
toward a favorable acceptance of Low Earth Orbit satellites at the World Administrative Radio Conference (WARC-92) to be held in Spain during February-March 1992. Partly due to VITA's work in domestic joint working group and industry advisory committees as well as the ITU's CCIR (technical communications committee), Low Earth Orbit satellites are on the WARC-92 agenda. While VITA's application technically describes a "fixed satellite service", we have made our proposals compatible with the "mobile satellite service" language to be considered by the WARC-92.

As this paper is written, the FCC has adopted a Report and Order recommending to the U.S. State Department that most of the 137-138 MHz band be allocated to LEO MSS on a co-primary basis with other services, with remaining LEO MSS use of this band on a secondary basis to the meteorological-satellite service; and that the 148-149 MHz and 400.15-401 MHz bands be allocated to LEO MSS on a co-primary basis. This is entirely consistent with VITA's proposals. No existing amateur frequencies are involved.

In summary, we believe that the VITASAT program has used resources available through amateur radio in an appropriate manner throughout the program. Phase One was a "proof-of-concept" experiment using amateur frequencies and volunteers, all of whom held amateur licenses. Phase Two still uses amateur radio volunteers and frequencies for testing purposes only, with "operations" on "non-amateur" frequencies (see Table I). VITA paid for the design of the PCE which has contributed to its success to date for the amateur satellite service. Phase Three will no doubt still use the human resources available through radio amateurs, but in terms of operation will be totally separate from the amateur satellite service.

VITA acknowledges a debt of gratitude to radio amateurs as individuals and to the amateur radio service which has and is providing an experimental environment for the development and evolution of the VITASAT system. VITA has actively promoted amateur radio among the non-hams it has worked with and has consistently tried to extend its appreciation of the contributions made by amateurs to the non-amateur public. Many hams have become VITA volunteers and we solicit others interested in joining VITA to become volunteers as well. We are proud of our working relationship thus far with the amateur community and look forward to continued and expanded contact with those supportive of our efforts.

VITA Volunteer Hugh Pett, VE3FLL, described his commitment seven years ago upon the successful launch and commissioning of the DCE on UOSAT-2 this way:

"If we are able to put more food on somebody's table five years from now, we'd be extremely proud of our efforts."

While that dream is a little "behind schedule," it is still very much alive.

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Table I.

VITA PCE and Proposed VITASAT Frequencies

	UPLINK	DOWNLINK
PCE	148.560	429.985 *
	148.260	428.010 *
VITASAT **		
"Solution A"	400.175	137.705
	400.225	137.735
	400.275	
"Solution B"	149.825	400.175
	149.855	400.225
	149.885	

* These frequencies are in bands classified as "shared" government and non-government (amateur) in the United States. Before the experimental application was submitted to FCC, consultation with ARRL was conducted and a determination made that any existing amateur activities would not be unreasonably disrupted.

** Solution A is fully compatible with a continuous coverage domestic LEO system using FDMA techniques (proposed by OrbComm). Solution B is fully compatible with a continuous coverage domestic LEO system using spread spectrum techniques (proposed by Starsys).

Table II.

Equipment used for VITASAT (PCE) Fixed Ground Stations:

80386SX -type computer

VITA	VGS software package (written by Dave Carre)
Kenwood	TS-790A dual band transceiver
PacComm	Micropower-2 Terminal Node Controller NB96 internal 9600 baud FSK modem
VPI/PacComm	Summing/Buffer amplifier board (for TS-790A)
M^2 Enterprises	2M-CP14 or 149T-C14 uplink antenna 436-CP30 downlink antenna
L.L. Grace Co.	KC Tracker Package for Yaesu 5600A Controller KC Tuner Option N4HY Quiktrak
Yaesu	KR-5600A rotors
Astron	RS-20A/220 power supply
Mirage/KLM	KP-2/70cm Mast-Mounted preamplifier for 430 Mhz

Table II.

THE PACSAT COMMUNICATIONS EXPERIMENTAL NETWORK

VITA has negotiated Memoranda of Understanding with several development organizations to use the PCE on a limited basis, and is now linking its prototype ground station for this purpose. The goal of the PACSAT Communications Experiment is to test the prototype VITASAT system through a limited number of pilot ground stations (35-50); the results of this phase of the program will be integrated into the design and construction of the operational satellites, VITASAT A/B.

PROBABLE SCHEDULE OF GROUND STATION INSTALLATIONS

1991

July

1. Sierra Leone

Linking PLAN International office in Freetown to VITA; eventually to headquarters in Rhode Island for normal administrative communications.

August

2. Tanzania

Linking electrical engineering departments of University of Tanzania, Dar Es Salaam, and University of Southampton, UK, for research exchange and batch processing experimentation

3. Djibouti

Linking VITA/ISERST office to VITA Arlington for scientific and experimental communications; training Christian Aid representative for installtion of goround station in Somaila.

November

4. Pakistan

Linking VITA Peshawar and United Nations High Commission on Refugees in Peshawar to VITA Arlington and the United NAtions Geneva for normal administrative communications

5. Somalia

Linking Christian Aid water project in northeastern Somalia through VITA Arlington to head office in London (UK)

November (cont..)

6. Ghana
7. Nigeria
8. Sierra Leone
9. Gambia
10. Vancouver

Linking stations at educational facilities in these countries to Commonwealth of Learning office in Vancouver (Canada) supporting West African Teacher Training (WATT) project.

11. Niger
12. Guinea Bissau
13. Mali

Linking AGRHYMET offices (Niger, funded by USAID and staffed by USGS) to national centers above for regional exchange of meteorological and climatic information/data exchange

14. Guatemala

Linking health program in Amatitlan to US-based health resources (National Library of Medicine) through VITA Arlington

15. Cuba

Linking Academy of Sciences in Havana to UNDP offices, New York through VITA Arlington

16. Indonesia

Linking office of Bandung Institute of Technology in Jakarta to outlying health centers outside Java. Possible use of two portable ground stations.

1992

January

1. Beirut
2. Nairobi (after initial success of Beirut operation)

Linking offices of YMCA International/Chicago to countries above for routine and urgent administrative operations, including disaster response and rehabilitation

PENDING:

1. Tanzania - Tropicales (Moshi) Institute for Tropical Architecture serving rural areas with international information centers, through VITA

2. Indonesia, Singapore, USSR, Israel, Argentina - Center for Information Systems and Research (US) for demonstration of linking educational systems and technology for improving educational opportunities for children

3. Nigeria - Trinity College Dublin and University of Nigeria at Nsukka to strengthen existing educational exchange programs

4. Zaire - Assoc Metals & Mineral Corporation (owned by the Government of Zaire) for improved market access through VITA Arlington

5. Nicaragua - University of Massachusetts/Amherst and National Engineering University/Managua for the exchange of data collected by remote data platforms on a hydroelectric power plant in La Fundadora, outside Managua

6. Kenya, Tanzania, Uganda, Zimbabwe, Mozambique - other medical schools in ESANET project sponsored by SatelLife

A RADIO ASTRONOMY EXPERIMENT FOR PHASE III-D AND THE SOLAR SAIL

Daniel Schultz, N8FGV

The upcoming launch of the Phase III-D satellite and the possible launch of one or more Solar Sail spacecraft both represent outstanding opportunities to carry science instruments to interesting places in the near Earth and interplanetary environment. Phase III-D will travel in anelliptical orbit with apogee high above the northern hemisphere of Earth, while the solar sail spacecraft may attain escape velocity and travel through the interplanetarymedium at great distances from Earth. A recent proposal from AMSAT-DL may even allow the two missions to be combined intoa single launch, by carrying a small interplanetary spacecraft inside the adapter cone that will be part of the Phase III-D structure. If this small spacecraft could carry and deploy a small solar sail, it may provide the launch opportunity that the solar sail community has long been waiting for.

In addition to their primary communications payload, the recently launched Microsat satellites carried several small science experiments, including an acoustic particle detector, an ultraviolet spectrometer, and a fluxgatemagnetometer. These simple instruments were designed by student groups at various universities and high schools. We should be considering what similiar type of science instruments could be built at low cost and flown aboard the Phase III-D and solar sail spacecraft.

Although most spacecraft science instruments cost many millions of dollars to develop and build, a radio receiver operating in the VLF to HF frequency range could possibly be constructed on an amateur budget. Few efforts have been made to collect radio astronomy data at frequencies below the Earth's ionospheric cutoff frequency, so this region ofthe cosmic radio spectrum represents a largely unexploredterritory, with the potential for new scientific discoveries.

The decimetric radiation from Jupiter is the radio source best known to amateur radio astronomers, but the Earth itself is a powerful radio source at kilometric wavelengths, in a frequency range of 50 kHz to 1 MHz. Thisradiation is generated by an unknown mechanism involving charged particles moving along magnetic field lines in the Earth's magnetosphere. It is known to be associated with the occurrence of the aurora in Earth's upper atmosphere, and is therefore known to scientists as auroral kilometricradiation (AKR for short). These radio signals are reflectedback out into space by the same ionosphere that reflects our amateur radio signals back to the ground and which was the cornerstone of long distance amateur radio communications in the pre-satellite era. The AKR is therefore not detectablefrom the ground and the existence of this phenomenon was totally unknown before the beginning of the space age, when satellites carrying VLF receivers were lofted above the ionosphere for the first time. The AKR emission is quite strong and would most likely wipe out the AM broadcast band were it not for the shielding provided by the ionosphere. For this reason, the proposed spacecraft receiver must have a very high dynamic range to protect against overload from strong AKR signals.

In an effort to understand the generation mechanism for AKR, and to otherwise study the Earth's magnetosphere, a large number of geophysical scientists are planning the International Solar Terrestrial Physics project, in whichsatellites built by several nations will be launched in the late 1990's into a variety of different orbits. Many of these satellites will carry VLF radio receivers and an effort will be made to correlate the data from these different receivers to form a high resolution map of the AKR source regions in a manner similiar to the Very Long Baseline Interferometry method employed by ground based radio astronomers to produce high resolution maps of extraterrestrial radio sources. The high inclination elliptical orbit of Phase III-D will allow a proposed VLF receiver on board that satellite to get an excellent view of the AKR source region. The Phase III-D spacecraft could thus become a participant in the ISTP project by providing an additional set of baselines for VLBI correlation, provided that the receiver was designed in such a way as to be compatible with the data format of the ISTP project. The solar sail could also contribute data to this project while it is still in the vicinity of the Earth.

In addition to studying the Earth's radio emissions, a radio astronomy receiver could also attempt to map discrete cosmic noise sources occurring outside our solar system and to obtain data about the interstellar medium and radio emissions from the Sun and Jupiter. The Radio Astronomy Explorer satellites launched two decades ago attempted to measure cosmic noise sources but were largely thwarted by the unexpected high intensity of the AKR radiation which overloaded their recievers. A receiver designed with the AKRoverload problem in mind might be able to complete some of these measurements.

The solar sail spacecraft will eventually escape Earth's gravity and enter a solar orbit, if all goes well. At this point it will be exposed to the solar wind, a high velocity stream of gas which is expelled from the upper atmosphere of the Sun. The sail itself will present a very large cross section to the solar wind, and the interaction between the sail and the solar wind will produce bow shock and wake effects similiar to the wake made by a boat as it passes through water. This disturbance in the local plasma environment will lead to electromagnetic effects which could be detected and measured by the VLF receiver on board the spacecraft.

During the Voyager flyby encounters with Saturn, Uranus, and Neptune, the Plasma Wave Instrument from the University of Iowa measured small bursts of noise associated with the passage of Voyager through the ring planes of each of these planets. It was originally thought that the noise bursts were caused by dust particles impacting with very high velocity on the antenna of that instrument, but by the time Voyager reached Neptune it was understood that the electromagnetic noise bursts were associated with dust impacts occurring all over the spacecraft. The high kinetic energy of the particle impacts produces a small quantity of plasma which is responsible for the radio noise burst. The very large cross section of the solar sail will intercept a great deal of interplanetary dust as it travels through the inner solar system, and a VLF receiver could provide measurements of the dust impacts that occur anywhere on the sail.

The most difficult aspect of integrating a radio astronomy experiment on board either Phase III-D or the Solar Sail will be the mounting and placement of appropriate antennas. A resonant VLF antenna structure would be so large as to be out of the question for the Phase III-D spacecraft,although a smaller antenna could be mounted on the spacecraft and still provide valuable results. The AKR radio emission could be detected with practically no antenna at all, or with the aerospace equivalent of a coat hanger antenna. It might also be possible to couple the VLF receiver to the existing VHF and UHF communications antenna support structures. The Solar Sail spacecraft presents an interesting opportunity to integrate a large antenna into the structure of the sail, indeed the sail itself will be a part of the antenna whether we want it to be or not. A theoretical effort to model and understand the radiation pattern of the sail when used as anantenna would be a valuable effort.

A crucial limitation for these experiments will be the ability of the spacecraft downlink to transmit data at a rate sufficient to return a usable amount of science data to Earth. A small DSP computer could provide some preprocessing of raw data prior to transmission to Earth, and would also provide the ability to uplink new operating parameters to the experiment in response to changing conditions and operational experience. It might even be possible to program the DSP computer to recognize interesting events as they occur and capture them in memory at high sampling rates for transmission to Earth at a much lower bit rate. This would also provide AMSAT with some experience in building and flying DSP chips in the space environment.

Cost considerations may require the receiver to be built with commercial grade components, which may suffer failures in the space environment, so it would be quite desirable to design the receiver with enough redundancy to allow the experiment to survive a single point failure and continueoperating with some capacity. Sufficient radiation shielding must be provided to protect chips from excessive radiation exposure from solar flares and the Van Allen belts.

There is a small but growing interest in radio astronomy among radio amateurs, and a radio astronomy experiment on board one or both of these spacecraft would do much to increase that interest and would provide educational opportunities for students in analyzing the data that would be returned from such an experiment.

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DEMONSTRATING CELESTIAL MECHANICS THROUGH MEASURED DOPPLER SHIFT

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ABSTRACT

Stable orbits (of natural and artificial satellites alike) require an equilibrium between gravitational and inertial forces. For a given satellite altitude, or orbital radius, there is but a single orbital velocity which affords such an equilibrium state. This paper shows how students at the Pennsylvania College of Technology utilize Doppler shift measurements of received satellite telemetry signals to accurately determine the orbital period of Amateur Radio communications satellites, and from it, their other orbital parameters.

FUNDAMENTAL ORBITAL MECHANICS

A stable orbit, whether of a satellite around a planet or a planet around a sun, requires that the inward pull of gravity and the outward pull of inertia be equal. Kepler tells us that all satellites orbit their primaries in an ellipse, and that orbital velocity changes throughout the elliptical orbit (fastest at perigee, slowest at apogee) in order to maintain equilibrium. For the present study, we will restrict ourselves to analyzing the behavior of satellites in roughly circular orbits (that is, orbital eccentricities near zero), so that the satellite's orbital velocity is essentially constant. Fortunately, the current generation of MicroSats fills the bill almost perfectly.

Newton's famous Inverse Square Law shows the force of the gravitational attraction between any two bodies to equal a fudge factor (the Universal Gravitational Constant), times the product of their masses, divided by the square of the distance between their centers of mass. Mathematically,

$$F = GMm / r^2 \qquad \text{[Equation 1]}$$

where M is the mass of the primary (in our case planet),
m is the mass of the secondary (satellite),
r is the distance between them (the orbital radius),
and $G = 6.673 * 10^{-11}$ Nt m^2 / kg^2, Newton's Universal Gravitational Constant.

We now consider the force of inertia pulling a satellite out, which (again according to Newton) equals:

$$F = mA \qquad \text{[Equation 2]}$$

where m represents the mass of the satellite,
and A is its acceleration, which in a circular orbit is found from:

$$A = v^2 / r \qquad \text{[Equation 3]}$$

with v representing the velocity of the satellite,
and r the orbital radius, as defined above.

Combining Equations [2] and [3] gives us:

$$F = m v^2 / r \qquad \text{[Equation 4]}$$

from which we could determine the inertial force acting on the satellite, given its mass and orbital velocity. Velocity is of course related to orbital period, which we will derive shortly from Doppler shift measurements.

Since our Amateur Radio satellites appear (thankfully) to be in stable orbits, we set Equations [1] and [4] equal to each other:

$$G M m / r^2 = m v^2 / r \qquad \text{[Equation 5]}$$

and then simplify:

$$G M / r = v^2 \qquad \text{[Equation 6]}$$

We can now solve Equation 6 for v:

$$v = (G M / r)^{1/2} \qquad \text{[Equation 7]}$$

or for r:

$$r = G M / v^2 \qquad \text{[Equation 8]}$$

and we see that the velocity and orbital radius of our satellite are inexorably linked, by readily determined constants.

DETERMINING THE GM PRODUCT

At the Pennsylvania College of Technology, second year electronics students have recently come up with an independent estimate of the Earth's mass, based upon recovering echoes from radio signals bounced off the surface of the Moon. Their novel EME experiment, which involved observing the lunar orbit and solving Equation 6 above for M, has already been treated in the literature [Shuch, 1991]. Their published result for the mass of the Earth, **$6.037 * 10^{24}$ kg**, appears to be in error by about 1%.

Let's utilize a more widely accepted value for the mass of the Earth: **$5.975 * 10^{24}$ kg**. Now we've already stated that Newton's Universal Gravitational Constant, a fudge-factor for dimensional consistency, is equal to **$6.673 * 10^{-11}$ Nt m^2 / kg^2**. Thus we see that the GM product encountered in Equations 7 and 8 above is not a Chevy at all, but rather $4 * 10^{14}$ m^3/s^2, a constant which relates radius to velocity for any satellite orbiting the Earth.

DOPPLER, AND OTHER SHIFTY CHARACTERS

The change in frequency of electromagnetic waves as a function of relative motion is now known as the Doppler shift. The phenomenon was first described by Johann Christian Doppler, a mathematics professor at the State Technical Academy in Prague, in 1842, in a paper delivered to the Royal Bohemian Society of Learning titled "On the Colored Light of Double Stars and Some Other Heavenly Bodies" (Magnin, 1986). Doppler shift varies directly with both the transmitted frequency and the relative velocity between the transmitter and receiver, and inversely with the speed of light. It is utilized in fields as diverse as aircraft radar (Shuch, 1987), spacecraft navigation, remote sensing, biomedical imaging, and of course satellite orbital analysis (Davidoff, 1978).

To understand the Doppler shift for electromagnetic waves, imagine the headlight on front of an approaching train, which is traveling at a substantial velocity - let's say, Mach 100,000, a tenth the speed of light. Now we know the radiation leaves the headlight at the speed of light, $3 * 10^8$ meters per second. Since it appears that the train is adding its forward velocity to that of the light beam, we would naively expect the light from the moving train to reach us at a speed 10% greater than that at which it left the bulb, or $3.3 * 10^8$ m/s.

But of course it can't. Einstein tells us that the speed of light in free space, whether measured at the point of transmission, the point of reception, or some point in between, will *always* equal exactly the same value, 300 million meters per second. The wave *cannot* change speed, regardless of relative motion between the observers. Yet the presumed additional velocity which we had expected the train's motion to impart to the wave has to go somewhere. And since it can't manifest itself in a speed variation, it instead varies the *frequency* of the wave.

The Doppler shift is remarkably symmetrical. It cares not whether the source of relative motion is the transmitter, the receiver, or some combination of the two. And the magnitude of the frequency shift is the same whether the length of the transmission path is increasing or decreasing, though of course its direction varies. Moving closer together, blue shift, increasing frequency. And moving farther apart, red shift, a decrease in frequency.

Radio amateurs have been aware of the Doppler shift within the context of space communications, ever since they began bouncing signals off the surface of the Moon nearly forty years ago. As the Moon is rising, moving toward us (or more properly, as we are rotating toward it), our echoes come back higher in frequency than the transmitted signal. The setting Moon (moving away from us, or more properly us away from it) gives us the opposite effect, down Doppler, decreasing frequency.

The phenomenon was spectacularly evident to those space communications pioneers who first recovered Sputnik I's 2Ø MHz beeps on October 4, 1957. [1] However, the Sputnik signals had so much chirp on them that more than one observer overlooked the Doppler shift as yet another manifestation of an instable transmitter. Today we often design the transponders of communications satellites with frequency inverting passbands, in an effort to partially cancel this ever-present "designed-in drift".

The easiest way to quantify the Doppler shift is to think of it as a simple ratio. The Doppler change in frequency f_d, is to the transmitted frequency (f_o) as the relative velocity (v) is to the velocity of the transmitted wave (which we know to equal c, the speed of light). We formalize this relationship as:

$$f_d / f_o = v / c \qquad \textbf{[Equation 9]}$$

The equation can also be solved for the relative velocity between the points of transmission and reception:

$$v = c * f_d / f_o \qquad \textbf{[Equation 1Ø]}$$

which will enable us to determine the orbital velocity of a communications satellite, from the maximum Doppler shift observed on its telemetry beacon, or other transmitted signal.

SATELLITE SLEUTHING

This avocation has been raised to the level of high artform by Geoff Perry and others of the legendary Kettering Group in England, and the techniques discussed here should certainly be attributed to them (Davidoff, 199Ø, 14-12 to 14-17). The key to determining the orbital characteristics of an "unknown" satellite is to observe Doppler-induced changes in its apparent frequency, and to graph them over time. If we can accurately observe Time of Closest Approach (TCA), along with Acquisition of Signal (AOS) and Loss of Signal (LOS) times, then we can estimate the satellite's orbital period. From that we can compute altitude and velocity, thence estimate AOS, LOS and TCA for future orbits.

The dedicated satellite sleuth relies upon not only direct observation, but past experience in determining orbital parameters. A thorough database of the characteristics of known satellites is built up, to which a newcomer can be compared in trying to determine its general orbit, and speculate as to its mission.

----

1. The word "beep" really is appropriate here, as the keyed signal was too long for a Morse "dit", and too short for a "dah".

SELECTING A SATELLITE

The true satellite sleuth delights in "discovering" new satellites, and working out as many of their orbital characteristics as possible, armed with little more than a receiver with which to recover their signals. The purpose of the present exercise is somewhat different: to demonstrate to the student the relationships between the orbital parameters of a satellite, and to illustrate how a balance of forces defines the orbit. Thus a truly "unknown" satellite is hardly a requisite. In fact, the exercise has even more instructional validity if the measurements are made on a satellite of known orbital characteristics, against which the student's results can be compared. Let us consider, for example, analyzing the 70 cm CW signals from the LUSAT-OSCAR 19 (MicroSat D).

This particular signal is chosen for my students' first exercise in orbital analysis for a number of reasons. The 437.127 MHz frequency is high enough to provide ample, easily observed Doppler shift (remember, f_d varies directly with frequency). The 750 mW beacon signal is strong enough to be readily received on relatively simple equipment. CW is the preferred modulation mode for accurate Doppler measurements, because the signal can be zero-beat on a receiver with direct digital frequency readout. Finally (and this is cheating), the orbits of low-altitude, circular, sun-synchronous, near-polar satellites such as all four of the 1990 MicroSats are especially well suited to the type of measurements required. In other words, if you pick a satellite with the right orbital parameters, it's easy to determine its orbital parameters! [2]

CONDUCTING THE EXPERIMENT

We begin much as the satellite sleuth begins, measuring Doppler shift over successive orbits and displaying it graphically. The procedure, well documented in the literature (Talcott Mountain Science Center, 1975), is repeated here for the benefit of those who might not have seen it in its entirety.

Once able to successfully (and consistently) receive the telemetry beacon from OSCAR 19, the student is asked simply to measure, as accurately as possible, the received signal frequency, at one minute intervals all the way from AOS to LOS. This is done initially for two successive orbits. The TCA of the satellite to the observer is indicated by the maximum slope of the plotted Doppler curves, as illustrated in Figures 1 and 2. These

----

2. There is a direct analog here to successful moonbounce communication (or any other exotic DX mode, for that matter): if you know in advance the other station's call, it's about 3 dB easier to pick his call out of the noise!

are of course the familiar Doppler S-curves, which we've used since the days of OSCAR VI. Their continuously varying slope (rate of change, or first derivative) holds the key to evaluating the satellite's orbit.

The time difference between two successive TCAs is a first order approximation of the satellite's orbital period. It is *only* an approximation, since the effect we are actually measuring involves not only the satellite's orbital motion, but also the eastward rotation of the Earth. For a more precise measurement, we determine the elapsed time between successive overhead passes.

FIGURE 1
LO-19, 22 Aug 91

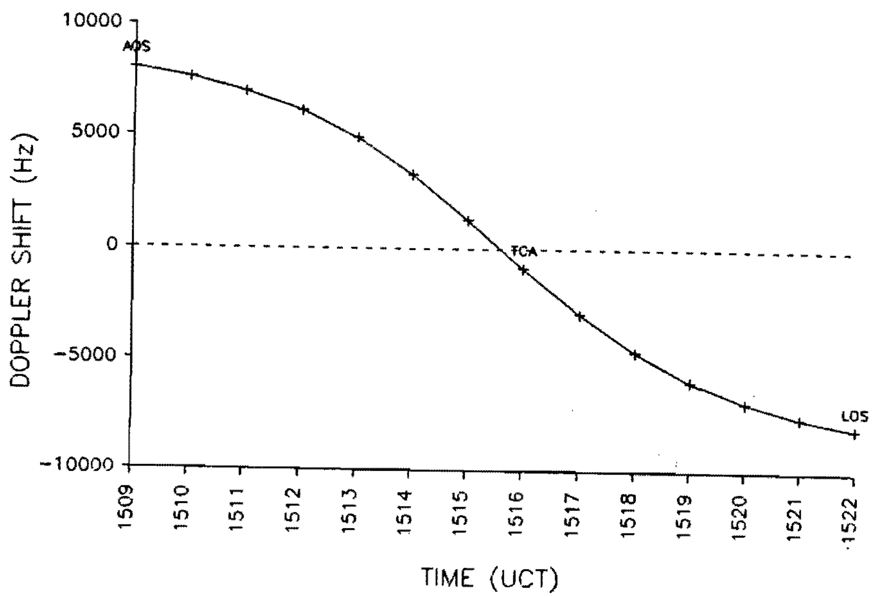
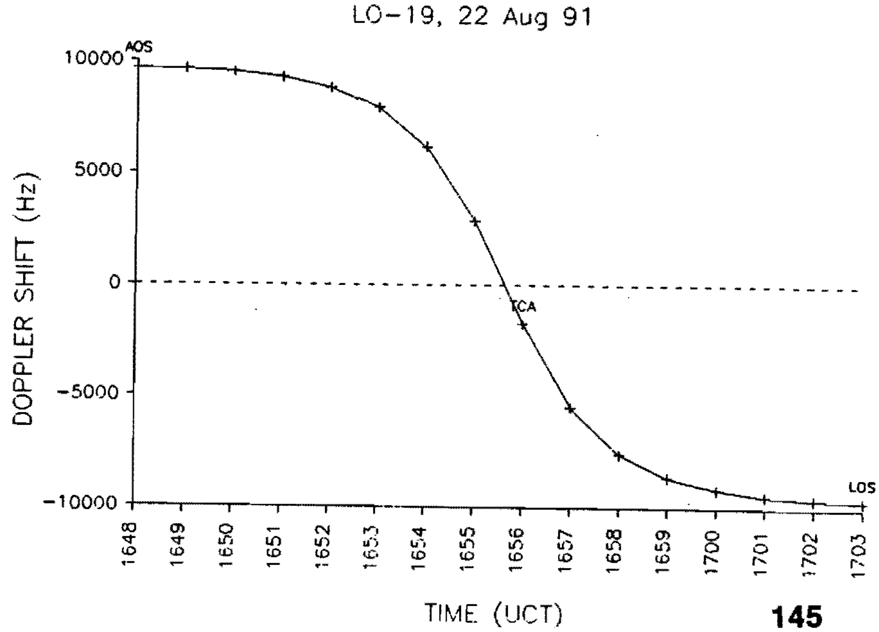


FIGURE 2
LO-19, 22 Aug 91



If the satellite is monitored for an extended period, eventually an orbit is encountered which closely approximates a direct overhead pass. This is evidenced by a maximum period of visibility (the difference between LOS and AOS), strongest signals at TCA, most rapid rate of frequency change around TCA, and maximum observed Doppler shift just at AOS and LOS. For the LUSAT-OSCAR 19 spacecraft, Figure 2 represents just such an orbit.

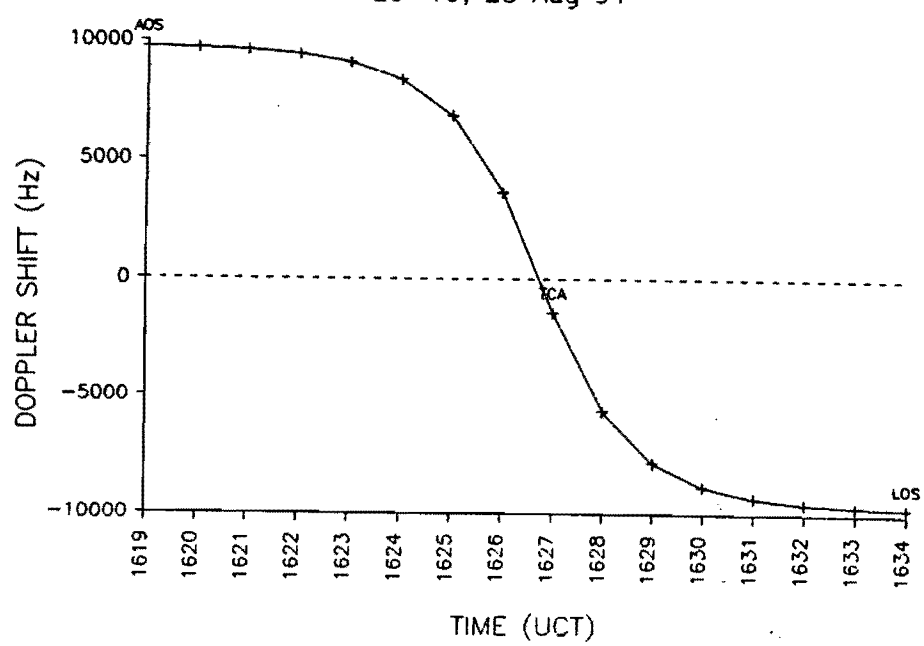
Our objective now is to produce a Doppler S-curve for the *next* overhead pass. With sun-synchronous satellites (and this is precisely why we chose one), the orbit tends to trace out identical ground tracks at one or two day intervals. So if we're persistent, within the next couple of days we'll see an S-curve which looks very much like Figure 2. In this example, we see the result in Figure 3.

The only thing we have to watch out for is that the two successive overhead passes must, as nearly as possible, be *identical* in relative motion. If the first observation (say, Figure 2) was made with the satellite ascending (moving from South to North), we don't want to use as our next orbit a pass in which the satellite is descending (moving from North to South). Directional beams should help to verify that both observations were made with the satellite traveling overhead in the same general direction.

Our Doppler S-curves (Figures 1 through 3) now contain all the information we require to determine orbital period, and from it, various other characteristics of the satellite and its orbit.

FIGURE 3

LO-19, 23 Aug 91



ESTIMATING ORBITAL PERIOD

The Doppler S-curves shown in Figures 1 through 3 depict received frequency over time, for 70 cm telemetry signals from the LO-19 satellite. Figures 1 and 2 represent two successive orbits, while the data for Figures 2 and 3 were taken one day apart. We will use the first pair of Figures to roughly estimate the orbital period of LO-19, and the second pair to refine our estimate.

Note in Figure 1 that the closest approach of the satellite to the observer (as indicated by the greatest slope of the Doppler S-curve) occurred at roughly 15 hours, 15 minutes, 36 seconds UTC. TCA for the successive orbit is noted from Figure 2 as 16:55:42, or about 100.1 minutes later. We thus have a rough estimate of orbital period, which contains an assumed error related to the Earth's rotation.

To correct the error, we note the TCAs for two successive overhead descending passes (Figures 2 and 3), which are seen to occur at 16:55:42 on one day, and then 16:26:48 the next. The elapsed time between these two overhead TCAs is thus 23:31:06 (1411.1 minutes), which must be nP, an integer multiple of the satellite's nodal orbital period.

But before we can accurately calculate P, we must have a value for the integer n. This we can determine by dividing the elapsed time between successive overhead passes, by the *estimated* orbital period. Mathematically,

$$n = \text{int}\ (nP / P_{est}) \qquad \text{[Equation 11]}$$

$$= \text{int}\ (1411.1 / 100.1) = 14$$

If two successive overhead TCAs are indeed separated by precisely (n = 14) orbits, then the exact orbital period must be that elapsed time divided by fourteen, or **P = 100.793 minutes**. Relative to this refined estimate, we see that our original estimate of orbital period, based upon two successive orbits, was off by about 0.7%. If we now compare our more exact measured value to that published for LU-19's orbital period [see Table 1], we see that we have reduced our error by roughly a factor of a hundred.

ESTIMATING OTHER ORBITAL PARAMETERS

It turns out that, for a circular sun-synchronous orbit, nearly all the important orbital parameters can be derived from the satellite's nodal period. This, after all, is why we picked this particular satellite for our experiment to begin with. I'll spare you the algebra and trig derivations; the pertinent equations are listed in the Appendix. With them, we calculate altitude, velocity, orbital increment, visibility angle, terrestrial range, access time, and Doppler shift for the LO-19 satellite.

TABLE 1
ANALYSIS OF RESULTS

Parameter	**Units**	**Observed**	**Theoretical**	**Error**
Period	min	100.793	100.8	0.007%
Mean Altitude	km	803.9	796.4	0.9%
Velocity	m/s	7454	7458	0.1%
Increment	°W/orbit	25.2	25.3	0.4%
Max. Doppler	kHz	10	10.3	2.9%
Max. Range	km	3045	3038	0.2%
Max. LOS-AOS	min:sec	15:00	15:20	2.2%

Table 1 above summarizes our results. Our "observed" values listed are either the results of direct student observation in the Penn College Telecommunications Lab, or values mathematically derived from those measured parameters. Similarly, the "theoretical" values shown are either published parameters for the LO-12 satellite given in Davidoff (1990, Appendices A and B), or values mathematically derived from those published parameters.

Note that the difference between observed and theoretical values[3] seldom exceeds a fraction of a percent. Does this mean that my students are uncannily precise? Hardly! Rather, we conclude that the experiment is structured to be forgiving of observational imprecision. We derived period, after all, by averaging elapsed time over fourteen orbits. Should this not reduce observational error by a factor of fourteen? Similarly, our Doppler S-curves depended not on *absolute* frequency measurement (always suspect), but rather on reasonably precise measurements of frequency *drift*. Even given dial calibration errors of several kiloHertz (the rule rather than the exception at UHF), we can still precisely estimate the rate of frequency *change*.

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3. To motivate my students, I hesitate to call them "errors", just "differences of opinion."

CONCLUSIONS

Since their inception in 1961, Amateur Radio satellites have significantly expanded our communications horizons. They have also proved an invaluable aid in the teaching of celestial mechanics, the study of how heavenly bodies interact. If there is truly an underlying order to the Universe, it is ham satellites which may best enable our students to glimpse it. As an instructional tool, the satellite may well rank in importance second only to the chalkboard.

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ABOUT THE AUTHOR

H. Paul Shuch has been utilizing satellites in the classroom for nineteen years, since the launch of OSCAR VI. He has been operational on all 19 ham bands between 1.8 MHz and 10 GHz, on modes as diverse as EME, meteor scatter, sporadic E, troposcatter and QRM. Paul holds a Ph.D. in Engineering from the University of California, Berkeley, where he won numerous fellowships and research awards. He has published half a hundred technical articles in engineering and scholarly journals, and is a co-author of the ARRL UHF/Microwave Experimenter's Manual. He holds AMSAT Life Membership #167, has served as Technical Director, Board Member, and Chairman of the Board of Project OSCAR Inc, and has chaired the ARRL VHF/UHF Advisory Committee. Dr. Shuch is listed in Who's Who in Aviation and Aerospace, Who's Who in California, Who's Who of American Inventors, and International Directory of Distinguished Leadership. He teaches flying when the bands are dead, and serves as an FAA Accident Prevention Counselor.

APPENDIX

PERTINENT CONSTANTS AND EQUATIONS

Inertia:	$F = mA$
Acceleration:	$A = v^2 / r$
Gravity:	$F = G M m / r^2$
Velocity:	$v = (GM / r)^{1/2}$
Period:	$P = 2 pi * (r^3 / GM)^{1/2}$
Increment:	$^{o}W = P (mins) / 4$ [+- Precession]
Gravitational Constant:	$G = 6.673 * 10^{-11}$ Nt m^2 / kg^2
Mass of the Earth:	$M = 5.975 * 10^{24}$ kg
GM Product:	$GM = 3.987 * 10^{14}$ m^3 / s^2
Mean Radius of Earth:	$R_E = 6.371 * 10^6$ m
Doppler Shift:	$f_d = f_o v / c$
Visibility Half-Angle:	$\Theta = \cos^{-1} (R_E / R_E + h)$
Max. Visibility Time:	t_{max} = Period * (2 Θ / 360 deg.)
Max. Terrestrial Range:	d_{max} = 2 pi * R_E * (Θ / 360 deg.)
Slant Range:	$SR = R_E * \tan \Theta$

SOLAR SAIL EXPEDITION TO THE MOON AND MARS
Mission Update

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ABSTRACT

An international scientific solar sail expedition and "race" to the Moon is planned for 1994. Participants from the United States, Europe and Japan are presently completing their spacecraft designs and arranging sponsorship. In 1990, a team led by the Los Angeles-based World Space Foundation was selected to represent "The Americas" and to participate in the so-called Christopher Columbus 500 Space Sail Cup to Mars. Now an arrangement has evolved whereby the "race" will be at least as much a scientific expedition.

AMSAT-NA has primary responsibility for the Solar Sail Race Vehicle (SSRV) avionic systems and tracking. As one of seven technical partners in the Solar Sail Project, AMSAT is to provide communications equipment and electronics for the spacecraft, with much of it based on Microsat and Phase III experience.

OVERVIEW

Although the time table may change a bit, the year 1994 is the target to initiate the international solar sail Earth-Moon expedition and race. The concept of solar sailing can be traced back to Russia in 1924 when Konstantin Tsiolkovsky and Fridrikh Tsander observed that light has momentum and when reflected by a mirror, a force is created. They surmised that if you have a very lightweight and large mirror or sail in space without aerodynamic drag, the force from sunlight will cause the sail to move without any propellant. The notion of a race was popularized by Arthur C. Clarke in his 1964 story "*The Wind from the Sun.*"[1]

A relationship between the Foundation and AMSAT-NA has been in place for eight years. Phase IIID spacecraft design elements, including an Amateur radio Mode S transponder, and tracking software are under consideration for functions aboard the SSRV.

In addition to AMSAT-NA, other partners with the Foundation on the SSRV are: McDonnell Douglas Space Systems Co., the Jet Propulsion Laboratory, Utah State University, Weber State University, The Planetary Society and Aura Systems Inc.

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[1] This short story, plus 15 other factual and fiction pieces on the theme of solar sailing, was published in 1990 in the paperback *Project Solar Sail*, edited by Arthur C. Clarke. New American Library/Roc Books, available at bookstores, $4.50. ISBN 0-451-45002-7. Proceeds benefit the Solar Sail Project.

PARTICIPANTS

The three expedition/race participants are: the Union pour la Promotion de la Propulsion Photonique (U3P) and Comision Vela Solar (CVS) for Europe, the Solar Sail Union of Japan (SSUJ) for Asia, and the World Space Foundation (Foundation) for the Americas. While the three groups are racing, they are also cooperating in a 3-way engineering and scientific expedition.

Founded in 1981 in Toulouse, France, U3P's objectives are to promote an Earth-Moon solar sail race and to build an entry in that race. Founded in 1989 as a part of the Aeronautical Engineer Association of Spain, CVS established the objectives of joining the U3P solar sail development project and soliciting funding through the Columbus Quincentenary activities in Spain.

SSUJ was created in 1985 in Sagamihara, Japan and took over the effort to study solar sails from the Japanese Rocket Society, established in 1982.

The Foundation is the oldest of the three race participants and was founded in 1979 in South Pasadena, California. The Foundation promoted the idea of using solar sails initially for asteroid rendezvous and other applications and has since developed engineering models and the world's only solar sail manufacturing facility.

THE RACE

Launch for all three spacecraft as a single "composite" package is currently planned for 1994 on an Ariane 4. The three spacecraft will be spun to 60 to 90 rpm for stabilization and initially placed in a 250 km x 36,000 km (155 x 22,300 mile) transfer orbit. After initial launch either the Foundation's FW-5 booster (donated by Hughes Aircraft) or a more powerful booster acquired by U3P will be used to raise perigee to somewhere between 15,000 km to 50,000 km. Following this insertion all three spacecraft will be de-spun and separation will occur. This will mark the beginning of the deployment sequence. The Foundation spacecraft is responsible for the launch vehicle mechanical interface, separation, spinup, apogee motor firing, spindown, and separation from the European spacecraft to which it is attached. The Foundation communications system is also required to handle tracking and communications for the composite prior to separation.

After the three spacecraft separate, the plan calls for 2-3 weeks of pre-departure operations to fine tune sail steering, maneuver characterization and ground crew familiarization. During this period it is forbidden for any of the participants to cross an imaginary starting line, perhaps a spherical shell at 50,000 km altitude.

Once the race starts, each participant will spiral toward the Moon and the first-in winner will be the spacecraft that is first to return an image containing the center of the Moon's far side. As in yachting, a handicapping formula will be used to calculate the true winner. The Foundation's sail will be heavier than the others, in part because we have agreed to carry the apogee kick motor topped with the other two spacecraft when launched together.

All three spacecraft are to race to the Moon. Only the Foundation's is planned to have interplanetary capability, and it will proceed to Mars if all goes well after its lunar encounter.

LAUNCH CONFIGURATION

The launch configuration integrates the Japanese spacecraft inside the French/Spanish sailcraft with the Foundation spacecraft attached to the launch vehicle underneath (Fig.1). This provides a lower center of mass and greater stabilization for spin and orbit insertion.

SAIL CONFIGURATIONS

The U3P-CVS design originally consisted of a 1,600 m^2 sail area with 400 m^2 control surfaces. This design has been replaced with a total sail area of 4000 m^2. Mass of the original sailcraft has been increased accordingly from 150 kg to 250 kg. The French/Spanish configuration has 4 diagonal masts of 45 meters in length. Masts are of carbon epoxy composite and are to be manufactured by SENNER in Spain. They are the same type as those used on the Ulysses spacecraft but much longer. Sail material will be either Du Pont Kapton™ 8 micron or Upilex™ and will be aluminized on both sides. Steering will be controlled by eight peripheral triangular flaps of a total area of 240 m^2 allowing a complete reversal in 200 minutes. The attitude sensor system is comprised of two Sun sensors (one on each face) and large field of view stellar sensors. All attitude determinations will be conducted on the ground. The original acceleration called for .12 mm/sec^2 maximum. Sail area to mass ratio is projected at 16 m^2/kg.

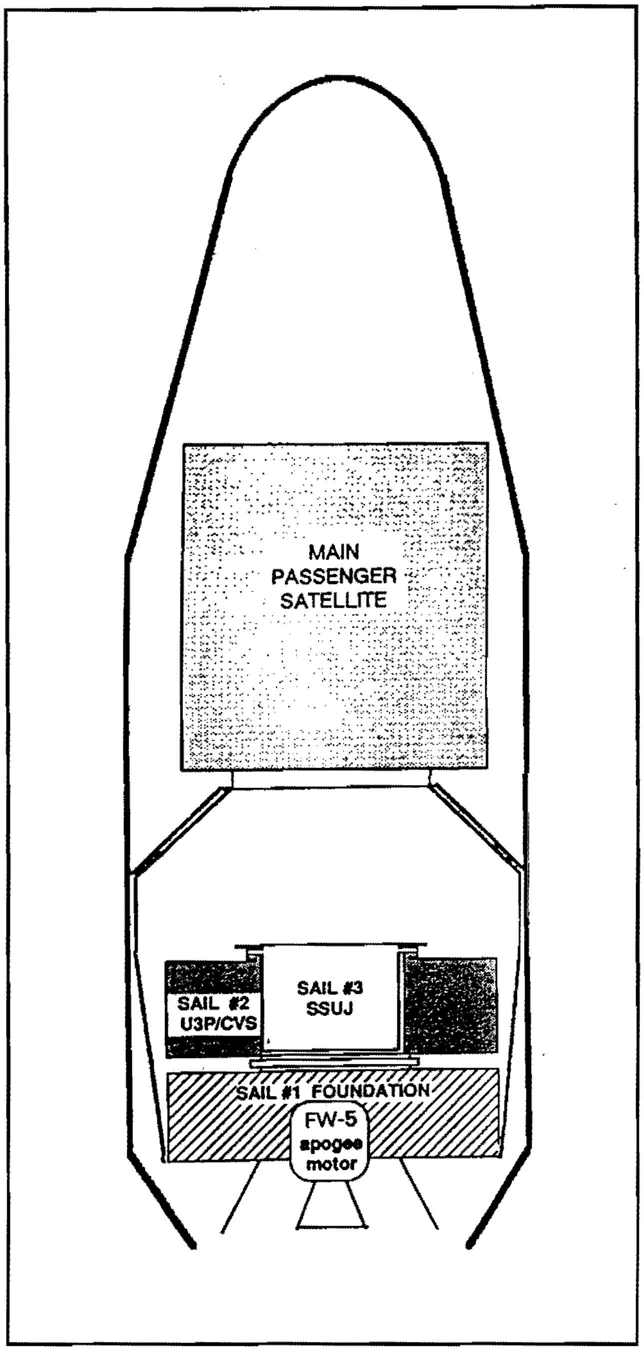

Fig.1 Launch Configuration - *Ariane-4*

The Japanese design has also gone through a process of evolution with a total of 4 designs considered. The original sail design called for a 70m x 70m sail area or a total of 4,900 m^2. Total weight was projected at 172 kg. with payload weight at 35 kg. This design was to provide roughly .07 mm/sec^2 maximum acceleration. The current configuration is for a sail area of 30m x 30m for a total area of 900 m^2 and a total weight of 96 kg, with these specifications subject to revision.

In the United States the sail design competition was primarily between teams from Johns Hopkins Applied Physics Laboratory (APL), Massachusetts Institute of Technology (MIT) and the World Space Foundation. Sail design varied from a heliogyro with eight blade-like 250-foot panels (MIT) to the APL circular sail. In the end the Foundation's sail design was selected as technically superior and for having the greatest development work behind it.

The Foundation's Solar Sail Race Vehicle (SSRV) builds on over 15 years of development work that began with the JPL Halley's Comet Rendezvous Mission. This work was picked up by the Foundation's Solar Sail Project Engineering Development Mission (EDM) design beginning in 1979. The current SSRV design incorporates an increase in sail area by a factor of 3.5 over the original EDM and the addition of two more control vanes for a total of four, providing greater maneuverability and redundancy. The final design is a three-axis stabilized square sail slightly larger than half the size of a football field (Figs. 2 and 3). This 3000 m^2 sail will be constructed of 0.00254 mm. (0.0001-inch) thick Kapton™ 55 meters on a side. This is the largest sail size judged supportable by a simple cantilevered beam system without guy wires.

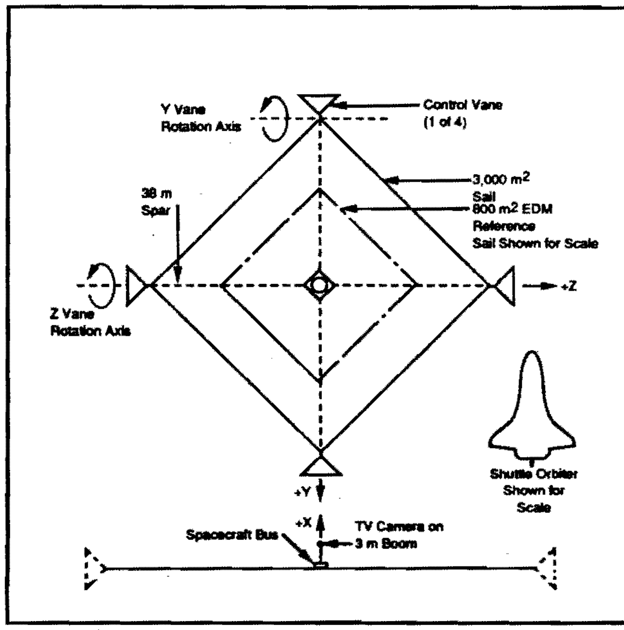

Fig.2 *SSRV*

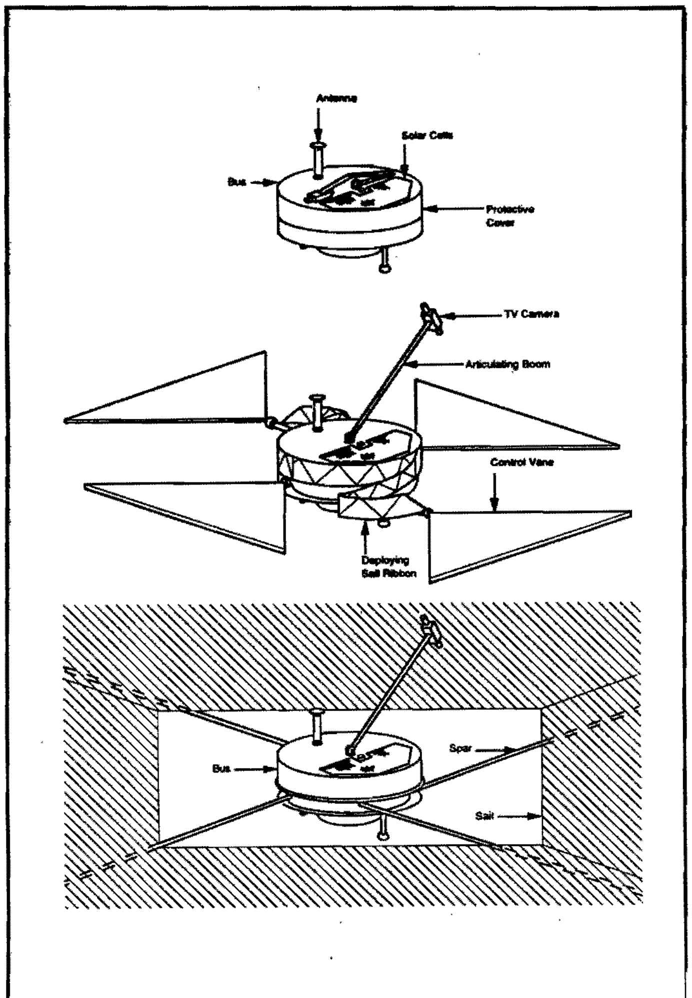

Fig.3 TV Camera Deployment and Operation

The bulk of deployment and propulsion systems will be jettisoned after initial sail extension (those items to the left of the dashed line in Fig.4). Without these systems and the FW-5 orbital raising motor, the SSRV launch mass will be 138 kg.

With it's support module gone, the SSRV will have an area density of 21 m^2/kg and a maximum acceleration of 0.17 mm/sec^2.

AVIONIC SYSTEMS

A key issue in the application of avionics from other AMSAT spacecraft to the SSRV is the impact of the expected radiation environment. At present, the launch plan calls for boost within two or three orbits after launch to an orbit substantially above the highest radiation regions of the Van Allen belts, but a lower starting orbit remains a possibility. If the specified starting orbit does end up within high radiation regions, we will have to consider additional shielding, radiation-hard versions of some chips, or even an alternative computer based on the AMSAT-OSCAR 13 (AO-13) system.

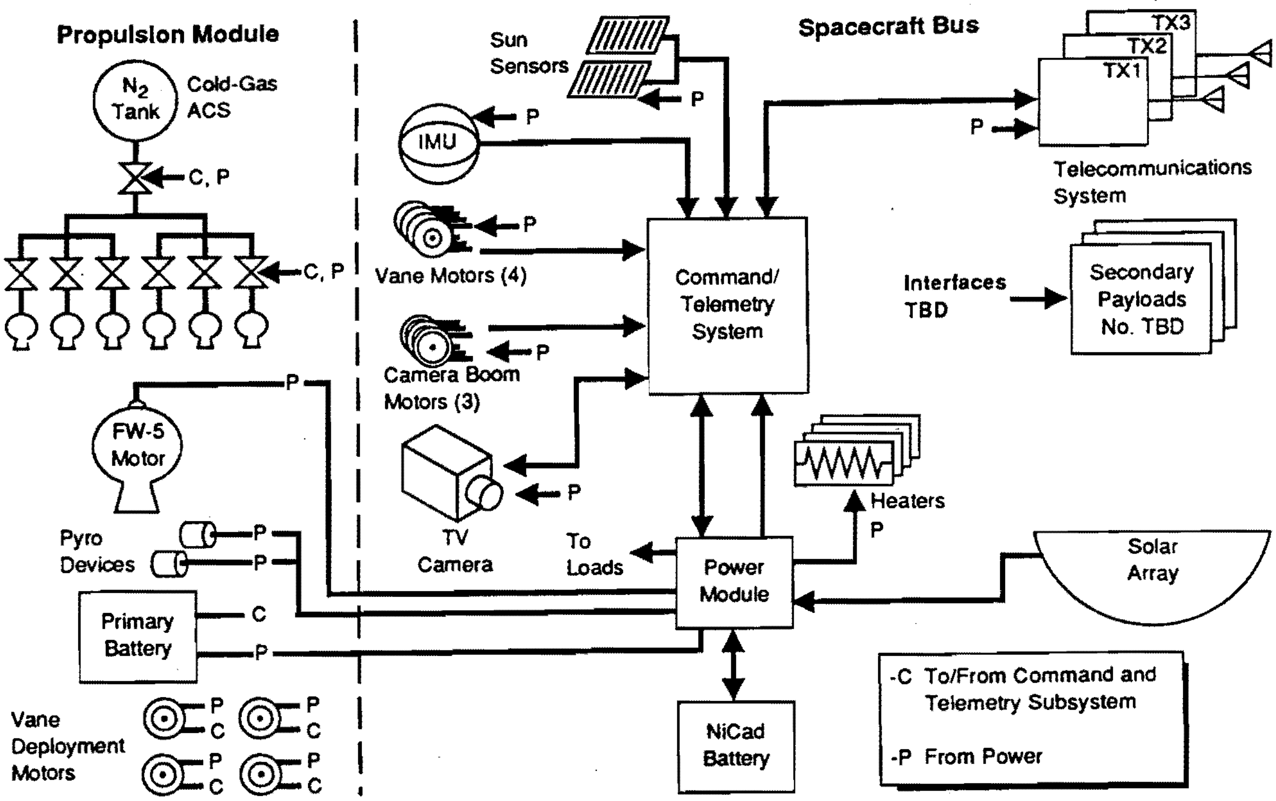

Fig.4 *SSRV* Functional Block Diagram

<u>Telemetry and Instrumentation System</u>

Our preliminary engineering studies indicate that Mode S (1.2 GHz uplink, 2.4 GHz downlink) is the most appropriate amateur operation for SSRV communications.

145.825	MHz	Proposed Educational Beacon
1.2	GHz	Command Receiver Channel(s)/Mode S Uplink
2.4	GHz	Spacecraft Telemetry/Mode S Downlink

The Jet Propulsion Laboratory is considering a 32 Ghz experimental Ka-Band beacon to demonstrate a new tracking capability for the Deep Space Net. This technology could permit reduction of tracking errors by an order of magnitude.

Command Receiver Module: The SSRV is to utilize the Microsat digital receiver module for command signal reception. This can support uplinks on any of five channels in the amateur satellite L-band (1260-1270 MHz). These channels can be set independently by the SSRV computer or ground control to receive frequency shift keyed (FSK) signals at either 1200 or 4800 bps. The feasibility of the latter rate at the Moon and beyond will be a function of the ground station's signal power--300 and even 75 bps are more realistic in interplanetary space.

Manchester encoding with HDLC formatting is to be used for this uplink data stream. At 1200 bps the bandwidth for the uplink signal is approximately 4 kHz and is pre-compressed for Doppler shift at the ground transmitter. When increased to 4800 bps, the uplink signal requires approximately 15 kHz of bandwidth. An FM discriminator reading is generated for each channel and sent back on the downlink so that the ground station can pinpoint the center frequency.

Telemetry Transmitter Module: The spacecraft transmitter will employ binary phase shift keying (BPSK) to implement digital transmissions. All transmissions are digital (NRZ-I, BPSK, HDLC) and compatible with the AX.25 Level Two packet data protocol. The latter feature is important because there is a substantial base of existing software for handling this type of digital software at 1200 baud.

The primary transmitter will operate in the 2.4 GHz amateur satellite band. Comparable S-band systems have already been built for the Pacsat and DOVE Microsats. Since the Microsat transmitters output 1W of power, an additional S-band amplifier stage (20W minimum) will be needed for the interplanetary phase of the mission. Transmitter power level will be selected based on a) data rate and link budget limitations, b) reasonable power generation goals for the SSRV solar panels, c) duty cycle, and d) signal strength required for tracking and data reception at post-lunar distances.

As with the receiver(s), data rates presently supported are 1200 and 4800 bps, with corresponding primary bandwidths of approximately 4 and 15 kHz. While the range of amateur products for this band is limited, a sufficient number of ground stations can accommodate this kind of downlink, and the numbers are growing. Higher data rates may even be possible with newer technology equipment.

Asynchronous Addressable Receiver/Transmitter (AART) Module: Each module in the modified AMSAT-NA Microsat bus, except the flight computer itself, is attached to an AART board required for two-way access to the microprocessor board. By standardizing I/O, this eliminates the need for a custom wire harness.

The AART is based on the Motorola MC144689 chip and functions as a simple, standardized CPU-to-module interface for both command and sensor signals. It connects to a 25-wire bus and supports ordinary ASCII communications at 4800 bps. For each module the AART provides: 24 discrete bits for module control, a 4-way conditioned thermistor multiplexer, and 8 bit multiplexing for analog telemetry ports. Analog measurements are made one at a time by the A/D converter in the flight computer module.

Spacecraft Antennas: Enhanced versions of the AO-13 and Phase IIID antenna arrays are more appropriate at lunar and martian distances than those from Microsat. Preliminary link analysis (see Table 1) shows that at least 37 dBW EIRP is required for the SSRV at Mars to achieve an acceptable data rate even with the 20 meter Table Mountain ground receiving antenna. This EIRP can be obtained with a 20W transmitter and a modest 6 dB gain circularly polarized antenna on the spacecraft. Options for having more than one antenna on the spacecraft, or for limited antenna steering, are being considered. Since sail orientation is critical to propulsion and orbit control, an arrangement is desired where communications sessions will require minimal interference with sail operation.

Camera: SSRV team member Weber State University has offered to provide a camera like the one flown on WEBERSAT. The camera is to be mounted on the control mast to view the sail surface, as well as the Moon, Mars and Earth. The camera, a Canon Ci-10 color unit, produces a standard NTSC analog color waveform which is frame synchronized by circuitry on a digitizer board. The digitized waveform contains all synch and chrominance information. Digitized information is then compressed and packetized for transmission to Earth using the same techniques employed on WEBERSAT. Ground terminals can then reconstruct the digital information using packet techniques to guarantee virtually error-free reception.

PAYLOADS

Plans call for the Foundation's SSRV to carry simple payloads in the following areas:

1. The WEBERSAT television camera as noted above.

2. A Jet Propulsion Laboratory-provided Ka-band tracking beacon and low frequency radio antennas will provide both practical and experimental communications.

3. Particle impact experiments will be conducted using the TV camera to image backlit sail damage. A cosmic dust package has been proposed by Prof. Dr. Ing. Igenbergs of Technische Universität München which could be carried on one or more of the three expedition/race spacecraft.

Table I Preliminary Link Analysis for Lunar and Mars Communication

Spacecraft Transmitter Power (20.0 Watts)	+13.0 dBW
System Transmission Losses:	-1.0 dB
Spacecraft Antenna Gain: (low gain)	+6.0 dBc
SSRV EIRP:	+37.0 dBW
Path Loss (2.40 GHz @ 78,076,000 Km): (opposition)	-257.9 dB
Path Loss (2.40 GHz @ 376,076,000 Km): (conjunction)	-271.5 dB
Path Loss (2.40 GHz @ 408,200 Km): (moon)	-212.2 dB
Polarization Matching Loss (RHCP space and ground):	-3.0 dB
Atmospheric and Ionospheric Losses:	-0.2 dB
Isotropic Signal Level, Ground Antenna: (opposition)	-221.1 dBW
Isotropic Signal Level, Ground Antenna: (conjunction)	-234.7 dBW
Isotropic Signal Level, Ground Antenna: (moon)	-175.4 dBW
Ground Antenna Gain: (20 meter dish)	45.0 dBc
Sky Noise Temperature: (2.0 dB NF)	170 K 16.7 dB/K
Ground C/No: (opposition)	46.5 dB-Hz
Ground C/No: (conjunction)	32.9 dB-Hz
Ground C/No: (moon)	92.2 dB-Hz
Ground Eb/No at 60 bps: (opposition)	28.7 dB
Ground Eb/No at 3.75 bps: (conjunction)	27.1 dB
Ground Eb/No at 57600 bps: (moon)	44.6 dB
Required Eb/No for 10e-5 BER:	9.6 dB
Link Margin: (opposition)	3.1 dB
Link Margin: (conjunction)	1.3 dB
Link Margin: (moon)	19.0 dB

4. Radiation tests will be conducted on the integrated circuits.

5. Two educational projects will provide direct student involvement.

RELATED EDUCATIONAL EFFORTS

Although specifics are not yet available, the International Astronautical Federation (IAF) plans to use race strategy as an educational tool.

The Rochester (New York) Museum and Science Center *SpaceArc* package will provide millions of school children the opportunity to speak to future generations by sending creative messages in a sort of interplanetary time capsule. So far nearly 100,000 students have taken the opportunity to prepare messages about life today and created images, thoughts, poems, writings, and music. Educational Testing Service is scanning and storing these messages for reproduction on CD-like digital optical media to be carried aboard the Foundation's sailcraft.

AMSAT-NA has offered *SAILTRAK* as a satellite based education program that will allow any student equipped with a radio capable of receiving in the 2-meter band to receive transmissions.

UNCERTAINTIES

Each of the expedition/race partners is presently seeking corporate and foundation sponsorship for the cost of their spacecraft plus one-third of common costs shared between the partners (primarily launch and integration). At approximately $6.5 million, the Foundation Team's spacecraft is the least expensive. Of this sum approximately $2 million is expected to be offset by in-kind contributions, exemplified by Du Pont's commitment to provide their Kapton™ film to the Foundation, and Hughes Aircraft Company's donation of the FW-5 apogee kick motor. Foundation Team members have offered substantial in-kind assistance, and will be paid for the rest of their work out of the project budget.

The rest of the Foundation's money must be raised. To assist with this, the Foundation has retained the nationwide public relations firm of Ruder-Finn, which is providing its initial services on a *pro bono* basis. The European and Japanese teams have established structures to accept sponsorship, and the French team has received modest assistance from French aerospace firms and Centre National d'Etudes Spatiales (CNES).

Launch date is dependent on the Ariane (or possibly Proton) schedule and the readiness of three expedition/race partners. The partners in 1990 formed the Earth-Moon Race Committee to coordinate the separate efforts to the best mutual advantage, arrange a launch, define vehicle interfaces, agree on race rules, provide mutual publicity assistance, and to plan for mutual assistance during spacecraft emergencies. The Committee has secured agreement of the International Astronautical Federation to officiate over the race. In 1992 the Committee plans to make a final launch vehicle selection and arrange the launch.

ACKNOWLEDGEMENTS

Hundreds of people have brought the Solar Sail Project to its present position and helped in the design effort and with the cooperative relationship between AMSAT and the World Space Foundation, as well as other partners. Some who come to mind are Jan King (W3GEY), Bill McCaa (K0RZ), John Garvey (N6VHP), Emerson LaBombard, Hoppy Price, Rod Pyle, Courtney Duncan (N5BF), Norm Chalfin (K6PGX), Joe Flaska (WB0RLY), Dick Daniels (W4PUJ), Rich Ensign (N8IWJ), Joe Kasser (G3ZCZ), Bob McGwier (N4HY) and others who should be mentioned. Other valuable assistance has been provided by The Charles A. Lindbergh Fund, California Space Institute, Silvestri & Massicot, Thiokol Corp., United Technologies Corp.'s Chemical Systems Division, California chapter of Students for the Exploration and Development of Space, and individual Associates of the World Space Foundation. Editing assistance was provided by Stephen Brewster.

ADSAT
THE ASTRONAUT DEPLOYABLE SATELLITE

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ABSTRACT

Weber State University is a four-year undergraduate institution with the mission of producing graduates capable of applying engineering principles to the solution of real problems. Its Center for Aerospace Technology (CAST) has put two satellites into space using thousands of hours from volunteers from the technical community, University faculty, and senior students in the School of Technology. Satellite projects have been an excellent means for providing real-world experiences through the three-quarter senior project sequence. A typical senior project includes designing circuits, interfacing to microprocessors, ordering parts, building the prototype, writing software drivers, debugging the final production model, integrating subsystems, and documentation. Students learn to use state-of-the-art computer aided design and production tools to model, analyze, document and produce working hardware while working with members of the project design team. The students are placed in technical roles seldom experienced by students or even entry level engineers.

Weber State faculty and students have learned many things through program implementation. This paper explores the lessons learned and points out some pitfalls encountered in the Weber State University satellite program. A new satellite abbreviated "ADSAT" presently being developed by WSU is introduced. The satellite is to be easily accessible to school children throughout the country and the world, with the mission of interesting school age children in science.

INTRODUCTION AND BRIEF HISTORY

Weber State University has been using satellites for some time to provide a realistic technological experience for its students. CAST, the Center for Aerospace Technology, was organized at Weber State to manage the satellite program and coordinate the extremely diverse and involved activities required to produce and launch a satellite. CAST's mission is to locate funding to finance the program, to find and reserve launch opportunities for the satellites, and to coordinate the efforts of students, faculty, and outside industry advisors.

Thousands of hours of work are required to produce a satellite. This work is provided by volunteers from the technical community outside the University, University faculty members, and students from the departments of Electronic Engineering Technology, Manufacturing Engineering Technology, Computer Science, and Mechanical Engineering Technology. For the students, it is an excellent opportunity to complete their senior project requirements in a real world situation. From the outset they are aware that their project will ultimately be a vital part of the satellite; their personal effort manifests their pride and professionalism. Their main limitations are inexperience and lack of knowledge. For this reason, student effort is supplemented by the University staff and community industrial technical advisors.

Weber State University has successfully deployed two satellites and is presently working on a third. NUSAT I was deployed from a space shuttle launch in 1985. WEBERSAT was launched from an ARIANE rocket from French Guiana in 1990. Presently, Weber State is preparing to launch ADSAT from the space shuttle in a few years. The mission of ADSAT is to educate and interest school age children in science.

NUSAT I

The first satellite launch by Weber State involved Utah State University to do the structural design and environmental qualification, and the FAA to design the experiment to be carried on board. Its mission was to calibrate the FAA radar antennas by measuring the radar fringe signal. The satellite was launched from the space shuttle at an altitude of approximately 200 miles and lasted for 20 months before it burned up upon reentry into the atmosphere.

WEBERSAT

WSU had two years to design, build and test WEBERSAT, the next satellite project. It was accomplished in partnership with the amateur radio satellite organization, AMSAT, and made extensive use of outside technical advisors as well as Weber State faculty and staff to complete the project.

The involvement of outside advisors with the satellite program was instrumental in bringing more industrial experience to the Weber State University faculty. Dr. Robert Summers, who managed his own engineering consulting firm, Orchid Engineering, was hired as the project technical advisor. Impressed by the satellite program, he later joined the Weber State faculty. Dr. Kermit Reister came to the program while employed by Rockwell International. After working with the WEBERSAT program for many hours as a volunteer Dr. Reister later joined the faculty as well.

WEBERSAT was launched on an ARIANE rocket out of French Guiana in January of 1990. The satellite cost Weber State around $150,000 in real dollars and thousands of hours of volunteer help. The satellite is presently orbiting at an altitude of 800 kilometers at an inclination of 98 degrees. It will remain in orbit for as long as 200 years with an operational life of approximately 10 years. The satellite carries a wide range of experiments on board, and functions as a ground programmable orbiting laboratory. Since the satellite also has an OSCAR designation (a licensed amateur radio satellite), it operates on the amateur radio frequencies of 144 Mhz up link and 437 MHz down link, and is available for amateur radio communication use. The first capability built into the unit is the ability to store and forward messages from one amateur to another. In addition, WEBERSAT was designed to carry a very diversified orbiting laboratory. The experiments on board include the following:

1. A CCD television camera with image digitization circuitry to photograph the earth, moon and sun.

2. Iris control and earth horizon sensing circuitry for the camera.

3. Eight megabytes of video storage memory with memory management hardware and software.

4. A 1.2 GHz video up link receiver for up linking video images and other analog data directly to the satellite.

5. An optical spectrometer that operates from infrared frequencies to the ultraviolet end of the spectrum, designed to measure the kinds and amounts of gases present in the earth's atmosphere.

6. A micrometeorite impact detector designed and built by Brighton High School, Utah.

7. A fluxgate magnetometer designed by Dr. Mario Acuna of NASA and developed by Dr. Summers of Weber State to measure and map the earth's magnetic field at 800 kilometers.

8. An AMSAT-produced computer with the capabilities of a desk top PC to control the satellite.

9. A full complement of standard instrumentation including current and voltage probes for battery and bus voltage, and temperature probes to measure the satellite temperature at key points throughout the unit.

WEBERSAT also carries all of the normal equipment needed to store energy from the sun and to manage the satellite power to prolong battery life. Experiments on the satellite can be turned on and off by ground control commands, and the data is relayed to earth in Amateur radio PACKET format.

The ground station for WEBERSAT is a bit more sophisticated than was originally anticipated. Two separate computers are required, one to track the satellite and to position the antennas, and the other to store and convert the data. The antennas are high gain, cross polarized yagi's mounted on a gymbaled mast and pointed by the tracking computer. A 437 MHz high sensitivity receiver is required with the capability of being tuned by the tracking computer to compensate for doppler shift. The antennas have low noise amplifiers and low loss double shielded coax cable. The received data is preprocessed in a Packet modem before it is received and converted to text in the data computer. Included in the report is a reduced diagram of the WEBERSAT system design and the ground station design.

WEBERSAT was originally envisioned to be easily accessible by anyone having access to inexpensive amateur radio equipment. The final design is more sophisticated than planned, requiring a considerable cash investment, and a high degree of understanding to use. In spite of the sophistication, many radio amateurs do use the satellite. To assist persons interested in accessing the satellite, Weber State is producing a user's manual and a software package available to all radio amateurs through AMSAT, the amateur radio satellite organization. The manual and software can be purchased at production cost by writing to:

AMSAT Corporation
P. O. Box 27
Washington, D.C. 20044
(301) 589-6062

ASTRONAUT DEPLOYABLE SATELLITE

The sophistication of WEBERSAT has made it difficult for the average person to use. A ten thousand dollar ground station is out of the question for most universities and totally unpractical for the grade schools, junior highs and high schools to purchase.

WEBERSAT also received outside technical help from AMSAT, Orchid Engineering, Rockwell, FAA, and other engineering firms. The future plan is to produce ADSAT completely in house, using mostly University students, faculty and staff support.

If the next generation of satellites is to be accessible to the schools, the receiving equipment must be inexpensive, and the data more accessible to the unsophisticated user. After the launch of WEBERSAT, the difficulties in data reception became apparent. Without the complex hardware and software programs, the data could not be interpreted. Without a high gain tracking antenna system, the digitally encoded signal loses bits, further complicating data reception.

For satellite reception to be made available to the schools, a simpler format was needed. The ADSAT concept evolved as the solution to the problem. ADSAT will use a speech synthesizer to verbalize data, allowing it to be transmitted as spoken English. The speech encoded signal can then be received using simple antennas and inexpensive receivers. The human ear and brain becomes the noise filter, allowing signal reception through a much lower signal to noise ratio while placing the students physically closer to the satellite reception process.

Information about conditions on board the satellite will be sent down as spoken English, synthesized on board using a speech synthesizer chip and vocabulary ROM memory chip. Data that varies too rapidly for speech transmission will be transmitted as tones that vary in frequency to correspond to the time varying phenomena. As an example, as the satellite rotates in the earth's magnetic field, a tone will vary in frequency to give the student a real time feel for the satellite's rate of motion. Other special sound effects will be generated to buttress data points, or stimulate the young scientist's interest as the data is being sent down.

All data from the satellite will be transmitted as FM modulated audio signals on the 144 MHz amateur band. The data can be easily received and recorded using an inexpensive Radio Shack scanner and an inexpensive audio recorder to store it. Weber State University will provide an experimenters manual with satellite circuit schematics as well as plans for setting up a ground station. Data transmissions will have a touch tone header that can be used to turn on the tape recorder for unattended satellite program capture. The experimenter's manual will contain schematics for those who wish to build the support circuitry. Kits and boards will be available for those who do not want to build the units from scratch.

As a further enticement to schools, Weber State invited high schools to submit ideas of experiments to go on the satellite. Requirements for the satellite experiments were simple:

Each experiment had to fit into a 2 inch by 2 inch by 4 inch box. It had to operate on a +5 or +10 volt power bus and could not use more than 20 ma of average current, and 100 ma of peak current. Power had to be able to be turned off if necessary. The experiment could send digital data over an 8 bit parallel digital bus, or analog data from 0 to 5 volts over an analog data bus.

Weber State has selected several experiments to fly on the satellite out of the many excellent ideas that were proposed. A few of the experiments and features being developed by the high schools and Weber State students and faculty are listed below:

1. A real time clock to give the time from launch.

2. A speech synthesizer to broadcast data in spoken English.

3. A sound synthesizer to highlight the broadcasts with special effects.

4. A touch tone generator to add control headers to automatically turn on audio recording equipment.

5. Solar detectors on each face of the satellite.

6. A three axis flux gate magnetometer to give the orientation of the satellite in the earth's magnetic field.

7. An eclipse detector to determine when the satellite enters the earth's shadow in order to measure the orbital speed of the satellite.

8. Current and voltage probes to monitor the satellite power system.

9. Temperature probes to measure temperatures on board the satellite.

10. A CMOS microcomputer to control the entire operation.

11. A watch dog timer for the computer to reset the system in the event the computer jumps out of the operating loop.

12. Signal and data processing firmware and hardware to convert the signals into speech and other audio formats for transmission to earth.

13. A power management system to help prolong battery life and to turn off unused circuits.

Five high school experiments selected to go on ADSAT are:

1. Micrometeorite impact detector submitted by John Barainca of Brighton High School.

2. An ionized particle detector submitted by Charles Clark of Roy High School.

3. An eclipse detector to measure the satellite speed submitted by John Summers a student of Weber High School.

4. Measuring particle deposition in free space using changes in an exposed crystal oscillator beat frequency by Bonneville High School.

5. A floating mass momentum detector submitted by Weber High School.

A final significant experiment to be carried on board ADSAT as a PhD research project is a magnetic repulsion engine designed by Jay Smith, a member of the Weber State University Electronic Engineering Technology faculty. It involves placing a large coil on the satellite with a bank of capacitors that are charged from the satellite batteries and solar panels. A small microcomputer will constantly read the magnetometer to determine the position of the satellite relative to the earth's magnetic field. When the satellite is rotated to a position where the coil is perpendicular to the earth's magnetic field, the capacitors will be discharged through the coil, providing a momentary impulse of inverse magnetic field that should slightly lift the satellite. The lift should be large enough to overcome the small particle impacts that cause low earth orbit satellites like ADSAT to fall back to earth in a relatively short period of time. If successful, Jay's experiment could enable ADSAT to stay in orbit for years instead of months.

The satellite is approximately the size and shape of a briefcase and is to be tossed off from the shuttle by an astronaut during an EVA experiment at an altitude of approximately 140 miles with a 57 degree inclination. ADSAT stands for Astronaut Deployable Satellite.

ADSAT should be easily received almost anywhere on earth as often as twice each day. The satellite will be programmed to completely cycle through all of its instrumentation, transmitting all data in audio format as speech, touch tone, variable tone, and synthesized special effects, all of which will be easily received and understood by schools and private individuals. The complete program will last approximately 10 minutes, during which time all instrumentation, time of day, and special interest data, will be transmitted. Each program and special data segment has a touch tone header which will automatically turn on standard audio tape machines to capture the data. An instructor can set the equipment up, capture the data at some random time and then play it back for the students during a scheduled class.

A block diagram of ADSAT is included, although the present proposed design is subject to change. Readers are invited to submit additional ideas. The page that follows the ADSAT system block diagram is a block diagram of a typical ADSAT ground station. The entire ground station can be built for under $300 dollars. By keeping the cost low, it is hoped that more schools will participate in the program.

For more information on ADSAT, call or write to:

Weber State University
Center for Aerospace Technology
Ogden, Utah 84408-1805
(801) 626-7272
(801) 626-7951 (FAX)

EDUCATIONAL ASPECTS

The beneficial aspects of using satellites as a teaching tool are numerous. Of necessity, a successful satellite requires the melding of several disciplines, which inevitably impact each other. For example, size constraints influence the form factors for the electronics and the surface area available for solar cells to produce the desired power. Thermal considerations impact the materials selected for the structure as well as the design of the structure itself. Orbital factors influence antenna design, and satellite stabilization influences antenna placement.

From manufacturing the space frame to the structural and thermal analyses, from celestial mechanics to computer programming, the students are repeatedly exposed to challenging requirements and problems, adding real-world dimensions to their assignments. Some of the requirements of a working satellite are that the components and circuits must be space rated. Everything must be interfaced to provide for microprocessor control. Power management schemes and low power consumption are essential, as is low-noise circuitry. It is absolutely necessary that top-down design occur for the microprocessor system, architecture, and software so that the issues of memory management and mass data handling can be properly addressed. Faculty and industry advisors work alongside the students to provide the necessary guidance and to insure the success of the project.

Students are involved in nearly all phases of the overall project. Although they generally are not intimately involved in the overall system design, they do help with the details. They also do circuit design, build and test prototypes, assemble the final version, do software and system integration, and perform functional and environmental stress testing.

Least favorite of the student activities is documentation, but students learn how important it is and generally produce good documentation packages.

There are some very challenging aspects of using students to build satellites. Whatever mistakes a seasoned engineer may make, the students will tend to compound. They lack experience, tend to underestimate the magnitude of the job and the time required for completing a project. Students also require a great deal of guidance. This provides the faculty with some excellent teaching opportunities but requires a greater faculty commitment than do more standard curriculum courses.

Student designs often come untried directly from text books or limited experience. Students often have other commitments with school and family, and are not available just before and during finals or in vacation periods. Although these things are difficult to manage in terms of satellite program deadlines, they do give the student a true-to-life experience.

FUTURE PROGRAMS

Building a satellite involves much more than technical skills. It requires the management of resources and personnel. Teams must be organized and responsibilities must be assigned to appropriate teams. This requires a good assessment of the skills of the participating students. Planning charts must outline critical path and milestones in the same manner as any project produced in industry. Students must learn not only to design circuits and make them work, but they must document their designs and software, and produce working manuals describing the system in detail. Students tend to want to take on more than they can reasonably do in a quarter. Realistic goals and projects must be assigned. Students need to be challenged, but should not be placed in situations where they have little chance of success. Some critical jobs must be duplicated to insure that the project will be completed on time. Each group needs to be aware of the other groups' part and progress. Information should be freely shared although friendly competition can be healthy.

Weber State University has found that some changes to the curriculum have been required to prepare students for participation in developing systems as complex as satellite systems. The program has resulted in more exposure to computer aided design (CAD) and computer aided analysis programs such as PSPICE. A new course has been added to the Electronic Engineering Technology program called "The Personal Computer As An Engineering Tool". The course takes students completely through a mock project, using the personal computer exclusively to plan, design, analyze, document, develop package, and lay out printed circuit boards. Programs like Word Perfect, Lotus, Time Line, PSPICE, ACAD, and HiWire are introduced with a subset of their rules and operating characteristics. Outlines of reports, manuals, parts lists, time lines, schematics, and block diagrams are studied as part of the course. When the students complete the course, they have an outline of how to manage a project from start to finish while generating all of the necessary drawings, charts, tables, schematics, and documentation. The course is taught during the sophomore year so that the information can be used and reinforced during later years.

The satellite program has attracted many talented people from industry to work at Weber State University as adjunct and regular faculty members. Their experience and contribution has added greatly to the success of the program. The majority of the Weber State University faculty have had extensive industrial experience and training. The combination has helped tailor the program to the needs of the industrial community. The satellite program gives students experience in a broad curriculum that approaches the environment encountered in the world outside the university.

PUBLIC SCHOOL INVOLVEMENT

The ADSAT project was intended from the outset to involve students from the public school system in various ways. During the design and construction phases, Weber State seniors will work on the satellite. Also during this period, local high schools have been invited to submit space experiments that can go up with the satellite. After the satellite is launched, students in elementary, junior high, and high schools throughout the United States and the world, will be able to listen to the satellite using inexpensive ground station equipment. For an investment of under three hundred dollars, the necessary hardware and experimenter's manual can be purchased, which will enable the students to listen in on the satellite transmissions. Since the satellite data will be verbalized in English, the students can immediately use the data, without decoding it, to do various experiments geared to their grade level. The inexpensive equipment and simplicity of design is in stark contrast to the investment and technological knowledge required to set up and operate the WEBERSAT ground station.

The whole intent of the ADSAT program is to push technology that is fun into the lower grades in the hope that more students will become interested in science and technology fields for careers.

SUNSAT - A JOINT UNIVERSITY OF STELLENBOSCH - SA AMSAT SATELLITE PROJECT DUE FOR LAUNCH IN 1994

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SUMMARY

SUNSAT, a 50kg amateur and experimental satellite is planned as an auxiliary payload on the 1994 Ariane Helios mission. Stellenbosch University, SA-AMSAT and major South African electronics companies, Altech, Grinaker Electronics, and Plessey, have combined forces in a feasibility study for South Africa's first mini-satellite. A position location payload and a 20m resolution 3-colour or stereo imager are planned, together with 1mrad accuracy attitude control system, and wide band down link. Mode A and S transponders, a 2m Parrot and bulletin broadcaster, and packet radio using 2m half duplex 1200 baud AFSK and 9600 baud mode J, will serve South African and international Amateurs. The non-amateur pay load will operate on frequencies outside the Amateur bands.

INTRODUCTION

For South Africans SUNSAT is an exciting step that we hope will stimulate industry, academic activities, and particularly a school interest in technology and amateur radio. This paper gives some history of the project, its present status, and some technical details.

ADVISORY BOARD

SUNSAT is a joint University of Stellenbosch, SA AMSAT and South African Industry project. In June 1991 an Advisory board was established to co-ordinate the interests of the various groups and to manage the project. The board includes representatives from the various interest groups and is chaired by Prof Garth Milne, holder of the Grinaker Chair in Satellite Systems at the University of Stellenbosch.

South Africa has an innovative electronics industry that wishes to benefit from new opportunities. It also needs competent technically trained people to establish and operate systems. The SUNSAT programme is a means of both increasing space segment knowledge in the country, establishing a satellite training capability, and exposing the industry's capability. Success of experiments on SUNSAT could also lead to marketable services.

The sponsorship of the Chair in Satellite Systems by Grinaker Electronics shows industry support for a growth in satellite expertise at Stellenbosch. Application of the established competence in microwave and RF systems, computer and control, and systems engineering to an experimental satellite will rapidly spread satellite-specific knowledge.

South Africa also has to motivate youngsters to accept the challenge of a technological career. The South African Radio League and SA-AMSAT's efforts to create an interest in radio and satellite communications with the youth is symbiotic with those of industry and the university. Involvement of the two organizations is of significant value to the whole project. The project is particular significant with the emergence of the "New South Africa" where specific attention is needed to introduce the "third world " component of the school going population to education with a more scientific content. This streches far beyond South Africa's borders where the need for science in education is even greater. It is thus visualised that projects undertaken using SUNSAT will involve many other developing countries on the African continent.

DESIGN

Initial system design has paid lip-service to size, weight and power based on the sizing of the UoSATs and Microsats. Intermittent operation of various systems permits the peak power consumption to significantly exceed the orbit average power.

The Helios mission provides a polar orbit similar to that ofthe AMSAT Microsats. The orbit offers obvious opportunities for store and forward communications, position location, and imaging. Cape Town and the South African SANAE Antarctic research base are simultaneously visible for a few minutes suggesting direct relay of high speed data.

Stellenbosch has a strong control systems, parallel processing, and simulation capability, making a contribution to microsatellite attitude control an obvious goal. Precise stabilisation makes high resolution pushbroom imaging viable, and also reduces radio fading due to satellite tumble. The imager then necessitates a wide band microwave down link for imaging over the RSA, which can then be further exploited for communications experiments between SANAE and South Africa.

SUNSAT thus has three main functions:

- Store and forward communications
- Position location
- Imaging

Because of the high power drain of the wide band down link, the imager and full precision attitude control (1mrad goal) will normally only be operated over the RSA.

The imager was originally planned to have a single reflective optical system with three linear CCD sensors mounted on a colour separating pentaprism for multispectral imaging. Remote sensing practitioners have recently suggested that a monochrome stereo imager would be of greater scientific value. A concept with two optical channels looking forward and backward is being considered. An alternative is to pitch the satellite to obtain the forward and backward looking views from one imager in the same pass.

The sun and horizon sensors have similar locations to those on UoSAT F. In addition, the imaging star looks on the orbit normal axis away from the sun for attitude determination when in earth shadow. The low light imager looks downward for polar imaging.

The power system is conventional. The flight control unit will include both an 80C186 and a transputer (T800 or T9000), and as large a memory as feasible.

The ranging system will perform the computations on-board so that ground transponders can be simple. The ranger will be used for precise orbit determination, and for the position location function. Details of the position location system are not yet available.

The attitude control system will use a microcontroller, backed up by the main computer, and the magnetometer in addition to the sensors already mentioned. The reaction wheels of 100mm diameter, 5mm thickness, and 100g mass will be able to slew the satellite through 180 deg in 50 s when driven with a 1 W average power servo motor. The magnotorquers will take 10 minutes for the same task and consume more energy, but they have an infinite life.

The earth observation system will use a linear CCD sensor with optics as previously described. The proposed aperture is 10cm, giving an Airy disk diameter of 13.6 m on the earth.

For an ideal lens, this will contain 84% of the light imaging onto a point on the sensor. A pixel spacing of 20m will probably be adopted to account for realisable optical performance and motion effects. The swath width would thus be 80km, 100km, or 120~km for 4000, 5000, and 6000 pixel sensors. A 14 mu sensor pixel size would require 560 mm focal length optics which can fit in the available space if reflective optics are used. The numerical aperture of F5.6 can provide near theoretical optical performance. Final decisions on the imager will only be made after detailed trade off studies.

AMATEUR PAY LOAD

- 2m Parrot 2m/2m FM, single frequency.

Uplinked audio (speech) is stored and rebroadcast on the common channel once the squelch or a timer drops out. Parrot users only require a 2m FM transceiver, making school use easy. Learning operating discipline is part of the education!

- 2m Broadcaster

The FM broadcaster will operate like DOVE, relaying SA-AMSAT bulletins that have been PCM converted, uplinked by the control station and stored. Voice or AFSK data of various rates and deviations can be handled.

- Mode A 145/29 MHz linear transponder.

- 24 cm/13 cm Linear Transponder.

- Digital modes

Bulletin Board

The BBS will be used for message storage and forward. It will be accessible via any of the digital up/down links. 2m 1200 baud AFSK single frequency. Operation with minimal digital equipment is encouraged by this mode.

Both digipeater and BBS operation will be possible.

- 2m/70cm, 9600 baud FSK (G3RUH).

Broadcast protocols can also be implemented.

- Image data Provision will be made to download user-requested image areas using any of the transmitters.

Telecommand and control

This will follow concepts proven on previous Oscars and allow both direct control of major functions, rebooting of computers from ground, and automatic operation. Whole orbit telemetry will be provided.

IMAGE-ENABLING YOUR SATELLITE STATION

Jeff Wallach, Ph.D.
N5ITU
Chairman, Dallas Remote Imaging Group

Satellite enthusiasts world-wide have witnessed an explosive growth of advanced technologies, amateur satellite launches, and declining equipment costs over the past several years. With the advent of very low cost, high speed personal computers, amateur technology now rivals professional satellite ground stations in their capabilities to communicate through and command space platforms in both low and high Earth orbit. FM and SSB voice communications, CW, RTTY, SSTV, ATV, packet radio and telemetry reception and analysis are just a few of the fascinating modes that amateurs may participate within satellite communications. One aspect of satellite technology often over-looked by the amateur is that of satellite image acquisition and digital enhancement of pictures from space. This paper will discuss the basic constructs of satellite image acquisition and enhancement by the amateur, and provide a primer by which the typical satellite enthusiast may "image-enable" their current satellite station.

As an incentive to increase your interest in satellite imagery, Fig.1. shows a photo of one of the first non-classified U.S. image from space, that of the TIROS 1 weather satellite (left) launched on April 1, 1960. Contrast the rather fuzzy image on the right of the U.S. Gulf Coast and Florida with the Fig. 2. photo of Florida taken by the Chinese Feng Yun 1-B weather satellite with High Resolution Picture Transmission (HRPT - 1.1 km. resolution) and captured by Tom Loebl of the Dallas Remote Imaging Group (DRIG). Note the roadways evident in the Everglades and the vegetative coloration differences! This quality of imagery is available on a daily basis to amateurs with equipment not much more sophisticated than that already in use for communicating with the OSCAR satellites. Let's repeat this point: the majority of amateur satellite enthusiasts ALREADY HAVE the basic station equipment required for satellite image reception and processing! Satellite operators with stations possessing an antenna, preamp, multi-band VHF/UHF radio, Terminal Node Controller (TNC), PSK demodulator, and a personal computer can easily upgrade their equipment to receive amateur, civilian weather, and some military satellite imagery! All that is required is a will to learn and that most precious commodity....TIME. Let's now take a look at the various types of satellites that transmit imagery, their frequency assignments, and the scope of equipment required to receive, display, and digitally enhance these outstanding images from the realms of outer space.

WEATHER SATELLITE IMAGERY

Bar far, some of the most exciting and easily accessible imagery is from U.S., Soviet, and Chinese weather satellites in polar and geostationary orbit. The lower resolution (4.0 km.) Automatic Picture Transmission (APT) images are downlinked in the 137 Mhz FM band, while the High Resolution Picture Transmission (HRPT 1.1 km.) and WEFAX (WEather FAcsimile - 7.0 km.) images are downlinked in the 1698 Mhz and 1691 Mhz bands, respectively. Fig. 3. is an APT image from a Soviet Meteor polar orbiter over the Mideast. Fig. 4. shows the better resolution of HRPT, taken by the U.S. NOAA 12 spacecraft over the Eastern Canada on May 15, 1991, orbit #12. (Soviet Meteor weather satellites do not currently have HRPT 1.1 km. resolution...only APT images are available). The APT imagery transmitted in the 137 Mhz band is an FM signal that contains an AM subcarrier (the video image) at 2400 hz. This tone is amplitude modulated to correspond to the light and dark areas of the Earth as detected in both the visible and infrared (IR) sensors on the polar orbiting spacecraft (U.S. APT has a visible and IR image during the day, and two IR images at night, while the Soviets utilize visible imagery during the day and IR at night on the newer Meteor 2 and 3 series platforms). The higher amplitude components of the 2400 hz. tone represents the lighter portions of the Earth's image, while the lower amplitude represents the darkest areas of the image. Intermediate amplitudes represent the shades of grey scale needed to complete the image of the Earth. This analog APT imagery (2 channels) is actually a derivative of the digital data of the Advanced Very High Resolution Radiometer (AVHRR) instrument on board the U.S. and Chinese weather satellites in polar orbit. The digital HRPT image (5 channels total - one visible and 4 IR) is downlinked as digital data (665 kbps) and requires slightly more sophisticated electronics to receive and process the imagery.

The polar orbiting weather satellites orbiting between 830 km. and 1200 km. in space continuously transmit images (approximately 2200 km. wide from an altitude of 870 km.) during a pass that may last over sixteen minutes. A typical 14 minute pass would result in a continuous image approximately 5800 km. long (North to South) and 2200 km wide, and would end when the satellite signal is blocked by the local horizon relative to the receiving station. In contrast, the higher altitude (36,000 km.) geostationary satellites (GOES and Meteosat) downlinks WEFAX (7.0 km.) images as analog data (1691 Mhz) on a pre-determined scheduled basis. The image takes 800 lines and paints it on the screen in 200 seconds (240 lines/minute). An example of imagery from the GOES West spacecraft is shown in Fig. 5 and provides an unbelievable view of the July, 1991 solar eclipse over the South Pacific ocean near Baja, California. Incredibly, the umbra and penubmra of the moon's shadow may be seen to the left of the image! For the purposes of this paper, we will concentrate on the equipment required to receive satellite imagery, and not the specifics of the space platforms nor image formats. A more detailed discussion of the APT, HRPT, WEFAX, and OSCAR image formats may be found in the 1990 AMSAT Space Symposium Proceedings (pg. 16-21), and the A.R.R.L. 1990 Handbook. A listing of the currently available weather satellites, their frequencies, and images transmitted may also be found in that article.

So, what does all of this mean to you, the amateur satellite operator? Simply put, utilize your current satellite station (2 meter omnidirectional or beam antenna, preamp, receiver or scanner covering the 137 Mhz FM band, personal computer, satellite tracking software), add a single AM demodulator card to the PC along with image capture and display software (commercially available for under $100.00) and YOU are now receiving APT images from U.S., Soviet, and Chinese weather satellites! The APT received signal is simply a series of tones that are demodulated by the AM demodulator circuitry (take output from earphone jack on receive and plug into AM demod card in PC), run through some filtering, and then an A/D converter chip to provide an 8 bit (256 levels grey scale) data file to the image display software application. The image file can then be stored as a binary 8 bit file, or converted to PCX format and brought into a PC paint program, or GIF format for viewing on other PCs, etc. But more on the image software in a later section. What about the issue your expensive multimode VHF/UHF receiver does not cover the 137 Mhz band? Well, there are some very inexpensive converters, or kits from Hamtronics, and off the shelf receivers from Quorum Communicatons, Dartcom, Vanguard, etc. And don't forgot the very inexpensive used scanners at flea markets that cover the 137 Mhz band. The upshot is that the receiver will be a minimal investment that will provide years of enjoyment from weather satellite imagery. And yes, the GOES WEFAX signal is at 1691 Mhz., but once again, a small downconverter will change the 1691 Mhz signal to 137 Mhz, and you can use the same receiver for GOES WEFAX as you use for APT. In fact, you utilize the same AM demodulator card and PC software for both image types. A loop yagi at 1691 Mhz or a small 4 foot dish with a coffee can feed (about $3.00 the build the feedhorn) will provide full quieting signals from 36,000 km. in space.

HRPT imagery is indeed the most complex (and expensive) weather satellite product to receive. The AVHRR instrument on board the NOAA and Chinese polar orbiters provide the truly outstanding 1.1 km. resolution image product containing the 5 data channels (visible and 4 IR). The HRPT signal at 1698 or 1707 Mhz (satellite dependant) containing the entire digital data set is a 665.4 kbps split phase encoded, phase modulated signal. Due to the high data rate, digital format and split phase encoding, more sophisticated electronics are required to detect and process the HRPT signals compared to the simpler AM demodulation of the APT imagery. But once again, a turn-key system developed by Dr. John DuBois and Ed Murashie of DRIG is commercially available from Quorum Communicatons and Timestep Electronics. The system consists of two plug-in IBM PC adapter cards, a bit sync card and a PSK demodulator card, as well as the required 4 foot trackable dish, feedhorn system, LNA, and image capture/display software. A complete description of this system was printed in the April 1990 Journal of Environmental Satellite Amateur Users Group (JESAUG) newsletter. This reprint, as well as a complete listing of all equipment, vendor contacts, etc. discussed in this paper are available from the author for a self-addressed, stamped envelope (9 x 12) with $2.00 postage attached.

NON-WEATHER (EARTH RESOURCE AND MILITARY) IMAGING SATELLITES

One very interesting side-note on APT reception. Many amateurs have the capability to automatically track the polar orbiting weather satellites and OSCAR constellations (Kansas City Tracker cards and InstantTrack software), "auto-acquire and auto-save" the images, and timestamp the files. (Actually, the auto-acquire and auto-save functions are features of the APT image software programs, and the majority of the commercially available units have these features). Several members of DRIG have returned home from work only to find some new imagery, decidedly NOT weather satellite imagery, residing on their hard drives, and captured automatically during the day, in their absence. One example of this is shown in Fig. 6, from a Soviet Okean 2 spacecraft in polar orbit. The image shows Florida and Cuba in a multi-spectral format, including a side-looking radar image on the left, and both visible and IR imagery to the right. The Okean 2 spacecraft transmitted this imagery on 137.4 Mhz. Okean series platforms are oceanographic satellites with side-looking radar (1-2 km. resolution), and provide all-weather monitoring of ocean ice conditions, flood regions, radar and optical monitoring of ocean dynamics, all transmitted in an APT format on VHF frequencies. The question arises as to how DRIG members knew what satellite transmitted on 137.4 if they were not at home during transmission, and the image format was (at that time) unknown to the Group. Well, since the APT software stamps the date and time at file open, we know when the image was captured. Using InstantTrack satellite tracking software, one may type in the date and time of an event, and the program will display ALL satellites in the 200 satellite database that were in view of the ground station at that time. A process of elimination of known weather satellites, geostationary platforms, and GPS (all in view during the +-15 minute period) indicated that Okean 2 was the answer. Independent confirmation with Geoff Perry of the Kettering Group verified our findings. Also, some of our systems will also stamp the frequency of the transmitted image within the file. This auto-capture mode is an excellent way to find new imaging satellites (some Soviet civilian and military) prior to official announcement of the launch!

IMAGING IN THE OSCAR SATELLITE CONSTELLATION

NASA, NOAA weather service, and the military are not the only organizations with image platforms (assets) in space. AMSAT currently operates two Microsat imaging satellites (Webersat WO-18, and UoSat 22 UO-5) in polar orbit, downlinking images of the Earth on amateur frequencies. Both platforms contain CCD color cameras and provide a store and forward capability to amateurs by downlinking the digital image files in standard AX.25 packet protocols to ground stations in the 437.100 Mhz SSB frequency range. Amateurs that are currently working the Microsats PBBS systems, and/or monitoring their telemetry streams only have to add some file capture and image display software to receive these exciting images from 830 km. in space. Once again, the details of the Microsat imaging platforms and the file formats were discussed in the 1990 AMSAT Space Symposium Proceedings, so these topics will not be covered under this title.

Equipment required includes the following: 437 Mhz antenna (preferably trackable beam, but omnidirectional antennas do work), preamp, multi-mode VHF/UHF receiver, TNC, PSK demodulator (1200 bps and 9600 bps for UO-5), and a personal computer with KISS capture software and image display routines. The Webersat downlinks the packetized image files at 1200 bps, while UO-5 utilizes the much more efficient 9600 bps data stream .
Thus, to capture images from both spacecraft a PSK demodulator with capabilities of 9600 bps will be required. Fig. 7. is an image of the Earth's horizon taken by the CCD camera of WO-18. Contrast this with the higher resolution shown in Fig. 8&9 from UO-5 spacecraft. The imagery from UO-5 CCD camera approaches the excellent resolution of APT weather satellites! The only additional items necessary are the PB.EXE KISS capture software programs to ingest the digital data stream from the Microsats, the WeberWare display software and GIF file viewers to display the images from WO-18 and UO-5, and some time to play with these fascinating images. But more on this in the next section. Again, it should be emphasized that adding imaging capabilities to the average OSCAR satellite ground station

can be done a minimal expense through the judicious use of bargain flea market equipment, public domain (free) software, and a little help from an experienced operator. In fact, most of the imagery from weather satellites, WO-18, UO-5, Landsat, Hubble, etc, is available for free from local packet and land-line bulletin board systems across the country. All you need to do to get started is to download the actual image files and a image viewer program, and you are well on your way to being hooked on this unique and exhilarating aspect of amateur radio.

PERSONAL COMPUTER REQUIREMENTS

Perhaps the one key element to producing excellent satellite imagery in the amateur satellite station is the quality and processing power of the personal computer and graphics display system. While this paper has been focusing on the IBM PC platform, the basic constructs presented here apply to Commodore Amigas, Macintosh systems, Apple GS, and other personal computers available in the market place. The personal computer and graphics display system are the heart of the satellite image acquisition system. The quality of the image, resolution and ground detail, and ability to digitally enhance imagery is directly related to the capabilities of the personal computer. The PC graphics display systems have evolved steadily over the past ten years. Originally the Color Graphics Adapter (CGA) display system only provided 4 colors, and no shades of grey scale. The Enhanced Graphics Adapter (EGA) was an improvement with 16 simultaneous colors on the screen, but once again no grey scale capability. In 1987 IBM introduced the Video Graphics Array adapters (VGA), with an enhanced 640 pixel by 480 lines at 16 shades of grey scale. Finally, a video adapter that could do justice to weather satellite imagery. Remember, APT and HRPT images are transmitted as 256 or 1024 shades of grey scale, with NO color present (that is done at the T.V. station by their personal computers). Thus, in order to resolve lakes, rivers, and other geographic features, the more shades of grey scale, the better the resolution of the objects.
Sixteen shades of grey scale (4 bits of data... 2 bits to the fourth power is 16) at 640 pixels and 480 lines on the screen give some very nice images. But the newer Super VGA (SVGA) adapter cards are capable of 1024 pixels by 768 lines at 256 shades of grey scale (8 bits of data) and give fantastic resolution! Small lakes, rivers, and even the shading differences around cities are resolvable on the APT and HRPT imagery at 256 shades of grey. The newer SVGA cards may be purchased for under $150.00 at discount houses and are well worth the investment. The video adapter requirements are the main reason why there are so few image systems for the Commodore 64 and older Apple II systems...their very limited display capabilities make for some lousy looking images. The newer Commodore Amiga and Mac's have display resolutions as good and even better than the IBM PC systems.

COMPUTER PROCESSING SPEED AND DISK STORAGE

The IBM PC platforms now come in four flavors: Intel 8088 (4.77 Mhz clock speed), 80286 (6-10 Mhz), 80386 (16-33 Mhz), and the screamer 80486 (33-50 Mhz) systems. The faster the processor speed, the faster the images will be enhanced, manipulated, etc. The older IBM XT systems work just fine with satellite imagery, but the new 80286-80486 systems will bring your satellite imagery station into the 1990's and beyond. One critical factor is access speed and storage capabilities of the hard drive. A typical 14 minute APT pass may take up to 9 megabytes of storage, depending on sampling rate (typically 2400-9600 samples per second). An HRPT pass with all 5 channels will require 100 meg plus! Thus, the hard drive in the range of 100-200 megabytes is not an unrealistic expectation in today's sophisticated satellite world. Webersat binary images typically are 156K each, while the GIF format of the UO-5 imagery approaches 275K. The message is purchase the largest hard drive you can reasonably afford. A math coprocessor is also useful for the number crunching satellite tracking programs, and some of the image processing packages also make use of math coprocessors (80287 and 80387 chips).

IMAGE DISPLAY AND PROCESSING SOFTWARE

The main advantage to collecting and storing satellite imagery on a computer is the ability to digitally enhance the images, false color the contents, add descriptive text, and improve the overall quality of the original image. There are a host of image processing and display programs for weather satellites, the OSCAR Microsats, Landsat imagery, and other satellite photos available to the amateur. Some of the programs are for a fee, but much of it is for FREE.

APT and HRPT Weather Satellite Image Processing

Almost all commercial APT, HRPT, and WEFAX imagery systems on the market today provide some type of image capture routines, digital storage as binary or other file types, and some form of digital image enhancement capabilities. Features may include automatic ingestion and saving to disk, various histogram curves to show rotation in hurricanes, moisture content in clouds, ocean currents, contrast enhancement, zooming, panning, rotation of images, and even temperature calibration of the IR imagery. One very excellent and inexpensive program is SATVIEW written by Tracy Lenocker and Ed Murashie of Dallas Remote Imaging Group. This mouse driven program is highly sophisticated and will operate on binary image files from weather satellites, OSCAR, etc. Any APT or HRPT binary file may be displayed and processing with zooming, panning, rotation, image enhancement, GIF production, noise removal, cutting a sub-image, and even vegetative indexing of ground cover. This program costs under $30.00 and is available in demonstration form from the the DRIG BBS at 214-394-7438.

Graphics Interchange Format (GIF)

Another technique is to take a binary image file from the APT or HRPT or UO-5 output and convert it to a GIF format. GIF is a Compuserve standard for defining a mechanism for the storage and transmission of raster-based graphics information, and allows porting of an image file to may different operating systems. Thus, the same GIF file may be viewed on an IBM, MAC, Amiga, Apple, etc. GIF file viewers are available for free from most BBS systems, and can be used to zoom, enhance, show all GIF files on your system, create a slide show, etc. Harold Price, NK6K, is using the RG8 program (available on DRIG BBS and Compuserve) to convert the UO-5 binary images to GIF format and may even have the images downlinked directly from the spacecraft as GIF images. Thus, it will be VERY easy to view and process these outstanding pictures from space. Several common GIF viewers for the IBM PC are VPIC and CSHOW, available once again from DRIG BBS and even on the Microsat BBS store and forward systems!

Weberware and UO-5 Image Display Software

Weberware is a image display and processing program used for WO-18 imagery, and available from AMSAT and Weber State University. It will take the binary KISS capture file (use PB.EXE in KISS mode to capture WO-18 packet image files), convert them to Black and White or Color images, and perform some limited image processing on them. CCDEXE.ZIP is a bundled program with RG8 that will take UO-5 binary files and convert them to GIF for viewing with the GIF viewers. SATVIEW should be able to handle the binary file as well.

DIGITAL SIGNAL PROCESSING (DSP) ... THE NEXT EVOLUTION

One common complaint by satellite operators is the wide expanse of modems, AM demodulators, packet TNC boxes, etc., that they have had to purchase to operate these various modes, and yes, it IS expensive. However, new developments in digital signal processing (DSP) have produced a single integrated box that uses SOFTWARE to update the type of modem required to process data (telemetry, APT imagery, RTTY, CW, AMTOR, Packet, low signal work, etc). Thus, a single box can do ALL of these modes. L.L. Grace and Advanced Electronics Applications have commercially available a DSP system that will allow you to simply use EPROM or program updates to add new functionality to your satellite station. Members of DRIG are currently coding some APT modems for the L.L. Grace DSP-12 system, and Bob McGwier is doing the same for the AEA DSP 1232. With a single box you can now receive telemetry, packet radio, APT imagery, WO-18 and UO-5 images (yes, 1200 bps and 9600 bps modems included), RTTY, and a host of other modes. DSP is the wave of the future and will provide some excellent price/performance ratios for amateurs across the world. You should most definitely research this exciting development and be ready for improving your processing capabilities by an order of magnitude.

CONCLUSION

This treatise on satellite image processing is just a brief tickler into the wonderful world of satellite imagery. With a major investment in your current OSCAR satellite station it will only take a minimal upgrade in software and/or hardware to begin receiving images from spacecraft orbiting at over 17000 mile per hour. And as a final incentive to "image-enable" your satellite station, I present Fig. 10, submitted by Marciano Righini and associates, of Italy, showing an HRPT image (Feng Yun 1-B, 28 Jan 1991) over Spain and North Africa. Note the mountain ranges and jet vapor trails to the center right of the image. This is the quality of imagery that you can receive in YOUR satellite image station!

Copies of reprint materials noted in text, vendor contacts, and other information on satellite imagery may be obtained from the author at:

Jeff Wallach, Ph.D.
N5ITU

PO Box 117088
Carrollton, Texas 75010

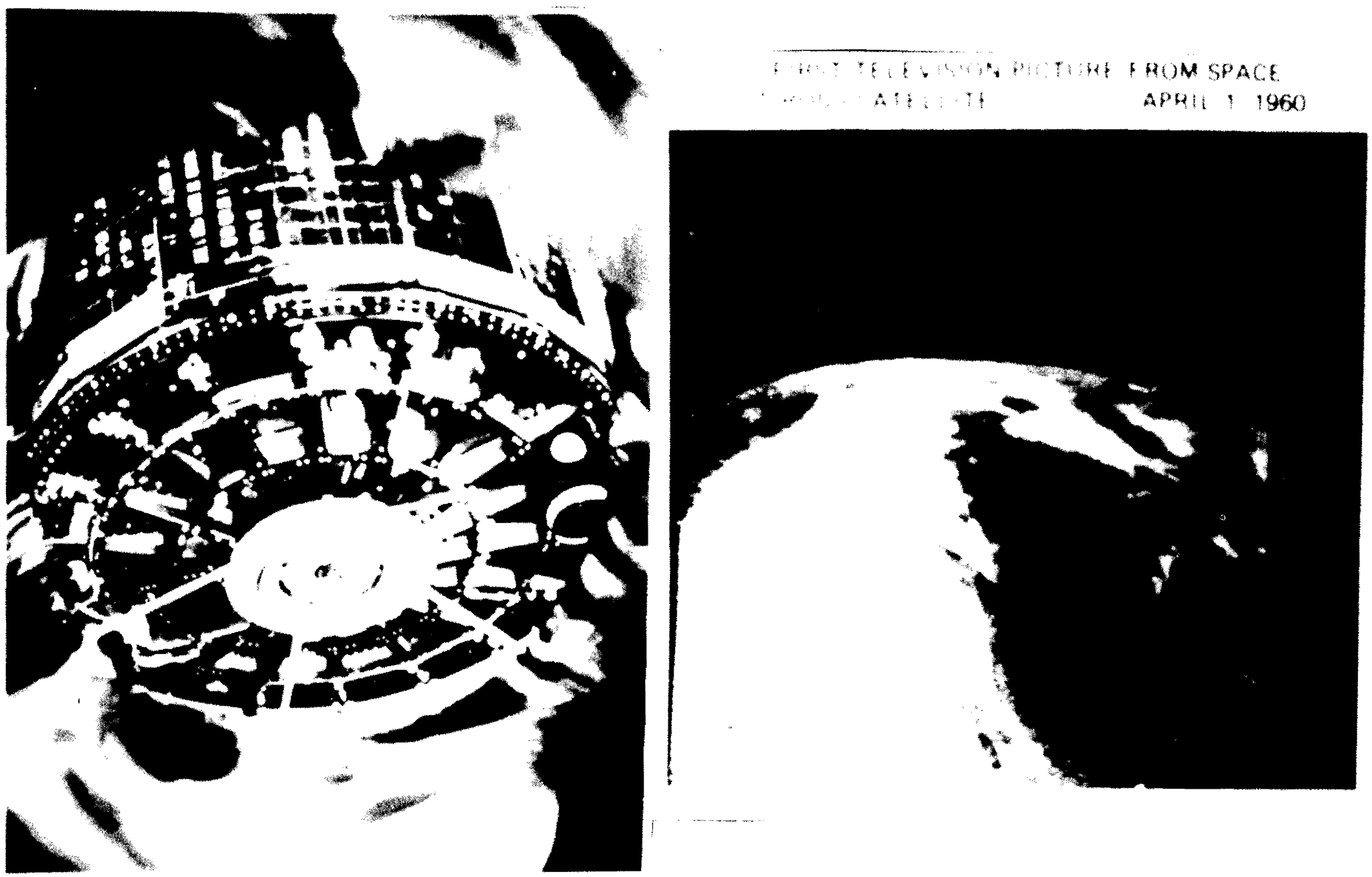

Fig. 1. U.S. TIROS 1 spacecraft and first U.S. weather picture from space.

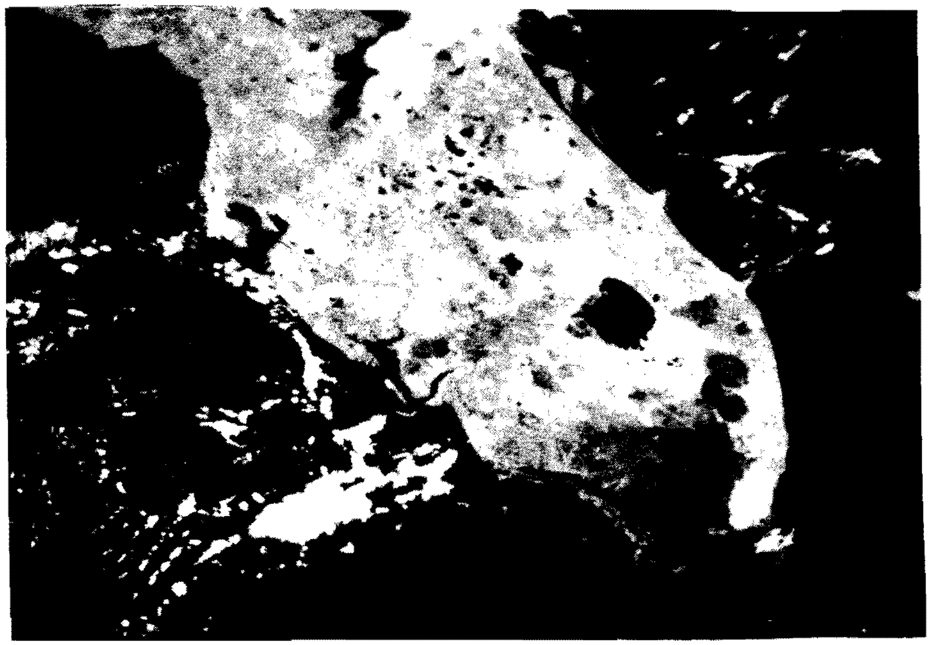

Fig. 2. HRPT image of Florida taken by Chinese Feng Yun 1-B satellite

Fig. 3. Soviet Meteor 3-3 APT image of N. Africa and Mideast

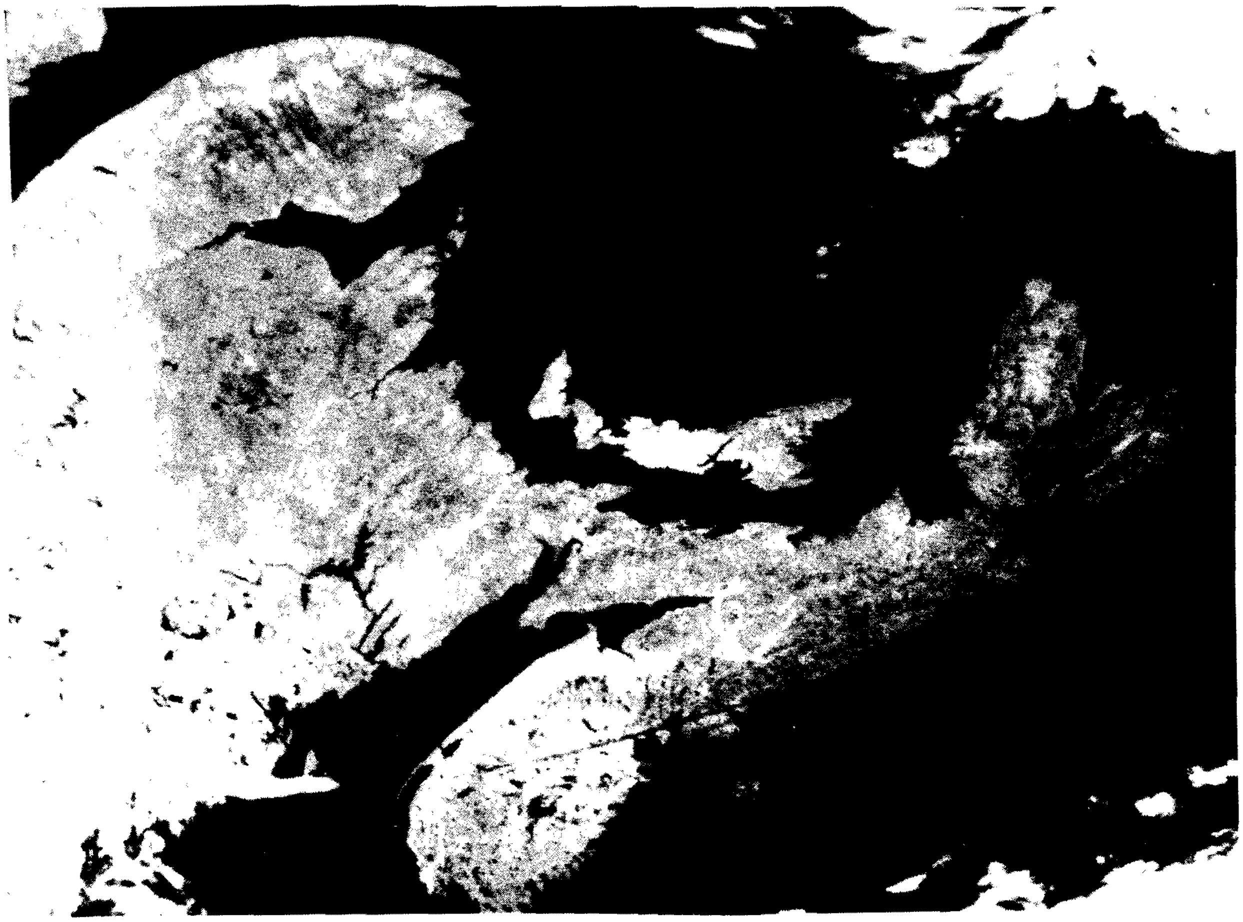

Fig. 4. HRPT image of Eastern Canada - NOAA 12 orbit #12

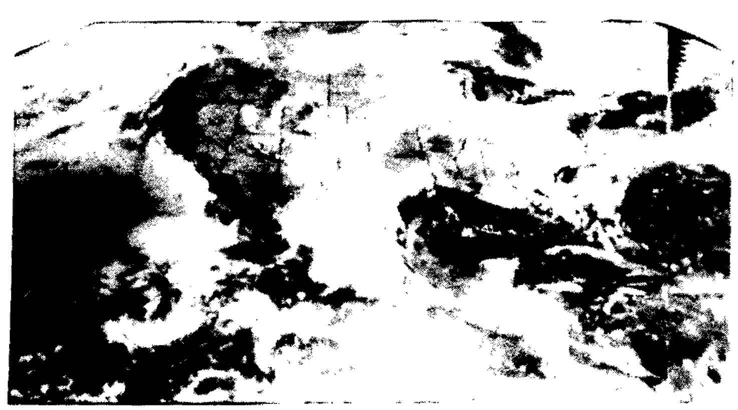

Fig. 5. GOES WEST image of July 1991 solar eclipse and shadow of moon over South Pacific and Baja, California

Fig. 6. Soviet Okean 2 APT image with side looking radar image of Florida and Cuba at left

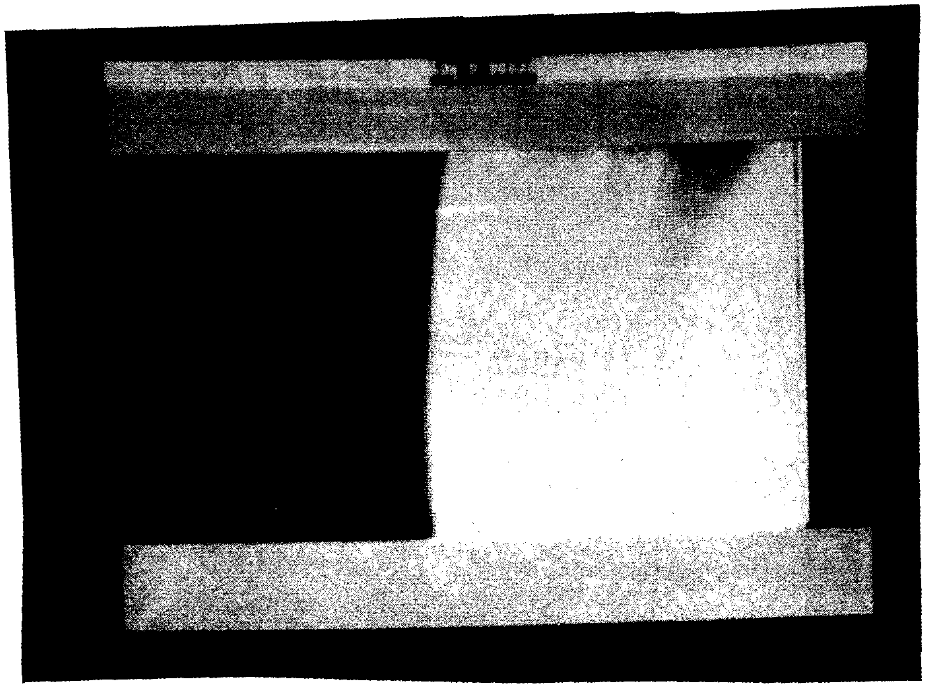

Fig. 7. WO-18 CCD image of Earth's horizon

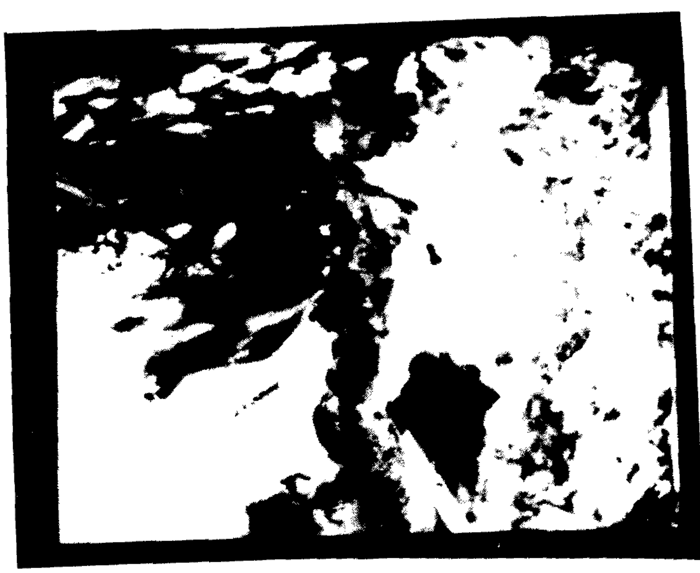

Fig. 8. UO-5 image of Baja, California

Fig. 9. UO-5 image of Mideast and oil fires smoke plumes

Feng Yun 1-B, 28 January 1991, 0810-0825 GMT, descending, HRPT Ch.2.
Spain and North Africa with long shadows cast by the grazing sun.

SEDSAT 1 1991 Status Report

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The University of Alabama in Huntsville Students for the Exploration and Development of Space, in cooperation with governmental, industrial and non profit organizations are developing a microsat class satellite. This satellite is designed to serve the international amateur radio satellite user community, act as a test bed for emerging satellite technology, and provide opportunities in education for students to learn about space and space technology. This paper gives an overview of the current design, and the project's status.

Introduction

SEDSAT 1 is a microsat class satellite potentially flying as a secondary payload as part of NASA's Small Expendable Deployer System (SEDS) flight demonstration project[1] . SEDSAT 1 is being designed to be deployed into a 680 X 792 km orbit at a 39° inclination. SEDSAT 1 will be deployed from a McDonnell Douglas Delta II 7925 second stage by the SEDS via a 46 km tether (upward deployment).

The objectives of SEDSAT 1 can be separated into three catagories. Operations, technology development, and education. Operationally, SEDSAT 1 will serve as a amateur radio satellite communications relay and remote sensing platform. From the technology development perspective SEDSAT 1 will measure the SEDS tether deployment dynamics, demonstrating the use of a tether as a propulsion system. In addition, the satellite will demonstrate new power, communications and on board computational technology. On the education front, students currently working on SEDSAT 1 can receive college credit for working on the project under the direction of UAH faculty. Also the satellite will have many features that will be utilized after launch for the teaching of math, science, engineering and amateur radio communications for students in college down to elementary school children

Project Organization

The SEDSAT 1 project is organized and located at the University of Alabama in Huntsville (UAH). The lead organization is the UAH chapter of the Students for the Exploration and Development of Space (UAH SEDS). This project is being carried out under the guidance of faculty advisors Dr. Charles Lundquist, Director of the UAH Center for the Commercial Development of Space, and Dr. S. T. Wu, Director of the Center for Space Plasma and Aeronomic Research. Dr. John Gilbert, of the Mechanical Engineering Department, acts as the faculty advisor for the imaging experiment on board the satellite.

Amateur radio organizations directly involved in the project includes the AMSAT-NA Detroit Spacecraft Lab, with John Champa, K8OCL and Steve Webb, KB8HI, leading the effort, members from the Marshall Space Flight Center Amateur Radio Club including Ed Stluka, W4QAU, Chris Rupp, W4HIY, and Gene Marcus, W3PM. Dr. Jeff Wallach, N5ITU, of the Dallas Remote Imaging Group, (DRIG) has provided very welcome input on imaging systems and approaches currently in use. Also, much good information and advice has been forthcoming from members of AMSAT/NA too numerous to mention.

Support from NASA has been forthcoming from many sources. Richard DeLoach, manager of the first SEDS mission has been of great help. At the Marshall Space Flight Center (MSFC) persons from Preliminary Design, Electronics Branch, and the SEDS program office are working with us in an advisory capacity to verify our design approaches and are helping us to test the subsystems of the satellite. Also, the SEDS tether deployer itself and the support for our mission is supplied by the SEDS program office at Marshall. Attitude determination software is being supplied to the SEDSAT 1 project from the Jet Propulsion Laboratory (JPL). The launch opportunity, if secured for the SEDS tether deployer mission, will come from NASA headquarters code M.

Participation from industry comes from Boeing Defense and Space, Renton, WA; Kopin Corporation of Taunton, MA; The Space Computer Corporation of Santa Monica, CA.; Quadron Inc. Los Angeles, CA.; Gates Energy Products of Gainsville, FL; Trec, Inc.; and Optechnology of Huntsville, AL.

Educational institution support outside of UAH comes from the Institute for Aeronautics and Astronautics, National Chen Kung University, Tainan, Taiwan; Weber State University, Odgen, Utah; and Students for the Exploration and Development of Space (also named SEDS) chapters located at colleges and high schools around the world. Figure 1 represents our team approach to this project.

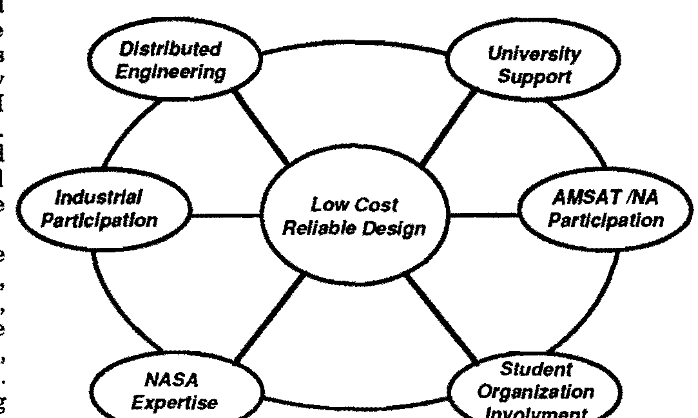

Figure 1 *SEDSAT 1 Design Philosophy*

SEDSAT 1 Overview

SEDSAT 1 is a microsat class satellite with a projected launch weight of 37 kilograms. The satellite is a 34.04 X 34.04 X 30.5 cm flattened cube This size was chosen as the one that best supported the tether dynamics studies while still fitting within the allocated secondary payload envelope of the Delta II second stage.[2] There are two sets of antennas on SEDSAT 1 to support amateur radio satellite communcations. The lower turnstile antennas are 70 cm transmit antennas, and the upper antennas on the corner, support the 2 meter uplink and 10 meter downlink. Figure 2 is a diagram of SEDSAT 1 with the -Z face removed.

Attitude Control

SEDSAT 1 attitude control is similar to the passive spin/magnetic type used on the AMSAT microsats.[4] Either the 70 cm., or the 2/10 m antennas can be used for solar vanes, while the hysteresis rods and permanent magnets are mounted as with the microsats. The flattened cube shape will guarantee that the spin axis will remain aligned with the Z axis. This will support the remote sensing as well as the communications aspects of post tether deployment operations.

An alternative for attitude control being considered is the use of a 100 meter short tether with a mini end mass as a deployable gravity gradient boom. The gravity gradient tether would accomplish the same alignment with respect to the earth as permanent magnets but with the drawback of more system and operational complexity.

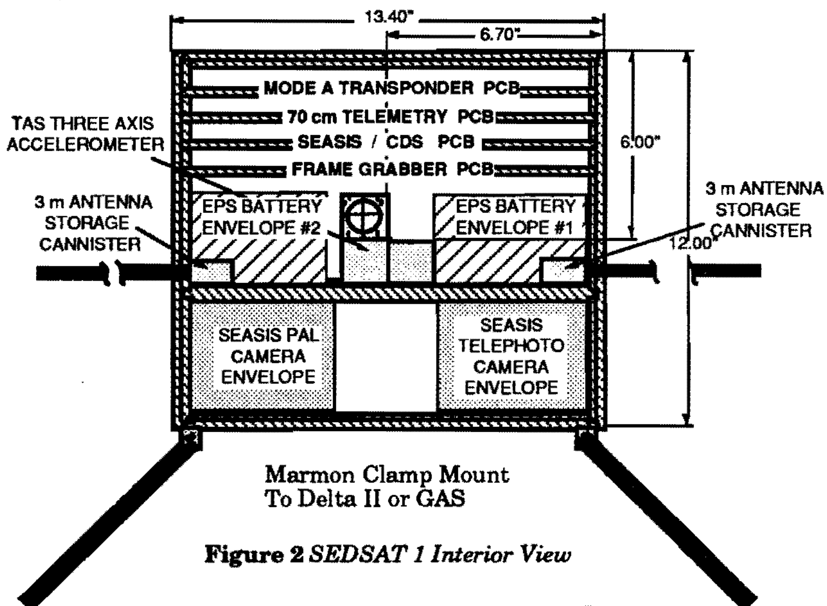

Figure 2 *SEDSAT 1 Interior View*

Structural Design

Modularity and testability is the key to the SEDSAT 1 design. A card cage design was chosen for the Electronic PCB's to simplify ground testing and enable quick disassembly in case of a late failure during satellite integration. The PCB's are mounted on a 6.35 mm square mounting plate that slides into the shell of the satellite. The experiments are also mounted on a slide out mount that will allow easy access to the experiments and the batteries.

The main structure of the satellite is made out of 1.27 cm (.5") 6061 T6 aluminum. Weight is not as much of a factor in the design of SEDSAT 1 as the requirement of making the satellite massive enough to keep tension on the tether during the deployment sequence.

This massive approach to structural design has a beneficial impact on thermal control. The thermal constant for the entire structure is on the order of 10,000 seconds. This large value will guarantee that the temperature of SEDSAT 1 will vary very little during operation of the satellite.[3] This is important due to the fact that the AlGaAs/CIS solar cells have greater absorptivity than silicon cells. Also at the inclination of SEDSAT 1's orbit, the shade time will vary from a maximum of 33 percent of orbit down to a minimum of 8 percent. The large thermal mass will help to keep temperatures within a range of values that allow us to characterize the power system in a thorough, systematic manner.

Student Experiments

SEASIS

SEDS Earth, Atmosphere, and Space Imaging System (SEASIS) is an imaging experiment that will visually record the attitude of SEDSAT 1.[5] SEASIS incorporates two Panasonic GPKD502 industrial video cameras with NTSC and RGB output. Each camera head has three Charged Coupled Device (CCD's) organized into a 492 X 682 array. Each CCD output, R, G, B, can be captured independently.

A flash analog to digital converter/frame grabber from Weber State University similar to the one used on WeberSAT is used to convert the cameras's NTSC or RGB output to a digital pixel array where each element is one byte in length. A dedicated SCC-100 parallel processor is used to transfer the image data from the frame grabber to memory. The SCC-100 compresses the images, to allow the storage of up to 2000 images in mass ram for later downlink to the Earth via 70 cm telemetry .

TAS

The Three-axis Accelerometer System (TAS) consists of a three axis set of very accurate, very temperature stable accelerometers (Sundstrand QA 3000-030). At the limit of their resolution, they can measure g levels on the order of one μg. These accelerometers will be used to measure the accelerations that the endmass is subjected to at the end of the tether.[6] The accelerometers are mounted at the exact center of mass and geometry of the satellite.

Command Data System

The command data system (CDS) design closely parallels the AMSAT microsat design in order to retain as much software compatibility as possible. This design consists of an Intel 80C186 microprocessor with a system architecture similar to the UoSat's.

The CDS also incorporates two serial controllers (Intel 8530's). These controllers will handle all communications with the ground as well as some interprocessor communications with the SEASIS processor. Also there will be 512k of 12 bit error detecting and correcting memory that will be used as the applications software operating memory. Another feature will be the inclusion of up to 128 analog inputs to two A/D converters, with 12 for TAS and 116 available to monitor the state of the onboard systems. These channels will be used to support the accurate in–flight characterization of the power system. To support the mode A transponder operation, there will be a digitalker similar to ones flown previously on OSCARS. Finally, there will be 512k of dual ported ram for image transfers between SEASIS and the CDS, with the AMSAT AART bus being used for controlling the communications transponders. There will be 128 Megabytes of mass ram available to the CDS processor through the SEASIS dual port ram. There will be some other interfaces between the two processors to support experiments in analog communications and secondary control of the SEDSAT 1 power system. The operating system software for the CDS system is the Quadron QPS real time multitasking system. Figure 3 shows a functional block diagram of SEDSAT's electronic systems.

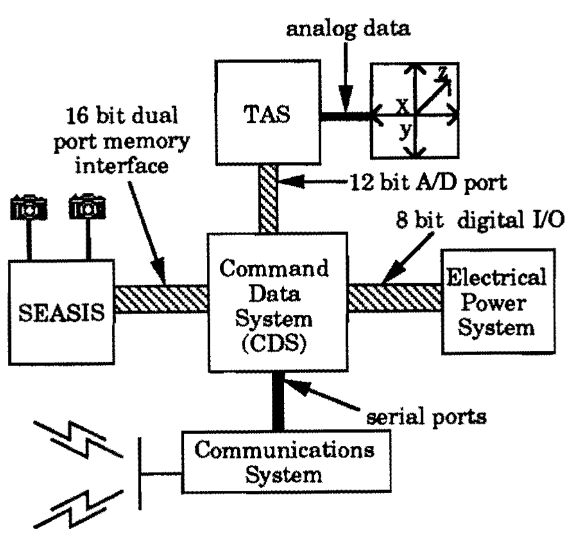

Figure 3 *SEDSAT 1 Electronics Systems*

Electrical Power System

In an effort to both broaden the scope and enhance the effectiveness of the SEDSAT 1 mission, UAH SEDS approached Boeing Defense and Space regarding the possibilities surrounding the use of their leading edge technology planar photovoltaic cells on SEDSAT 1.[7] In the ensuing negotiations with Boeing, and their subcontractor Kopin Corporation of Taunton, MA, it was mutually agreed that the (AlGaAs)GaAs/CIS thin-film, tandem cells jointly produced by the two companies would be the optimum solution in powering SEDSAT 1. In the course of technical discussions about the satellite, it was realized by all parties involved that not only would the cells be the optimum solution for SEDSAT 1, but also a flight demonstration of these cells on a microsat class satellite would be greatly beneficial to the rapidly developing field of small, low-cost satellite systems.

These (AlGaAs)GaAs/CIS cells coupled with new high-energy battery technology and a unique power system developed by UAH SEDS with the support of NASA Marshall Space Flight Center, offer the small satellite industry a doubling of available power and a decrease in system complexity compared to currently used approaches. This combination of new technologies opens up new and exciting possibilities in the further development of small satellites and their applications.

To complement the vastly increased performance offered by the incorporation of the thin film tandem cells, it was decided by the SEDSAT 1 design team to pursue the inclusion of batteries with a performance to match that of the solar arrays.[8] While weight is not a problem with SEDSAT 1, internal volume and center of mass is. Use of NiMH batteries affords SEDSAT 1 a doubling of energy storage with no increase in either weight or volume. Two batteries with an energy storage capacity of 150 watt hours were chosen. These batteries fit within the allocated volume and enable SEDSAT 1 to run full power with a very low depth of discharge on the batteries.

With the goal of reducing the manufacturing cost and complexity of SEDSAT 1 a distributed power architecture was selected. This architecture provides a smaller size, lighter weight, more efficient operation with battery power, and more efficient subsystem isolation and redundancy than a centralized design. The number of cables required to carry power is decreased by having only a single distribution voltage with local conversion to the needed voltage.[9]

Until recently, this approach was not optimum due to the inefficiencies in the DC-DC converters in use. SEDSAT 1 is using the Interpoint MTR series DC-DC converters. These converters offer efficiencies of power conversion in the 78% to 84% range. It was decided that the efficiencies provided by the converters were good enough to justify the trade off of decreased system complexity, increased reliability, and lower manufacturing cost.

Communications System

The communications system for SEDSAT 1 is intended for the use of amateur radio satellite operators worldwide. There is one mode A linear transponder with a second downlink for satellite engineering and science telemetry on the 70 cm band. The mode A transponder has a 60 KHz bandwith. The tentative downlink frequency is 29.300-29.360 Mhz. The uplink frequency is proposed at 145.820-145.880 Mhz. The 70 cm telemetry downlink frequency is currently TBD.

In addition to the science and engineering telemetry that will be on the 70 cm downlink, there are several exciting communications experiments that will be conducted with the mode A transponder. One experiment will be a 300 baud FSK packet bulletin board located at the low end of the transponder. Right above that will be a voice synthesized, compressed SSB AM compatible digitalker channel. This channel will provide vital statistics on the health of the satellite and other information that can be picked up by amateurs using extremely simple and inexpensive 10 meter gear. Another feature that will be tested on the mode A transponder is a new form of message store and forwarding. This method will take advantage of the massive computational abilities provided by the SCC-100 computer supplied by Space Computer Corporation. The throughput of this processor is 100 *million* floating point operations per second. This vast processing power will allow us to set up a message system whereby an amateur radio operator would be able to uplink a short data file with the source and destination call letters and a subject header. Then the operator would be able to uplink a message of up to thirty seconds in duration. This message would be converted to digital format, compressed and then stored in the mass ram included for the SEASIS image storage ram. (Most of this ram will not be necessary for image storage after the tether mission is complete.) When the operator for whom the message is intended reads his call letters in the message directory, he or she can then initiate a message playback with Pacsat similar commands. The stored message is uncompressed and reconverted into an analog voice signal and transmitted through the mode A transponder downlink to its intended recipient. The name of this unique satellite message system is Message-sat. The uses of this system could be extensive, from passing inconsequential messages from Ham to Ham, to passing vital emergency traffic in a form that would allow the timely response of rescue personnel with information that would allow them to be better informed and prepared to deal with whatever situation is presented. This capability for voice message-forwarding is being explored by the SEDSAT 1 project group and suggestions and comments would be welcome.

Other experiments for the mode A transponder being considered are QRP tests using the high power transmit mode capability. This would be used to enhance the effectiveness of SEDSAT 1 for mobile and emergency communications.

The 70 cm downlink will transmit engineering telemetry and science instrument data at 9600 bps with AFSK modulation identical in nature to the UoSat protocols. Image information will be stored in a compressed format and transmitted down as data that will be able to be manipulated with our DATAware software package. The accelerometer data will be stored in a numerical format and processed on the ground by DATAware software that will be available through the AMSAT-NA software exchange.

Project Status

In the year since the last AMSAT-NA Symposium there has been a great deal of progress made on the SEDSAT 1 project. In March of this year, an agreement was reached between the SEDSAT 1 project and Boeing Defense and Space regarding the use of their solar cells on SEDSAT 1. Also in March, presentations were made to the director of NASA MSFC, the result of which garnered their support in the testing of the integrated satellite and associated subsystems. In June, collaboration on the design of the SEDSAT 1 electrical power system commenced with the NASA MSFC Electronics Branch. Also during the summer the NASA MSFC Preliminary Design Branch began a review of the mechanical and thermal systems of SEDSAT 1. Persons in each of these departments volunteered to serve on our design review board for our up coming SEDSAT 1 design review in November. In addition, members of the student design team were able to enroll in a special topics course and receive engineering credit for work on the SEDSAT 1 power system.

In July, support from our educational partners in Taiwan became a reality with the inclusion, in the budget of the Institute of Aeronautics and Astronautics, National Cheng Kung University, of funds to support the SEASIS imaging experiment.

August was a crucial month in the evolution of the SEDSAT 1 project with presentations being made to senior management from NASA headquarters both in Washington, D.C. and Huntsville, AL on our project. The SEDSAT 1 satellite is now making an official request to be manifested as the end mass payload on the second flight of the SEDS deployer on a Delta II sometime in 1993. Also in August, a letter of agreement was signed between the SEDSAT 1 project, NASA MSFC Electronics Branch and Gates Energy products on supplying Nickel Metal-Hydride batteries for ground testing and eventual flight as the energy storage system on board SEDSAT 1. Also in August, papers on the SEDSAT 1 project electrical power system design and DATAware software approach were presented at the Fifth Annual Small Satellite Conference where we gained additional support.

In September the project gained further support with an agreement with Space Computer Corporation for the flight of the SCC-100 parallel processor on board SEDSAT 1. This incredibly powerful computational system is only 53 mm X 73 mm X 10 mm! The inclusion of this capability at the same power cost as the previous processor will allow the exploration of services for the amateur satellite community unique in scope and unheard of in almost any other satellite flying. Proposals have been made to DARPA, NASA HQ and MSFC on monetary support for our project. Some monetary support will be necessary to enable us to pay for the parts needed for the transponders, power system and Command Data System.

In October we are planning to receive from Weber State the frame grabber for the SEASIS experiment and in early November the first of two cameras also for SEASIS. Also in November the printed circuit version of the TAS signal conditioning electronics will be flown on the UAH CONSORT 4 sounding rocket along with representative accelerometers to measure the microgravity levels on board the materials processing in space mission.

This has been a tremendously exciting year for the SEDSAT 1 project. As can be seen much progress has been made. We look forward to this next year to building the hardware, assembling satellite and making it all work. We currently are planning to have the satellite finished and ready for shipment by Christmas of 1992. We are looking forward to a year where hopefully all of the pieces of the puzzle come together as we work together to make this mission happen.

Acknowledgments

It would be impossible to identify and thank all of the people who have helped this project in the last year. People from all of the organizations mentioned in this paper have all been of tremendous help to us in accomplishing our goal of putting this mission together. We at the SEDSAT 1 project want everyone who has helped us and believed in us to know that without out your generous and gracious support our project would have never happened. We also wish to thank the creator of all things who made fun things like space exploration possible.

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Foreword

We're pleased to publish, as part of this Proceedings book, papers that especially deal with the educational use of Amateur Radio satellites and space operations. AMSAT and ARRL co-sponsored an educational workshop for speakers to give presentations during the weekend of the AMSAT Symposium. Topics of papers that authors wrote included integrating satellite operations in to high school physics classrooms, use of satellites in college engineering courses and ways to involve very young students in satellite and Shuttle Amateur Radio EXperiment (SAREX) activities. We've always known that Amateur Radio and education can go hand in hand, quite nicely, at all grade levels. These papers prove this theory, and give readers examples of how teachers actually put the theory into practice. We hope to see hundreds of teachers take advantage of Amateur Radio satellite and SAREX activities to make their regular classroom studies more vital for students.

David Sumner, K1ZZ
Executive Vice President, ARRL

November 1991

USES OF AMATEUR SATELLITES IN ENGINEERING COURSES

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Several engineering courses that include space applications are taught at the U.S. Naval Academy. Amateur satellites such as DOVE-OSCAR-17 and OSCAR-13 are used in these courses to demonstrate satellite tracking and aspects of spacecraft engineering. Students capture and decode telemetry for both laboratory exercises and homework assignments. The use of amateur satellites in the classroom increases student motivation, stimulates interest in the space program, and exposes young men and women to amateur radio.

Introduction

The Naval Academy offers seven engineering majors including Aerospace Engineering and Systems Engineering. Midshipmen majoring in Aerospace Engineering may follow the Astronautics Track, a formal program of concentrated study in space systems engineering. Several astronautics courses such as Spacecraft Systems and Astrodynamics were developed as part of the Astronautics Track. Those Systems Engineering majors who are interested in space often take these courses as electives.
Astronautics courses begin with the second class (junior) year of study. Midshipmen in the Astronautics Track first take an introductory course in space applications, then a semester of astrodynamics. In their first class (senior) year, these midshipmen take courses in spacecraft engineering and space environment. Topics of astronautics electives include advanced astrodynamics and spacecraft thermal control. In the final semester before graduation, these students conclude their studies with a spacecraft design course in which they complete a conceptual design of a spacecraft.

Introduction to Space Course

The first course in the astronautics curriculum is Introduction to Space, a lecture course with some laboratory exercises. Topics covered include simple orbits, basic spacecraft engineering, and RF communications. One of the laboratories instructs the students in tracking Molniya-type satellites. After calculating azimuth and elevation angles, the students command the large 12 meter parabolic dish antenna at the Academy to track the satellite. Originally, the exercise was to use the four Soviet Molniya television satellites, but these spacecraft were deactivated in January 1991. AMSAT OSCAR-10 and OSCAR-13 are in elliptical orbits, so these amateur satellites are now used for the laboratory in place of the Molniya satellites.

Other amateur satellites are used to introduce the concepts of tracking low Earth orbit spacecraft and receiving telemetry. The antenna requirements for these satellites are modest, so a simple crossed dipole was installed on the roof of the building. The students are directed to predict when DOVE-OSCAR-17 is in view, tune a receiver to the DOVE beacon frequency, and record telemetry packets with a printer. The students decode the telemetry by hand using formulas provided by AMSAT. The students are to estimate the spin rate and orientation of the spacecraft by using the solar array currents. The hardware used in this lab includes a computer, a terminal node controller, a receiver, a serial printer, and the antenna on the roof. The only software used is a tracking program, but a telemetry decoding program could easily be added.

Astrodynamics I Course

Midshipmen in the astronautics track are required to take one semester of astrodynamics; further orbital mechanics courses are offered as electives. Computers are used extensively in all these courses for tracking exercises. Amateur satellites, especially DOVE, are used to illustrate tracking spacecraft in low Earth orbit. A modest scanner is used to verify the presence of the downlink from a satellite at predicted times. OSCAR-10 and OSCAR-13 are used to illustrate tracking spacecraft in high elliptical orbits.

Spacecraft Systems Course

In their senior year, students learn about the various subsystems of spacecraft in detail. The Spacecraft Systems course includes power, thermal control, attitude control, and communications subsystems. Telemetry from amateur satellites is used with some homework assignments. For example, students are given the thermal parameters of DOVE and asked to predict the spacecraft temperature in sunlight. The students are also given some printed telemetry packets from DOVE in order to verify their predictions.

The telemetry from DOVE is the easiest to use since the only equipment required (apart from a receiver and printer) is a packet radio terminal node controller. While a satellite modem adds to the cost, it is a good investment since telemetry from virtually all amateur satellites can be received. Most satellites apart from DOVE require computers for decoding telemetry, but the students have been introduced to telemetry decoding in previous courses and are experienced computer users.

Amateur satellite contacts are real-world examples of communications links. Students can be assigned to estimate link margins given the amount of transmission power the satellite uses as well as the type of transmit antenna. Different satellites use different coding schemes, so the effectiveness of these schemes can be shown.

Space Environment Course

Seniors in the astronautics track also take a required course in space environment. Amateur satellite telemetry offers an opportunity to view the effects of the environment upon spacecraft. For example, Fuji-OSCAR-20 includes memory unit error counts in its telemetry. A student could review telemetry from several passes to see if the error counts were higher when the spacecraft passes through the South Atlantic Anomaly where ionizing radiation is higher. Students could examine the gradual degradation of solar cells of an amateur satellite by tracking solar array current and voltage over several months.

Project Courses

Aerospace Engineering majors may take a research or design project course as an elective while Systems Engineering majors are required to complete a project for their degree. These courses make it possible for midshipmen to pursue ambitious undertakings. Students exposed to amateur satellites in previous courses often become so interested in the topic that they propose a project in this field.

One project under way is for a Systems Engineering major to assemble and integrate all the components of an amateur satellite ground station. While the Academy will acquire the computer, transceivers, terminal node controller, and satellite modem, the student will be responsible for connecting the equipment properly and learning how to operate the station. The midshipman will receive much hands-on experience with satellite communications gear and make numerous satellite contacts. He also will provide the Academy with a working ground station that can be used by other students in the future.

Another current project is that of a midshipman building and testing Yagi antennas for use with OSCAR-10 and OSCAR-13. The student will build and tune the antenna as well as fabricating the azimuth/elevation pointing system. The midshipman will receive hands-on experience with antenna construction and use.

Conclusions

Amateur satellites provide an opportunity for engineering students to gain real-world experience with actual spacecraft. The AMSAT satellites are being used in several courses. In addition to the purely educational purposes, the satellites stimulate interest in both the space program and amateur radio.

SAREX-A POST FLIGHT REPORT FROM TWO SCHOOL SESSIONS

This article is a report on the SAREX activities of schools in Pennsylvania on both STS-35 and STS-37 missions. Did the experiment meet its' goals and what can we do to improve future SAREX sessions?

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I can remember reading Bill Tynan, W3XO's article HAMS IN SPACE UPDATE, in the November 1989 AMSAT Journal and thinking about how exciting it could be to participate. Here is a report on SAREX as experienced by two school groups in eastern Pennsylvania. From the perspective of the kids and the community, did we promote interest among young people in science and technology and space in particular; and did we promote a positive image for Amateur Radio and interest new people in the hobby? I think we did this and much more and here's why.

HOW IT BEGAN, THE SCHNECKSVILLE SHUTTLE...

When I learned of the renewed efforts for SAREX opportunities on the STS-35 and 37 missions, I had been helping with the reconstruction of an old Marine Corps bus into a hi-tech mobile classroom for space science for the Schnecksville School in the Parkland School District. The bus exterior is a close facsimile of the actual shuttle. Although the bus completion did not coincide with the missions, work continues at the Mack Truck testing and research facilities here in Allentown. Many other companies near and far are helping with the efforts. The bus will remain the property of the Schnecksville School and the Parkland School District. And of course, it is being outfitted for amateur radio including satellite operations!

In addition, the school had a history of related science and space programs, including students and teachers who had attended Space Camp in Huntsville, Alabama. I suggested to teacher and project coordinator Bob Boehmer, their programs and SAREX would be a perfect marriage. Although Bob is a non-ham, he helped me solicit the help of the Delaware Lehigh Amateur Radio Club in the appeal to the ARRL and the SAREX committee. We hoped the quality of our program and the SAREX program goals would result in a two-way QSO opportunity.

Peter O'Dell, WB2D had the pleasure of calling to say that ARRL's Educational Activities Manager Rosalie White, WA1STO, and Ron Parise had picked us for the first QSO. We were honored to have been selected, especially after considering all the many equally worthwhile groups hoping to participate.

It was soon realized, however, that being first would not be without its problems. The time slot for the QSO was 34 hours 24 minutes MET, not much time to coordinate all the efforts required in terms of setup, and coordinating other schools and media. Six months of mission eventually took it toll with dwindling enthusiasm for both participants and media alike.

A lot was learned about the difficulties of an ambitious program mated with an unpredictable event like a shuttle launch. The delays had the benefit of creating a learning curve for future SAREX projects.

Students at the Schnecksville School wait with Tom Daniels, N3CXP, for their chance to talk to Ron Parise. (Photo by Clarence Snyder, W3PYF)

When the mission finally lifted off, the anticipation of a chance to talk with Ron Parise quickly renewed the interest of both the students and the public alike. The hours before the session passed quickly by and finally after all those months, Junior DeCastro, PY2BJO, attempted to call Ron with little success. The enthusiasm degenerated quickly into frustration and sadness. We watched the precious minutes tick away and only heard several garbled syllables from Ron. Several of the children even cried in disappointment made worse by the delays. The crowd present was very sympathetic and supportive of the attempt. The media was also very positive in its coverage and praise of the SAREX attempt. We disconnected the telebridge and shut down our HF voice link with WA3NAN at the Goddard Space Flight Center before they could tell us about a future time slot. Several hundred persons went home very disappointed on that December afternoon.

When Bob Boehmer and I learned of a second opportunity, we mutually agreed to coordinate a less publicized event, considering our previous experience. Were we surprised when the small school gymnasium filled up with more press and visitors than the the first try. An evening session this time provided a much more relaxed and informal atmosphere. Our warnings went out about the "experiment" and possible failures. The group in attendance seemed to accepted this attempt as a challenge which they could, in some way, help to execute. There were several anxious minutes of spacecraft attitude adjustment made just for this session before contact was made. I will never forget the warm applause and cheers when we all heard Ron Parise respond to Gordan VK6IU's call: "VK6IU this is WA4SIR how do you copy?"

Ron proceeded with several questions with mixed success before our turn. As fate would have it, we were very fortunate this time as Jeff Garte asked: "What has been your most memorable experience so far?" Ron's response was "that was quite a ride!....maybe the most memorable one was the first time looking out the window at the earth, it's really an awesome site that you never forget!". After an exchange with another student, Kara Plikatis we began to have dropouts and LOS.

There had been problems, delays and cancellations, and discouragement. When we finally were successful the whole exchange only lasted two minutes or so, but the consensus of everyone who participated was overwhelming success.

THE HANOVER EXPERIMENT...

Four months later, I found myself listening to Ken Cameron's downlink here at N3CXP as he passed over the southern US and answered questions at W5RRR. In just several hours, we would get another opportunity to introduce many local students to SAREX. In contrast, things had gone flawlessly to this point. The launch timetable only had a minor weather delay. SAREX coordination on the part of the AMSAT volunteers was more streamlined and the schedule less ambitious. At the school, we were able to wait until the morning of the contact to set up equipment. The press coverage did not have to be repeatedly cancelled.

During the previous week, the students and teachers were introduced to the experiment. Pre-SAREX enthusiasm was extremely high at the Hanover School as Taylor Cameron, Ken's nephew attended the school. Although Taylor and several of his friends were in Florida for the launch, the Cameron connection made this event rather special for all concerned. Principal Jack Burke wanted to make sure that all the children in the school had been prepared to understand what was to happen. He had arranged for me to speak to them on a grade by grade basis. I tried to make them understand that there might be communication lapses and showed them how by orienting my son's model of the shuttle over a globe. Many of them figured the antenna pointing problem out with my simple demonstration. The questions were submitted after my visit and picked from a pool of several hundred and students were picked by the faculty among those could best represent the school.

Ken Cameron, WA4SIR, and the students of the Hanover Elementary School (photo by Tom Daniels, N3CXP)

I posted a notice on packet about our scheduled contact throughout Pennsylvania, Delaware and New Jersey. Bob Reynolds, WB3DYE, a reporter with WNEP-16, an ABC affiliate in Wilkes-Barre/Scranton, read my message and made previous arrangements to cover the SAREX experience in a continuing story, including pre and post SAREX interviews with the kids. The story eventually aired throughout northeastern Pennsylvania in three parts. In addition to Bob's efforts to provide as much coverage as possible for SAREX, he made arrangements to use the station helicopter equipped with two meters to warm up the kids the morning of the schedule.

The hour or so before the contact went extremely quickly as introductions on the program were made. This time with only two other schools on the bridge, there was time for exchanges between all parties and W5RRR. As AOS passed, Ted, HC5K, began to encounter difficulties with dropouts. NASA confirmed a bad shuttle attitude with our Equador ground station, and no contact was established. NASA initiated a roll maneuver just before LOS, and we all hoped for better success with our SaoPaulo ground station, Junior DeCastro, PY2BJO. After several minutes, communications began to improve. We transmitted our question in the blind, as ten year old Katie Granson asked for the altitude at which you lose gravity. After several seconds of noise and a repeat of the question, Ken's response came through loud and clear. The attitude adjustment allowed the other two schools to QSO with Ken as he passed over SaoPaulo, Brazil. Junior also remarked to Ken that he now had a visual sitting of the orbiter. Ken excitedly replied that they were also taking pictures of San Paulo.

Several weeks later, the Hanover School was fortunate enough to get a visit from Ken and all the SAREX questions were answered. Ken shared with us many of his moments from the mission and answered many more questions. His enthusiasm for amateur radio and the SAREX program was very gratefully received by two schools in the Bethlehem School District.

DID THE PROGRAM MEET ITS GOALS?

The response to SAREX in eastern Pennsylvania was very satisfying. Even though the exchanges were short, the goal of putting a young student in a question and answer session with an astronaut had been accomplished through a rather amazing worldwide amateur radio network. The media did a commendable job of publicizing the event in many articles too numerous to mention. There were stories about amateur radio and amateur radio satellites and interviews with the kids and teachers before and after the experience. Television and radio coverage was also very extensive, although the postponements of STS-35 understandably had the effect of diminishing the interest of the larger Philadelphia network stations. WPVI-6, the ABC affiliate did make the sixty mile trip to cover the event.

The Schnecksville connection made the cover of the Local/Regional section of the Allentown Morning Call, complete with a large picture. The Hanover connection was even more newsworthy as it took up most of the front page Sunday morning. Included was a half page photo of Katie Granson wearing her Atlantis sweatshirt waiting to ask her question. That morning Saddam Hussein had to settle for the second best.

Never before had such a remarkable amateur effort been attempted on a worldwide basis. The experiments had succeeded in promoting a widespread interest and awareness of both the shuttle program and amateur radio alike. The several hundred children fortunate enough to be present at the two locations, attentively listened for long periods with obvious interest despite the concern by the teachers about how to keep the kids occupied. Requests for talks about SAREX are still being generated and much positive feedback has been received. Amateur radio class attendance has also markedly increased here in the Lehigh Valley.

THE FUTURE....

I was assured by Ken Cameron that he and Ron were as excited to make the SAREX contacts and to find out about they were received as the rest of the earthbound participants were. We all may not realize how important this program could be to NASA and to the grooming of future astronauts, engineers, scientists and hams. In Ken's words: "It brings the space program right into the classroom in a way that I don't think anything else we have has been able to, by bringing amateur radio into the classroom, the students and the whole school become much more a part of a mission."

The past success hopefully will go a long way into making SAREX a permanent part of the Manned Space Program. Based on past experiences, a few things might improve the program:

- o Antenna location on the shuttle must be improved. In the mean time, ground stations could be added to "surround" the flight path. By selecting stations on both sides of the path, the dropouts could hopefully be minimized by maximizing a chance to direct rf at shuttle windows. This effect was confirmed as the shuttle was received Q5 here in Pennsylvania for eight minutes, while dropouts were occurring at W5RRR as the shuttle passed over the gulf.

- o A network of SAREX coordinators might be established, using past participants to help new groups establish meaningful and successful sessions. The coordinators could also help with educating students and teachers about the experiment, provide technical assistance and press coordination. In addition, it would alleviate the load on AMSAT and ARRL volunteers.

- o School participants must be aware of the difficulties that can happen and must remain flexible. A plan should be developed that can be implemented repeatedly.

Finally, the success of the program can't possibly be summed up better than by Jennine Schweighardt, now in eighth grade. She was a student at the Fogelsville Elementary School, who had gone on to junior high school by the time STS-35 lifted off. Although Jennine did not get to speak, I received this letter several weeks after the session:

> Dear Mr. Daniels,
>
> I'm one of the Springhouse Junior High students who was on the panel to speak with astronaut Ron Parise. Although there wasn't enough time for me to speak on the radio, it was an exciting experience to just be a part of the project. It was an event I'll never forget.
>
> Thank you for all the work you did in helping set up the ham radio communication link with the shuttle. I know you put in a lot of time and effort, and I really appreciate it.
>
> Sincerely,
>
> Jennine Schweighardt

It will be fun to watch what happens to participants and observers like Jennine, Jeff and Katie as they pursue educations and careers. The SAREX program will hopefully continue to be a valuable program in the future development of NASA, AMSAT, amateurs and students alike.[]

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USES OF AMATEUR RADIO SATELLITES IN EDUCATION

As the IARU recognizes the importance of using amateur radio satellites in education to attract young people to amateur radio, these projects can not be underestimated.
As Satellite Coordinator IARU, I have to inform all groups involved in building amateur satellites and experiments about the ITU and IARU resolutions about the Amateur Satellite Service.
I have to report to the IARU all projects in the amateur satellite field.
Because the IARU recognizes the importance of attracting young people in amateur radio, the following pages are my contribution to the Amsat NA/ ARRL workshop about the use of amateur radio for educational purposes.
I hope the workshop will define new ideas in this field, that can contribute in attracting the new radio amateurs of the future.
This paper was made to clarify the IARU policy about the Amateur Radio Satellite Service especially for education and to give some " food for thought " to the Amsat-NA/ARRL workshop.

Amateur Radio is a hobby where self - education is part of the satisfaction we can receive from all experiments involved with radio communication.
The ITU has recognized this many years ago and adopted a resolution where " self-training " is clearly stated :

> Amateur Service A radio communication service for the purpose of self-training, intercommunication and technical investigations carried out by amateurs, that is, by duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest.
> Amateur Satellite Service : A radiocommunication for the same purposes as those of the amateur service.

The IARU as the representative organization of radio amateurs has adopted a resolution, a guide for all those interested in the Amateur Satellites.

concerning amateur satellite usage

The IARU Administrative Council, Orlando, September 1989,

recognizing the important contributions made by amateur radio societies in the following areas:

* demonstration to the professional community that radio amateurs contribute to the development of state-of-the-art technology and techniques,

* Provision of new and challenging operational opportunities and training ground for radio amateurs to acquire new skills,

* providing opportunities for training in an exciting technological field by direct participation, in schools, universities and professional organizations, and

* stimulating the interest of young people in a worthwhile activity, and encouraging the pursuit of a technological career to provide the next generation of industrial and research engineers.

Wishing to stimulate the growth of the Amateur Satellite Service in an orderly manner; and

Strongly supporting the following goals :

* the encouragement of a wide dynamic range of activities stimulating training through increasing intellectual challenge.

* the stimulation of young people in schools and universities to develop an interest in amateur radio trough participation in amateur satellite activities,

* where allowed, the provision of emergency services, especially to parts of the world that are less technologically developed, and

* the adoption of a " code of practice " that ensures the use of amateur frequency allocations by satellites in accordance with the spirit and ethos of amateur radio.

Resolves

1. Member-societies shall make Administrations more aware of the value and achievements of the Amateur Satellite Service.

2. Satellites operating within amateur frequency allocations shall carry payloads and experiments that are relevant to, of interest to, and freely available for participation by radio amateurs worldwide.
3. Operational frequencies of amateur satellites shall be in accordance with all the applicable IARU band plans.

4. The use of higher frequency bands by amateur satellites shall be encouraged.

This resolution is the result of the work of Amsat organizations, radio amateurs and IARU.
We radio amateurs have accepted this resolution and together with the ITU definition of amateur radio is the basis of the rules from our National Administration.
From these basic guidelines, one can see that there could be many cases where these definitions do only partly apply or where it is difficult to determine if a satellite experiment is to be considered as an amateur radio experiment.
For all these dubious cases, the amateur radio spirit and ethos can best be served by consulting the amateur radio community before the experiment is set up.

We can compare an amateur radio satellite experiment for education against these guidelines and if the balance is negative we should consider to abandon the experiment.
Moreover, if one can find no clear connections with these guidelines, we can classify such a proposal as being a non-amateur radio experiment.

In judging an educational experiment, we can not classify a project within the amateur radio satellite service, simply because of the word " amateur "
ex. " Amateur " astronomy has nothing to do with " Amateur " radio.

The same can be said about education.
An experiment to " educate " geography is not to be seen under the classification " amateur radio for education "
The ITU definition refers to self-training not to " education " in the broad sense of the word. Geography is not self-training in radio. So a satellite providing education in geography is not an amateur radio satellite.
The same can be said about physics, computers, language arts, etc...

We can also classify " service " other than the emergency service defined by the ITU regulation : emergency service in case of a major disaster.
The amateur frequencies are not provided for any other services : service to community, service for medical purposes, humanitarian services, etc....
Only in case of a disaster, amateur frequencies can be used for emergency communications. Several national administrations are because of humanitarian reasons, accepting certain services on amateur frequencies but this is not clearly defined in the ITU and most countries do not accept some of these services as " amateur radio ".

So a satellite providing service or education as the primary payload can not be accepted in the amateur radio satellite bands. It would be very easy to build a complete satellite for a " service " and include only a very minor " amateur radio experiment ". This can not be considered an amateur satellite. It does not suffice to have some radio communication on board of a satellite to allow the satellite to use our frequencies.

So it must be clear that educational experiments can only be allowed as a means to recruit new hams, not as a means to have better education.
However, satellites for better education are very laudable but not in the amateur radio service. The ITU has made frequencies available for educational purposes outside the amateur radio bands.

Needless to say that a pupil in school studying geography through radio amateur satellites can be attracted to our hobby and become interested in amateur radio. So we can not neglect this way of " attracting young people " in the hobby. An educational experiment focused on geography as secondary payload of an amateur radio satellite could be tolerated.
A simple " amateur radio experiment " providing synthesized speech can attract very young people in amateur radio.

I refer to an IARU Region 1 resolution adopted recently that recognizes this. Attracting young people in amateur radio is part of the ITU definition of amateur radio and the IARU resolution.
A resolution just proposing the opposite, received support of most amateur radio societies and was only changed at the very last moment.

On the other hand we could not tolerate for ex. our 145 MHz satellite band full of " DOVE's speech synthesizers or full of experiments for geography.
ex. Do we really need more than 3 satellites with a CCD camera taking pictures of the earth more or less the same as all weather satellites do, solely for the purpose of giving builders the opportunity of building the experiment ?
Should we tolerate satellites filling up our bands with fax systems for the purpose of providing builders the opportunity of developing their technical skills ?
Orbital mechanics are a tool for Radio amateurs to help them with radio satellite experiments and it is obvious that this is part of the self-training within the amateur service.
A ranging experiment (experiment that determines the distance between the satellite and the observer) is not necessary for communication experiments and does not contribute to amateur radio (except for interplanetary missions)
A good educational project has recently been proposed by a group of students (UKSEDS), unfortunately the satellite life will be restricted to about one month:
An electrometer can be useful for propagation research and would fit within the amateur radio definition.
Having downlinked the information of this experiment in a simple form would benefit even more radio amateurs who are not skilled in satellites but could use the information for HF propagation experiments.
However, would this satellite handle commercial traffic and only temporarily provide electrometer data to the amateur community, the satellite could not be considered as an amateur radio satellite.

So maybe the line between Amateur Radio Satellite and non-amateur radio satellite is not so difuse and gray as we first thought.

This may all sound as amateur radio politics to you, but we have to keep our hobby in good spirit and ethos and every radio amateur has the responsibility to preserve this spirit and educate young people in amateur radio to secure the future of amateur radio.
We do not want to sell our frequencies to every " good buddy " around just for his fun or to have our ranks grown. We all prefer to welcome newcomers, not for having a large amateur radio population but to have a group of well self-educated radio experimenters with whom we can communicate, exchange knowledge and experiment together on our frequencies.

I hope participants of this workshop will find new ways within the amateur satellite service to fulfill these obligations to "educate" young people in amateur radio.
The IARU is particularly keen to support any satellite experiment that will promote amateur radio in the class room.
As Satellite Coordinator I will do every effort to support amateur radio in the educational field.

Let me wish you all a very fruitful educational workshop.

Addendum :

Suggestions for including educational experiments into amateur radio satellites :

- Combine experiments with amateur radio experiments.
- Diversify educational experiments e.g. do not repeat experiments in several satellites.
- Use existing amateur radio experiments into educational programs.
- Try to use self-training self-education in all these experiments.
- An experienced radio amateur teacher has a better chance of success.

There is only one case of direct education into amateur radio for third world countries.

The PADC program of the IARU provides assistance for direct education in amateur radio for third world countries.
(PADC = Program for Amateur radio in Developing Countries)

A SPACE SHUTTLE EXPERIMENT WITH RADIO WAVES AT AUDIO FREQUENCIES

A joint NASA/high school/amateur experimenter's research project

Presented to: The Joint AMSAT/ARRL Educational Workshop
Los Angeles, California
November 8, 1991

by: Jim Ericson KG6EK

An ionospheric/magnetospheric experiment on the STS-45 Shuttle mission scheduled for March, 1992 will involve a high-power electron beam accelerator modulated by audio tones. Amateur and private experimenters, together with 10,000 US high school physics classes are being invited by NASA and other sponsors to participate in scientific data taking by listening to and recording the signals. A simple and inexpensive VLF receiver kit is being made available to interested experimenters. To make this project fully effective, amateurs need to 'bridge the gap' between the scientists and the high schools -- providing assistance in helping students build the kit, giving classroom demonstrations of AMSAT satellite-tracking software, and possibly giving advice and guidance in searching out remote and radio-quiet listening sites for the March '92 mission.

Tired of hearing the same old stuff on your radio? Do you tend to think of 160 meters as the 'bottom of the band'? In this paper we'll discuss both manmade and natural radio activity between 100 Hz and 10 kHz, the absolute bottom end of the VLF (Very Low Frequency) spectrum. If we call 5 kHz the center of the band, we're talking about a 60,000 meter wavelength! We'll be describing a simple and inexpensive (under $40) VLF receiver design, and present some ideas on how you can participate in scientific data gathering with space scientists involving VLF propagation (and possibly share some of your ham radio expertise with US high school students and other experimenters) during a March, 1992 space Shuttle experiment. Letters inviting participation in the listening experiment have already gone out to 10,000 high school physics classes in the US, and both amateurs and private experimenters are also being invited to participate.

A QUICK HISTORY OF ACTIVITY BELOW 10 kHz

The story begins in World War I Europe. Though primitive by today's standards, there was a mature telephone technology when the war began, and that technology soon found its way into the trenches. Electronic Counter Measures arrived immediately thereafter in the form of high-gain vacuum tube amplifiers which each side employed to intercept 'leakage' from the other's communications. The general idea was to run wires from widely separated ground stakes to the input of a sensitive amplifier, sampling stray or induced currents from the enemy's telephone system. For the most part, this worked well enough to be worth the trouble, but now and then eerie descending whistler tones appeared in the monitors' headphones. Some likened them to the sound of phantom shells passing overhead.

German scientist H. Barkhausen became quite intrigued with these particular sounds. Over the years he and other researchers pecked away at the puzzle, and by the late 1920s there was fairly general agreement among researchers that lightning was responsible for the whistler-like tones. This turned out to be a correct interpretation, but the 'how' of it remained elusive until the 1950s.

As researchers learned, lightning is a spark discharge -- a huge spark -- embodying peak currents of thousands of Amperes and potentials on the order of 250 million volts! Any electrical spark is a source of electromagnetic energy, and rather than being a coherent signal confined to a particular frequency or band of frequencies, lightning's radio emission is a broad spectrum burst -- all frequencies appear in it at once, from hundreds of Hertz through hundreds of MHz. Scientists discovered that a large percentage of lightning's effective radio energy is concentrated in the 1 to 20 kHz region, loosely defined as VLF.

VLF PUNCHES THROUGH THE IONOSPHERE!

VLF static bursts caused by lightning propagate with great efficiency in the waveguide formed by the earth's surface and the lower regions of the ionosphere. Tuning through this frequency range, you will hear static that sounds pretty much like what you hear on an AM receiver. But if you listen carefully below about 10 kHz you'll discover that sometimes (but not always) the static crackles become liquid 'pings' or 'whistles' which sound like rapidly descending musical notes.

Today, the mechanism of VLF whistles and pings is quite well understood. When radio signals pass through a non-vacuum medium, those of higher frequencies travel faster than those of lower frequency. Since an impulse of lightning starts out as a mixture of high and low frequencies simultaneously, propagation in the earth-ionosphere waveguide naturally sorts the frequency components; the highs arrive first, and the lows later. By measuring this 'dispersion' of the signal, investigators can deduce how far the signals have traveled.

Early investigators were puzzled by the fact that nobody could find signal paths on earth that were anywhere near long enough to account for the huge amount of dispersion heard in long whistlers. Eventually new techniques including spectrum analysis helped to unravel the mysteries of whistlers. L.R.O. Storey and R.A. Helliwell of Stanford University were among the group which developed a new view of Earth's near-space environment and laid foundations for the field of magnetospheric physics. As it turned out, the long dispersive whistler paths were ducts in the magnetospheric plasma which extend between the northern and southern hemisphere. These ducts (sort of like the lines you see when you sprinkle iron filings over a bar magnet) arch to a maximum distance of several earth radii, far beyond the boundaries of our ionosphere. This explains why some whistlers have a duration of several seconds when heard here on Earth.

THE ANTARCTIC ANTENNA FARM

In the 1950s researchers chose Antarctica as a perfect spot to put up 40 kilometer (26 mile) long VLF dipole transmitting antennas. Plenty of room, mile-thick ice (a nice insulator), and almost no interference from AC power! Using powerful CW transmitters they succeeded in producing the first manmade whistlers.

Later research employing a powerful VLF transmitter at Siple Station, Antarctica was carried out in the 1970s and 80s. CW transmissions from Siple generated a variety of magnetospheric signals which were heard by a monitoring station in the magnetic conjugate region near Roberval, Quebec, and by a variety of satellite monitors. These experiments have advanced scientists' understandings of the ionosphere and magnetosphere, and have also suggested many avenues for future research.

THE NEED FOR MORE 'EARS'

Until recently, VLF research was carried out using only a handful of listening stations manned by the Government and a few Universities. In 1989 high school and amateur listening participation was invited in a joint NASA/Soviet experiment involving the Soviet satellite ACTIVE. The Soviet satellite attempted artificial stimulation of the magnetosphere by passing large 10.5 kHz currents through a 20 meter-diameter loop antenna. Unfortunately, the loop apparently deployed in a twisted configuration, and the SWR was very high. Several months of monitoring by NASA, Soviet observers and dozens of private experimenters in the US failed to produce any copy. These joint experiments were nonetheless successful in that they provided the first occasion for participation by amateurs and high school groups. The possibilities of a large network of coordinated monitors had never before been explored.

INSPIRE 1992

INSPIRE stands for Interactive NASA Space Physics Ionosphere Radio Experiments. Private industry sponsors at this time which are coordinating with NASA include TRW Systems and Micro Power Systems in California, and MESA Art and Printing in Arizona. In March 1992, NASA plans to launch the Space Shuttle (STS-45) with the first mission in a series of ten flights called ATLAS (ATmospheric Laboratory for Applications and Science). One of the ATLAS investigations is called SEPAC (Space Experiments with Particle ACcelerators) which is an experiment involving the Earth's atmosphere, ionosphere, and magnetosphere. The 7 kW SEPAC accelerator will emit a beam of electrons modulated by a series of audio tones from 50 Hz to 7 kHz. A unique feature of the transmitter is that it does not directly utilize an antenna. The modulated electron beam projected into space will become its own 'virtual' antenna!

SEPAC will use coordinated high school and amateur experimenter teams to listen and tape record the radio waves. The locations where the transmissions can be detected will define the 'footprint' of the signal, an impossible task without a large number of participants.

HOW TO HEAR AUDIO FREQUENCY 'RADIO' WAVES

Radio signals in the VLF region occur at frequencies ranging from a few hundred Hertz to something above 10 kHz. These frequencies are readily accessible to human hearing but even so, they are not directly audible. Why? This is because they are electromagnetic events which do not produce the mechanical vibrations in the air that our ears need to detect them as sound. In order to hear these waves we must convert their electromagnetic activity to acoustical vibration. Conversion is done with a transducer -- a simple amplifier connected to a loudspeaker or headphones --

that uses the electrical energy to move air molecules to produce a sound that we can hear.

BUILDING A PRACTICAL VLF RECEIVER

It is fortunate that very simple and inexpensive circuits can be used to hear and record both natural and manmade VLF signals. Beginners can build them; it is not necessary to understand the theory of operation in order to make equipment that works very well.

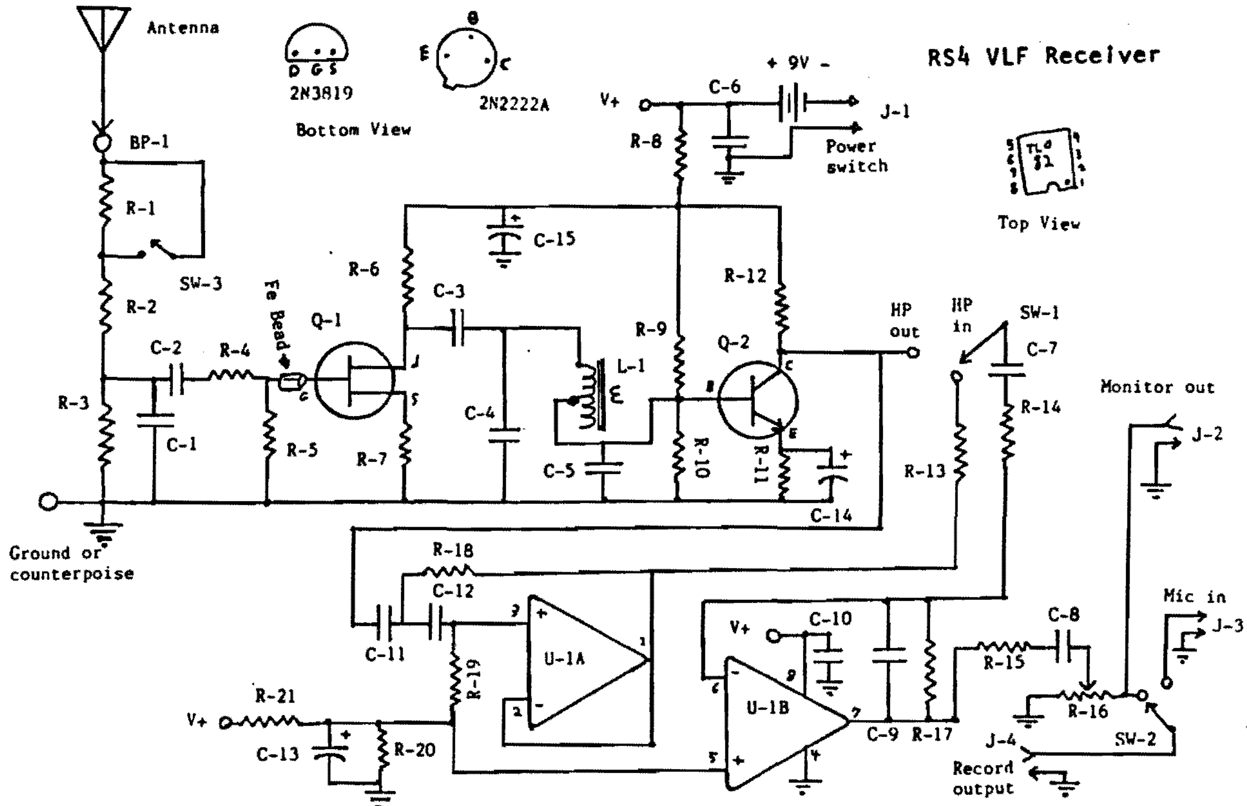
The receiver described here has been dubbed the RS-4 by its designer, amateur experimenter Michael Mideke (WB6EER). The identical design (in kit form) will be constructed and used by the participating high school physics classes. All essential components are listed in the current Radio Shack catalog.

The receiver uses a FET input stage to transform the extremely high impedance of a short (1 to 10 foot) antenna to a more practical value. A low pass filter rolls off frequencies above 7 kHz in order to prevent overloading from high power OMEGA radio-navigational signals at 11.2 kHz and above. The active high pass filter (controlled by SW-1) significantly rolls off frequencies below 1 kHz, helping to reduce the hum from 60 Hz power line harmonics. A ferrite bead in the FET gate circuit helps prevent overloading by radar and TV. Resistor R-1 should be shorted via SW-3 when using an antenna longer than about 30 feet. A switch and jack are included to allow the operator to use a microphone for insertion of time marks and commentary while recording. Note that the receiver uses a jack instead of a conventional power switch. Inserting a shorted plug into the power jack completes the battery negative circuit, applying power to the unit. This approach prevents accidental turn-on of the receiver while it is being transported. There is nothing more frustrating than pulling the receiver out of your knapsack to discover it has gotten turned on and the battery is dead!

Layout of the circuit board is not particularly critical. Try to keep 'output stuff' as far as possible from the antenna input. Component values aren't critical either, except try to keep the 11K and 22K resistors associated with U1-A within 5% or so. Since Radio Shack doesn't supply 11K resistors, you can parallel two 22K units, or series connect a 10K with a 1K.

When all components (including jacks and switches) are soldered in place, it is a good idea to double check the wiring and do some preliminary tests before mounting in the enclosure. The first check is to remove U-1, and connect the 9V battery to the circuit in series with a milliammeter. It should read about 0.5 mA. If the meter indicates much more, or no current at all, something is wrong; go back and check your work. The second test is to disconnect power and insert U-1 in its socket (check for proper orientation). When you reconnect the battery, current consumption should be 3 to 6 mA. If it is, chances are good that everything is ok.

When the receiver is completed, raise the whip antenna a few inches and attach a ground (or several feet of wire if no ground is handy). Listen with 'Walkman-type' headphones or a monitor amplifier, and verify that you have hum and noise. Touching the small antenna, or even moving your hand near it should increase the hum intensity. Switching the high pass filter in and out should make a noticeable change in the sound of the output. The series antenna resistor will make little difference whether in or out.



RS-4 PARTS LIST

RESISTORS- Excepting R-16, ¼W metal film 5% units are preferred.

R-1	470K
R-2	47K
R-3	2 Megohm
R-4	15K
R-5	2 Megohm
R-6	680 Ohm
R-7	220 Ohm
R-8	20 Ohm
R-9	33K
R-10	10K
R-11	4.7K
R-12	10K
R-13	6.8K
R-14	1K
R-15	1K
R-16	100K, Audio taper
R-17	10K
R-18	11K
R-19	22K
R-20	33K
R-21	33K

MISC ITEMS-

Ferrite Bead	Amidon FB901-43 or similar.
BP-1,2	Binding posts
J-1, J-3	3.5mm Mono Jacks
J-2, J-4	RCA type "phono" jacks

one 8 pin IC socket
one 3.5mm plug for power switch
PERF BOARD- Radio Shack #276-150

ENCLOSURE 5 1/4" by 3" by 2 1/8"

CAPACITORS- 16 volt or higher.

C-1	27pF dipped silver mica
C-2	.01uF ceramic or mylar
C-3	0.1uF " "
C-4	.022 uF mylar
C-5	.022 uF mylar
C-6	.01uF ceramic or mylar
C-7	0.1uF " "
C-8	0.1uF " "
C-9	.022uF " "
C-10	0.1uF " "
C-11	.01uF mylar
C-12	.01uF mylar
C-13	10uF Aluminum or tantalum
C-14	1.0uF " "
C-15	10uF " "

ACTIVE DEVICES-

Q-1	2N3819 or similar
Q-2	2N2222A or similar
U-1	TL082, LF353 or similar

INDUCTOR-

L-1 1KCT to 8 Ohm miniature output transformer. Radio Shack #273-1380 Mouser 42KM014 or similar.

Battery 9V alkaline recommended. External supply up to 12 V can also be used.
Battery clip DC Electronics #1290 is good.

SW-1, SW-2 Miniature SPDT toggles.
SW-3 Toggle or slide OK.
WHIP ANTENNA- Radio Shack #270-1408 or similar.

MONITOR AMPLIFIER- Radio Shack #277-1008

USING THE RECEIVER

Even though highpass filtering is incorporated in the receiver design, it is not a cure-all for the pervasive hum radiated by AC power lines which dominate our modern civilization. To get reasonable reception of VLF signals, you're going to need to find a site which is at least 500 meters from AC power lines. You'll also need some kind of ground or counterpoise. Usually a simple 1-foot nail or spike provides enough grounding to prevent squeals in the receiver. The chassis of an automobile (engine off!) also works nicely. Try the little Radio Shack whip antenna if you are in the open, and maybe a 20 to 50 foot wire if you're in the woods. You will hear some AC line hum, but if you've picked the right site you'll also hear clicks, pops, and with patience...some whistlers!

ALTERNATIVES TO 'BUILDING RS-4 FROM SCRATCH'

The volunteer non-profit INSPIRE organization is offering the RS-4 receiver in kit form to the high schools, and the same deal is available to radio amateurs and private experimenters. At $49.95 postpaid (plus $4.12 sales tax if ordered from CA), the kit includes:

- All components, enclosure, etched PC board, and detailed assembly instructions.
- A 23 page history of VLF, as well as tips and advice on observing, describing, and recording natural and manmade signals at very low frequencies written by Michael Mideke. It is titled, "The Beginner's Guide to Whistler Hunting."
- A 60 minute narrated cassette tape by Mideke which samples the incredible variety of sounds that can be heard in the VLF range. Included are notes describing the audio segments, and sample spectrograms of some of the signals.
- Instructional materials designed to assist you in working with high school students to mutually learn more about natural radio and the ATLAS-SEPAC INSPIRE mission.
- You will also receive updates by mail about SEPAC operation schedules, and the status of the mission.

To order an INSPIRE kit, send a check made out to INSPIRE to:
Bill Pine
Science Department
Chaffey High School
1245 N. Euclid Avenue
Ontario, CA 91762

If you need a receipt, or have any questions, please include a SASE. INSPIRE is a volunteer organization, therefore <u>any</u> requests requiring a return mailing must be accompanied by a SASE.

If you decide to build the RS-4 as described in this paper but don't anticipate direct project participation, you still may want to get a copy of the Mideke Beginner's Guide and Audio Tape. The Guide is $6 postpaid in the US (plus 50 cents sales tax to CA residents), $7 elsewhere; The tape is $10 postpaid in the US (plus 83 cents sales tax if ordered in CA), ($12.50 outside North America). Write Michael Mideke at P.O. Box 123, San Simeon, CA 93452-0123.

For those not interested in construction (but who would like to experiment with a receiver), Conversion Research has a new VLF pocket receiver available completely assembled for $48 postage paid in the US (you poor CA folks have to add $3.96 sales tax). The circuit is not exactly the same as the RS-4, but it is fully effective, includes a 33-inch telescoping whip antenna, battery, and is housed in a sturdy die-cast aluminum enclosure with on/off switch, audio gain control, and a 3.5mm jack for stereo earphones. Order from Conversion Research (Frank Cathell K3YAZ), P.O. Box 535, Descanso, CA 91916.

Project INSPIRE offers an opportunity for amateurs to be involved in a truly significant research project. To make it fully effective, we amateurs need to 'bridge the gap' between the NASA Shuttle experiment and local high schools. Pick up the phone and connect with the physics teacher at your neighborhood high school. If he (or she) hasn't heard about INSPIRE, have them send a SASE to Bill Pine in California for information. Offer your assistance in helping students build the kit, and maybe give some advice and assistance in searching out a remote and radio-quiet listening site for the March, 1991 mission. Or, how about a classroom demonstration of AMSAT Instant Track and Quicktrak software! Good hunting on 60,000 meters!

Bringing Space into the Classroom

Joe Kasser, W3/G3ZCZ
Software For Amateur Radio
POB 3419
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ABSTRACT

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

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

Introduction

There is no substitute for the excitement of hands-on experience in awakening an interest in space. There are on-going programs in educational institutions [1][2] which bring signals from space into the classroom, providing students with first hand experience in receiving signals from outer space. This capability is not as difficult or as expensive as one may think. Signals from Orbiting Satellites Carrying Amateur Radio (OSCAR) built by amateurs for educational and communications purposes are currently being received in hundreds of homes and classrooms around the world using simple low cost equipment.

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

The Spacecraft

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

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

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

The Digital Communications Experiment demonstrated the concept of store-and-forward digital communications using spacecraft in low earth orbit. The Space Dust Experiment measures the impact of dust particles, and calculates the momentum of the particles. The CCD Video Camera Experiment takes pictures of the earth at a resolution of

Table 1 Some of the Characteristics of OSCAR Downlinks.

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

NOTES

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

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Table 2 Orbital Parameters of the OSCARs

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

384 x 256 pixels with 128 gray levels. This experiment does not seem to have returned any usable pictures. The Digitalker Experiment provides clear digitized voice using a fixed vocabulary and is switched on from time to time.

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

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

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

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

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

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

SARA (OSCAR 23) which was launched on July 17, 1991 is a French Amateur Radio Astronomy satellite monitoring radio signals from Jupiter. SARA downlinks the measurements on its telemetry beacon.

The Future

The Future is bright. At least seven additional spacecraft have recently been announced as being in various stages of construction in several countries [3]. A brief summary of the announced spacecraft is listed in Table 3. The most exciting of which is the

Table 3 Amateur Radio Spacecraft Currently Under Development

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

proposed radio amateur MARS mission. This mission can be achieved using technology already developed by radio amateurs. Other telemetry experiments are also planned for the Soviet MIR space station [4].

Receiving Signals from Space

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

Receiving Signals from DOVE

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

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

Receiving PSK Modulated Signals in the 70 cm Band

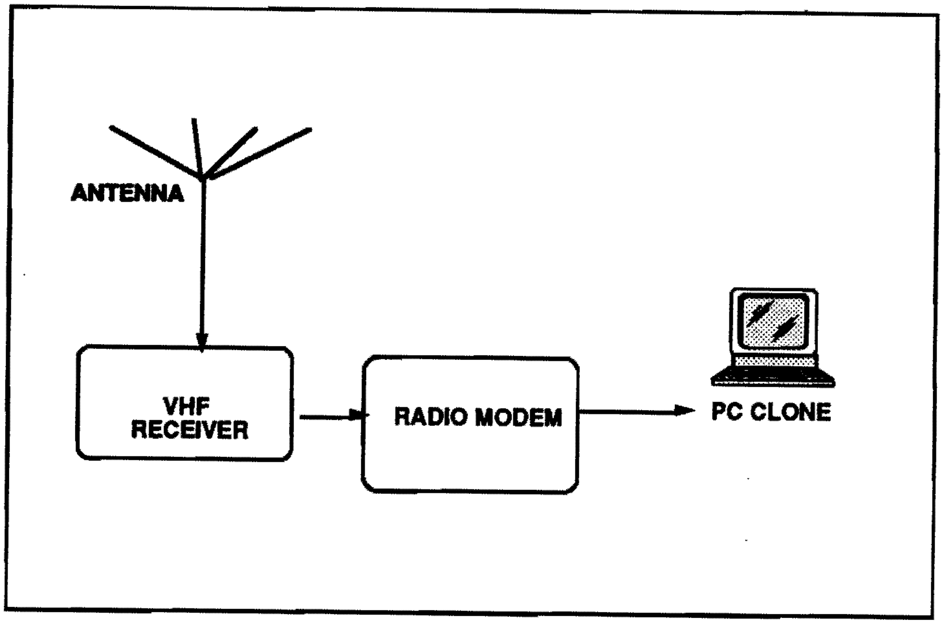
Receiving signals from AO-16, WO-18 and LO-19 as well as from FO-20 requires somewhat more complex equipment. These space-craft transmit on downlink frequencies in the 70 cm or 430 MHz band. As they use PSK, the receiver has to be a conventional communications receiver. This can be either a communications receiver designed for that frequency range, or a conventional short wave receiver with a front end down converter. A PSK modem attached to the TU is also required. Typical receiving configurations for these satellites are shown in Figures 2 and 3.

The difference between the two approaches is that the first uses a communications receiver designed for the 70 cm band; the second approach uses a general short wave receiver and a front end down converter.

Receiving Signals from UO-2

The same basic radio receiving system used to receive signals from DOVE can be used to copy the telemetry from UO-2. This spacecraft however has a

Figure 1 Basic Receiving System for DOVE-OSCAR 17.



lower powered transmitter than that of DOVE and consequently has a weaker signal strength on the ground. This lower signal level, coupled with the fact that the modulation is plain ASCII data means that errors will be seen in the received data due to signal fades and noise bursts (interference) from local sources. Better antennas are needed for reliable reception, and antennas that track or move and always point at the spacecraft are desirable.

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

Receiving Signals from AO-13

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

Receiving System Components

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

Antennas

Antennas receive signals, and each type of antenna has some degree of directivity and polarization. When the

Figure 2 Basic Receiving System for PSK Modulation.

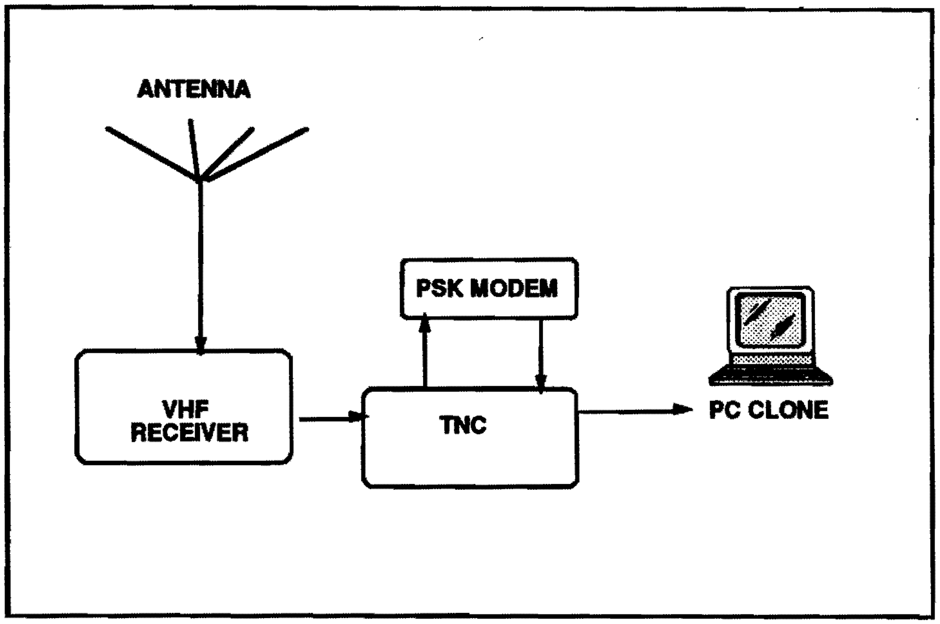
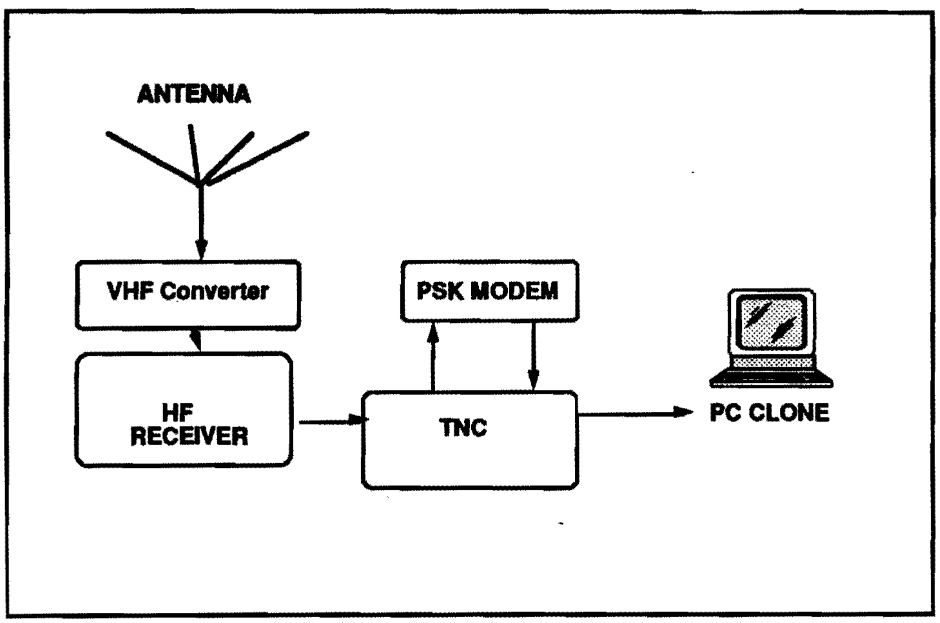


Figure 3 Alternate Basic Receiving System for PSK Modulation.



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

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

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

Receivers

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

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

Terminal Units or Modems

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

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

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

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

Computers

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

Tracking Software

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

Satellite Data Formats

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

Examples of the raw UO-2, DOVE and FO-20 telemetry are shown in Figure 4. Examples of decoded display pages are shown in Figure 5.

Telemetry Processing Software

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

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

Figure 4 Examples of Raw Telemetry.

Figure 4a Examples of Raw DOVE Telemetry.

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

Figure 4b Example of the Raw FO-20 Telemetry.

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

Figure 4c Example of a Received Raw UO-2 Telemetry Data Frame

```
00519D01413702676503614004046605O3;4 6019E07045608040C08036C
10519C11298312000313056114069A15529A!6188;17545218590519505 8
```

Note Reception Errors due to noise bursts.

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Figure 5a Sample Decoded Page of DOVE Telemetry

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

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

Figure 5b Sample Decoded Display (General Housekeeping) Page from FO-20.

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

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

usually do it in real time, or provide any tools for analyzing the data.

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

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

During a typical pass, data are captured, decoded and displayed in real time. Post pass, data from selected channels can be extracted and read into a spread sheet for analysis. Graphs can be plotted of the value of different telemetry channels throughout the pass. Data can be compared over several passes. Doppler curves can be plotted by measuring the change in the radio frequency during the pass. In fact, the whole world of the professional spacecraft data processor in miniature is present in this simple ground station. A sample Doppler curve plotted using data from a real satellite pass is shown in Figure 6. A similar example of a changing parameter is shown in figure 7. A whole semester can be usefully spent discussing why the predicted and actual Doppler curves are different or why the UO-2 solar array current telemetry parameter changed during the pass.

Costs

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

The Future

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

Table 4
Range of Equipment List Prices

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

Let's make a start with these spacecraft, then look to a follow on activity. An OSCAR does not have to be a separate spacecraft. The Soviet Union has provided their amateurs with payload space aboard their weather satellites [12]. NASA could do the same for an amateur scientific spacecraft which would monitor radiation, the earth's magnetic field and solar activity; such data being of use to radio

Figure 6 Doppler Curve for WO-18

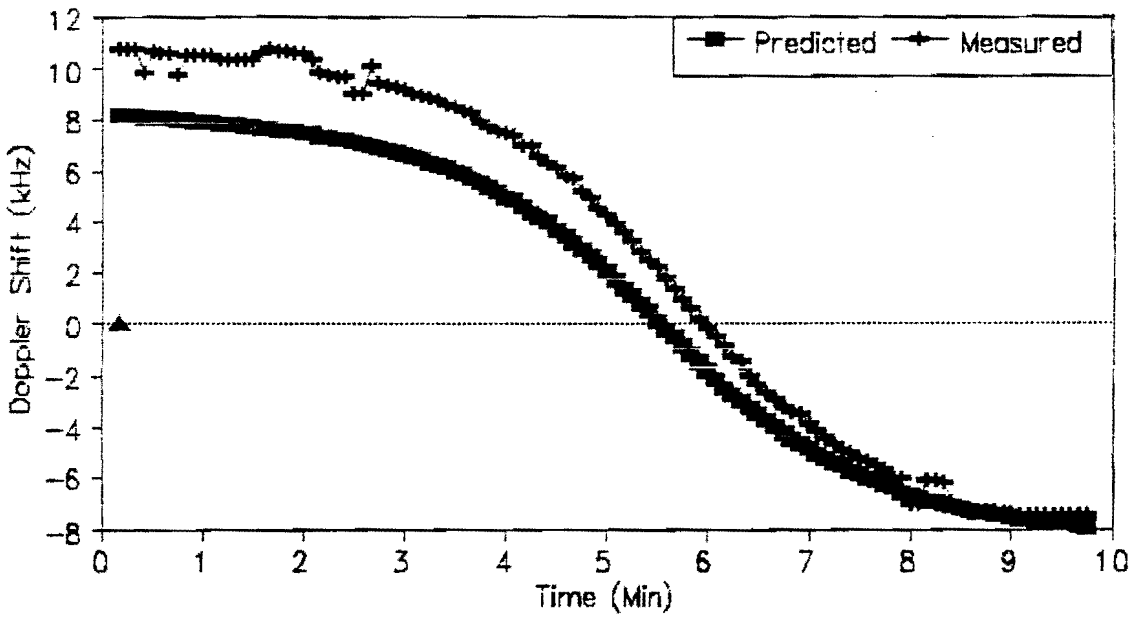
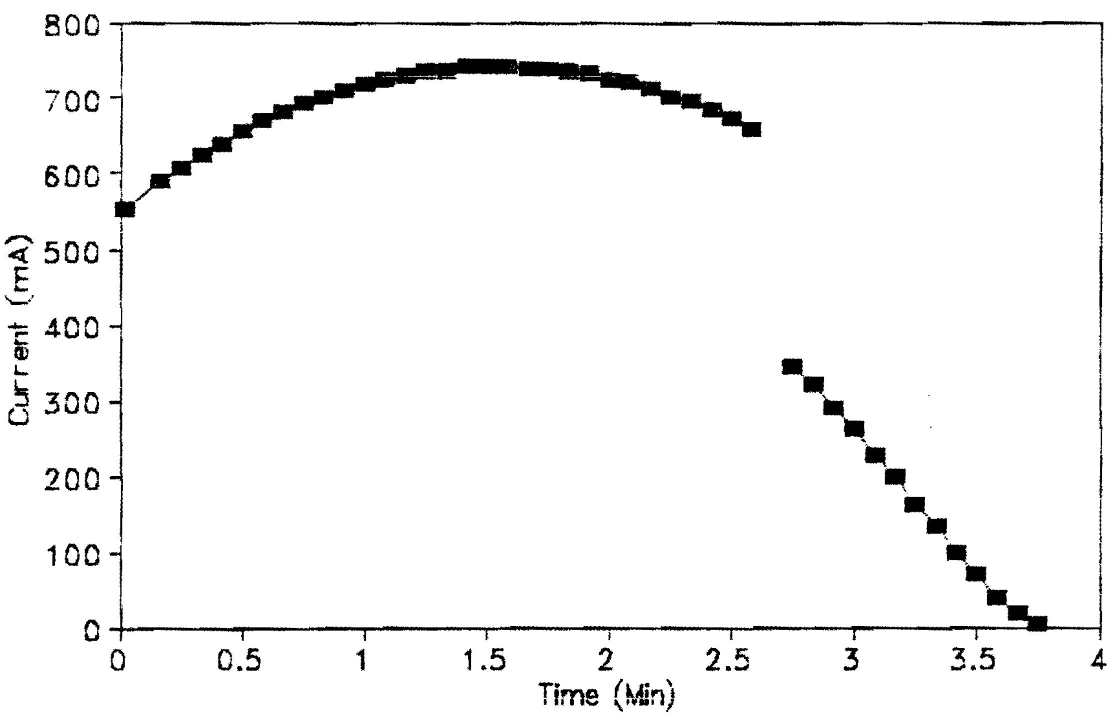


Figure 7 Change in UO-2 -Y Array Current During the Pass



amateurs for predicting propagation and providing schools with data about the earth's environment. NASA has a 'Mission to Planet Earth' project to provide an Earth Observation Platform in 1997. An attached secondary payload to that platform, transmitting packetized scientific telemetry data (with well publicized formats) in the 145 MHz amateur band or in the 136 MHz scientific band could really bring not only the space program, but the educational and scientific use of space, into every educational institution in the country.

Summary

This paper has been a top level overview of a fascinating field. Equipment is simple and low cost, and, if real time satellite tracking can be added to the educational curriculum, has the promise to bring space science to life.

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

Further Information

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

World Classroom Foundation, 85 Parkledge Drive, Amherst, NY., 14226.

ARRL, 225 Main Street, Newington, CT., 06111.

Project OSCAR Inc. POB 1136, Los Altos, CA. 94023-1136.

AMSAT-NA, 850 Sligo Avenue, Silver Spring, MD., 20910-4703.

AMSAT-UK, 94 Herongate Road, Wanstead Park, London E125EQ, England.

Glossary

AMSAT	The Radio Amateur Satellite Corporation
AO	AMSAT-OSCAR
AOS	Acquisition of Signals
ARRL	American Radio Relay League
CCD	Charge Coupled Device
DO	DOVE-OSCAR
DOVE	Digital Orbiting Voice Encoder, also used interchangeably with DOVE-OSCAR or DO.
FM	Frequency Modulation
FO	Fuji-OSCAR
FSK	Frequency Shift Keying
LO	LUSAT-OSCAR

LOS	Loss of Signals
OSCAR	Orbiting Satellite Carrying Amateur Radio
PSK	Phase Shift Keying
RTTY	Radio Teletypewriter
SSB	Single Side Band
TNC	Terminal Node Controller
TU	Terminal Unit (Radio Modem)
UO	UoSAT-OSCAR
WO	WEBER-OSCAR

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The Great Eclipse of 1991 -- A Bird's Eye View

By Brian Porter and Edwin Torpoco

There is a point in the study of physics where practical use must be taken into consideration. No matter how much time is spent reading a textbook, true understanding does not come without experience. Such an experience was the Eclipse Day of September 30, 1991. The purpose of this day was to recreate the solar eclipse of July 11 and analyze the data from a LUSAT satellite which passed through the umbra of the eclipse.

This was the first experience that many of the students had with this type of activity. Kristina Lengel was the group leader whose duties were to coordinate and supervise the various class presentations. Wesly Waldron, William Erliger, Samantha Sargent, and Ryan Stankevich worked with the Traksat program to accurately recreate the eclipse on a computer. Greg Fisher and Brandon Cangiano interpreted the data which the X and Y solar panels of LUSAT collected during the eclipse. Nataraj Madhure and Mark Aviles presented a picture which the Metor weather satellite, that was near LUSAT, obtained of the eclipse. Jeff Kim and James Hamill re-edited for presentation a video which was taken by Mr. David Reeves at the Punahou School in Honolulu, Hawaii. Using a mechanical solar system model, Jeff Keco and Daryl Heffernan recreated the eclipse to visualize the occurrence of July. LUSAT models were constructed by Lisa Leonor and Shelly Ketter for use in the class. Joan Phantong, Koichi Konoma, Salvatore Pizzuti, and Laura Herrigan recorded the telemetry of LUSAT on a normal day for comparison. Dan Levack made the orbit predictions. Finally, Jee Lee and Kristina Lengel coordinated the publicity mailings.

Many of the students began the LUSAT project discouraged at the enormity of their tasks, but in the end all were surprised by their accomplishments. Eclipse Day was a success, and most importantly, each student gained a better understanding of physics. A report of Chaminade's Eclipse Day will be presented at the AMSAT/ARRL Educational Conference on November 8, 1991 in Los Angeles, California.

LUSAT AND THE SOLAR ECLIPSE

By Dave Reeves, KF6PJ

Introduction: On July 11,1991, people of Hawaii, Central and South America were treated to one of nature's most awesome events, a total eclipse of the sun. This total solar eclipse was the first in Hawaii since 1850.

A small group of radio amateurs were able to watch this eclipse through the "eyes" of a tiny Argentenian satellite called LUSAT. As the moon's shadow moved to the east across Baja California at several thousand miles an hour, LUSAT traveled south at about fifteen thousand miles an hour. For a short few seconds their paths crossed. Jim White (WD0E), an expert on satellite motion, was particularly interested in examining solar array currents and temperatures as LUSAT passed through the transition zone, the penumbra, to darkest zone, the umbra. In this activity you will also study these results!

Objectives:

1. To learn to use satellite tracking program,
2. To learn about the path of a solar eclipse.
3. To learn to interpret solar array data from LUSAT.
4. To learn to picture the motion of LUSAT in space.

Procedure:

Part I: Replay the encounter between LUSAT and the Eclipse on the computer.

1. Start the satellite tracking program on your computer. The program should run from 17:00 to 19:00 UTC on 7-11-91. (Specific instructions for using TRAKSAT are included at the end of this activity.)

2. Make a drawing of the eclipse on clear acetate. The size of the drawing will depend on the size of your TV screen. Use the template included with this activity to design the drawing. Be sure your template shows both the umbra and the penumbra.

3. The Orthographic mode of Traksat displays a picture of the globe centered on your location. As soon as the drawing of the earth is complete on the computer screen, use an erasable marker (or paper dots) to mark the position of the eclipse on the globe each 15 minutes from 17:15 to 19:00 UTC on the TV screen.

Time	Long.	Lat.	Location
17:15	164	19	West of Hawaii
17:30	155	20	Hilo, Hawaii
17:45	146	21	Pacific
18:00	137	22	Pacific
18:15	128	23	Pacific
18:30	119	24	Pacific
18:45	110	25	Baja, California

4. Watch the time on Traksat and move the eclipse template each 15 minutes to watch the speed of the eclipse.

5. As LUSAT pops over the horizon, watch as it moves with an encounter with the eclipse.

Part II. Evaluate the Solar Data during the encounter. Raw telemetry data from LUSAT was collected by Bob Argyle at Weber State University in Utah and reprinted by Richard Ensign in the AMSAT Education News.

1. Select telemetry data form one of the four "side" panels of LUSAT. They are called -X,+X,-Y and +Y.

2. Using a sheet of graph paper, plot the data from the channel you are studying. Place time in seconds on the horizontal axis and solar panel current in raw data units on the vertical axis.

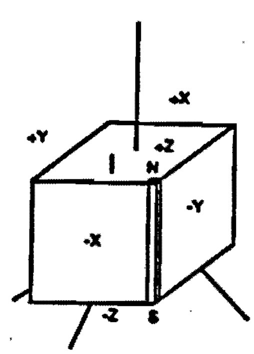
3. Estimate the time between successive peaks on your graph. Discuss the meaning of these peaks with your classmates.

4. Use a dotted line or another colored pencil to fill in the peak (or peaks) that was blotted out by the eclipse.

5. Compare your graphs with those other classmates who are plotting the other channels. Can you decide at what time the satellite encountered the umbra of the eclipse, and at what time it once again entered the sun light. Determine how many seconds was LUSAT in total eclipse?

6. Discuss with your classmates the rotation of LUSAT. Does it spin clockwise or counter-clockwise. Determine the order that the panels turn on and off.

7. Mark the names of the panels (+X,-X,+Y,-Y,+Z,-Z) on a small cubic block of wood. Use a pipe cleaner bent around the block to represent the Z axis. (The pipe cleaner could be inserted through a small hole drilled in the block.) Use your model and the globe of the earth to demonstrate the motion of LUSAT during the eclipse.



Analysis Questions:

1. Briefly describe the orientation and motion of LUSAT as it passes over the equatorial region of the earth.

2. Assuming the path of the eclipse is about 250 km wide and the satellite is traveling about 7,000 m/s, predict the duration of the encounter?

3. Describe any changes in the the solar panel data that would indicate that sun light hitting the satellite was decreasing as LUSAT passed into the penumbra of the eclipse.

4. List the order in which the solar panels are exposed to the light of the sun. Is the satellite rotating clockwise or counterclockwise?

5. What is the period of the rotation of LUSAT in space?

LUSAT SOLAR PANEL RAW DATA DURING THE SOLAR ECLIPSE OF JULY 11, 1991 AS
DATA BEGINS AT 18:37:06 UTC

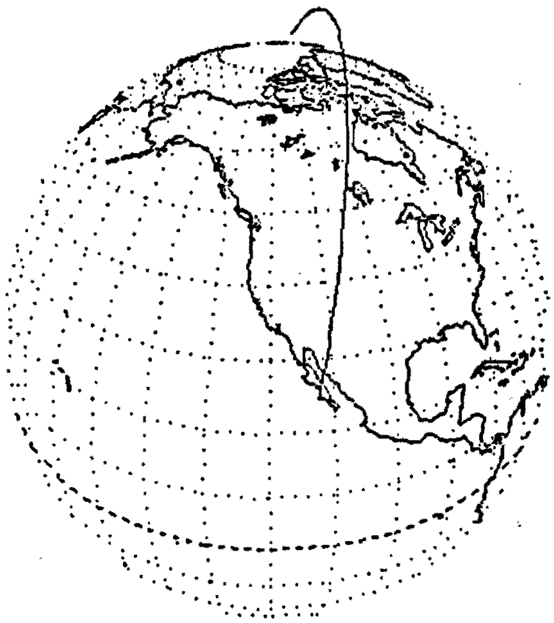
UNIX (SEC)	TIME (SEC)	+X	-X	-Y	+Y	-Z	+Z
679257426	0	23	0	0	22	45	28
436	10	38	0	0	0	46	26
446	20	45	0	0	0	44	27
456	30	35	1	3	0	42	25
466	40	6	0	28	0	40	25
476	50	0	0	31	0	40	24
486	60	0	14	25	0	37	24
496	70	0	17	11	0	39	22
506	80	0	18	0	1	42	21
516	90	0	14	0	0	35	18
526	100	0	8	0	22	28	17
536	110	0	1	0	28	31	17
546	120	1	0	0	21	31	16
556	130	20	0	0	0	33	16
566	140	25	0	0	0	33	15
576	150	23	0	0	0	31	16
586	160	13	1	2	0	28	12
596	170	0	0	17	0	30	14
606	180	0	0	22	0	24	12
616	190	0	17	14	0	22	10
626	200	0	24	0	0	24	11
636	210	0	17	0	0	22	11
646	220	0	2	0	11	18	11
656	230	0	0	0	20	18	11
666	240	0	0	0	24	13	10
676	250	5	0	0	20	17	8
686	260	17	0	0	0	23	8
696	270	24	0	0	0	13	8
706	280	20	0	7	0	4	8
716	290	8	0	17	0	19	10
726	300	1	0	18	0	16	9
736	310	0	0	16	0	14	12
746	320	0	8	10	0	13	7
766	340	1	6	0	0	5	9
806	380	2	0	0	0	0	6
816	390	5	0	0	0	0	5
826	400	4	0	1	0	0	4
836	410	4	1	0	0	0	2
846	420	2	1	0	0	1	3
856	430	0	0	0	1	0	1
866	440	0	0	0	0	1	1
876	450	1	0	0	0	0	1
886	460	1	0	0	0	1	1
906	480	4	4	0	0	0	0
916	490	1	3	1	2	1	1
926	500	0	0	2	12	0	2
936	510	0	0	0	15	0	2
946	520	11	0	2	18	1	2
956	530	22	3	0	12	0	1
966	540	28	4	0	0	0	2
976	550	26	0	2	0	0	0
986	560	17	0	16	0	0	0
996	570	1	0	29	1	0	0
679258006	580	0	0	34	0	0	0
16	590	1	20	39	2	0	0
26	600	4	38	26	0	0	0
36	610	5	51	0	1	0	0

DATA ENDS AT 18:47:16 UTC

From: AMSAT Education News
Richard Ensign -- AMSAT Science Education Advisor
421 N. Military, Dearborn, Michigan, 48124, USA

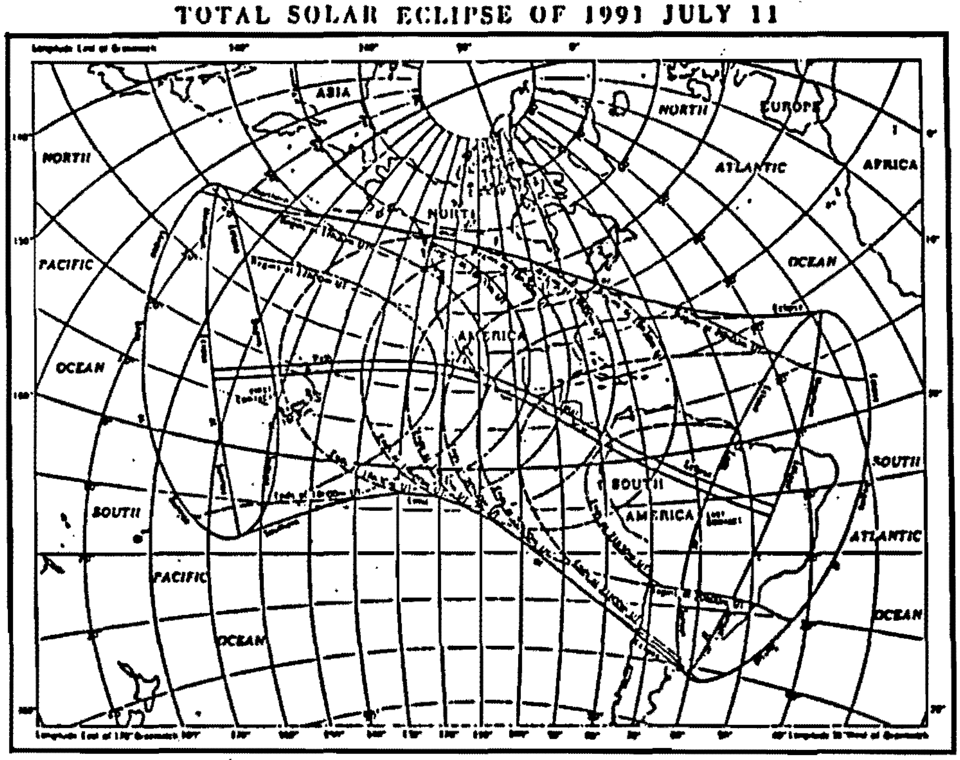
TRAKSAT Version 2.65

UTC 18:44:24.0 Date 07/11/1991 Satellite Name: LO-19
Local 11:44:24.0 Date 07/11/1991 Tracking Station: SIMI VALLEY,CA



Lat 27.4744° Azimuth 143.0463° Range 1261.9 Km Ph 45.06
Long -113.1394° Elevation 34.5550° Rev # 7652 Visible

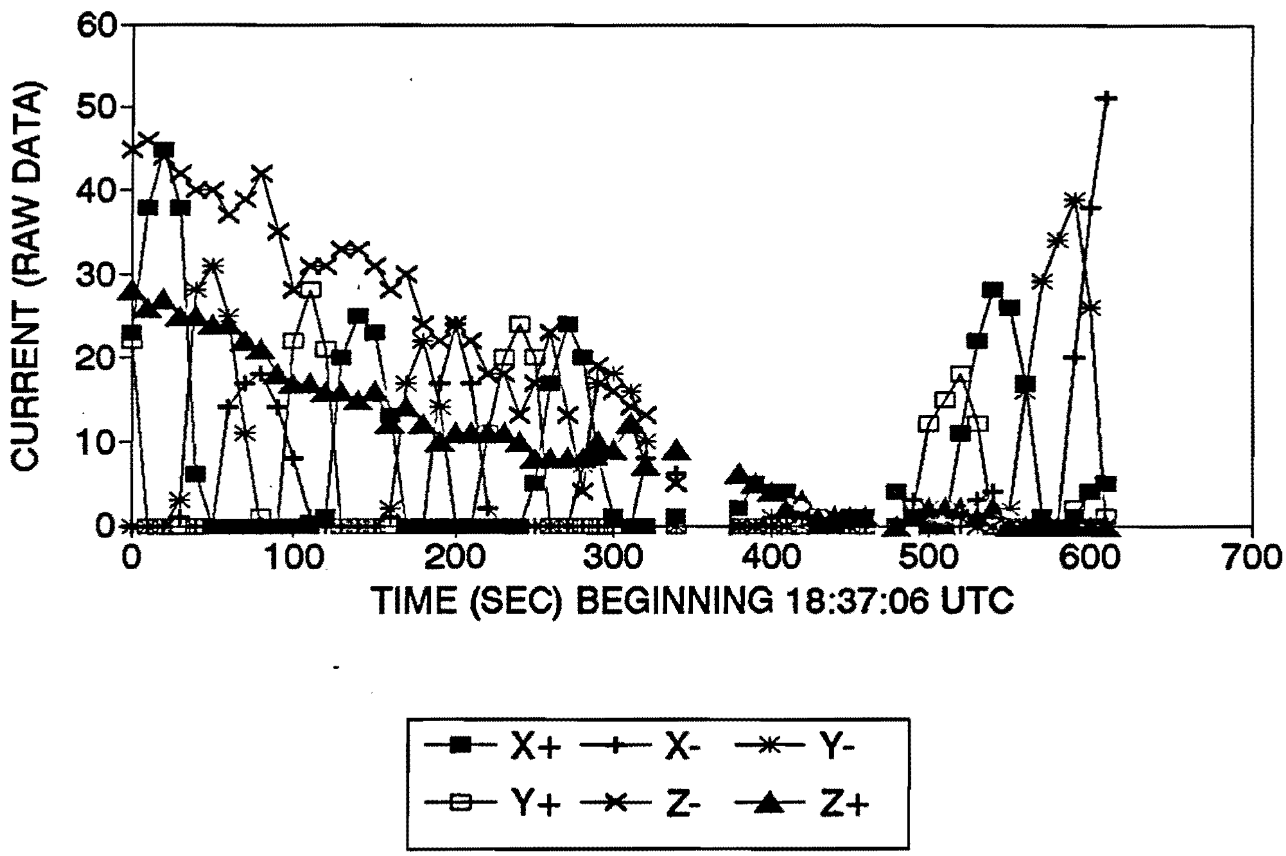
TOTAL SOLAR ECLIPSE OF 1991 JULY 11



U.S. NAVAL OBSERVATORY

SOLAR ECLIPSE OF JULY 11, 1991

LUSAT SOLAR PANEL CURRENTS



TRAKSAT -- Version 2.65 by Paul Traufer

Traksat is an excellent classroom tool for displaying satellite motion. The program allows for two graphic displays. The first called "Ground Tracks" draws a Mercator projection (flat) map of the earth. The second is called an Orthographic projection and shown an almost 3D view of the earth. The Orthographic view is slow on an older model computer, but the results are worth the wait. Ground tracks can show several satellites at the same time.

Another great feature of Traksat is the ability to draw star charts with the satellite projected against the night sky. This feature is used for visual sightings of larger satellites such as the MIR space station, Hubble, or the Space Shuttle.

The program requires a 3.5 inch diskett or a hard disk drive. It does not fit on a regular 5.25 inch disk. Traksat may be a good reason to upgrade that old computer with a hard disk drive. Of course the program runs fast and pretty on a VGA 386 machine, but if you have the time, it still works great on an older PC.

If you obtained a copy of Traksat from me (send any size disk and a S.A.S.E. and its yours), it will come with two files:

TRAK625.EXE	333 KB	Compressed distribution file
ECLIPSE.TXT	1.4KB	NASA 2 line Kepler set for July, 1991.

Create a directory on your hard disk drive called TRAKSAT. Copy the files on your hard disk, and type:

```
C:\TRAKSAT> TRAK265 <ENTER>
```

The program and files will unpack themselves (you will need almost 1.1 MB of disk space). NOTE: Before proceeding, you might like to print the 71 page instruction manual that comes with TRAKSAT. It is well worth having around.

To start the program type:

```
C:\TRAKSAT>  TRAKSAT <ENTER>
```

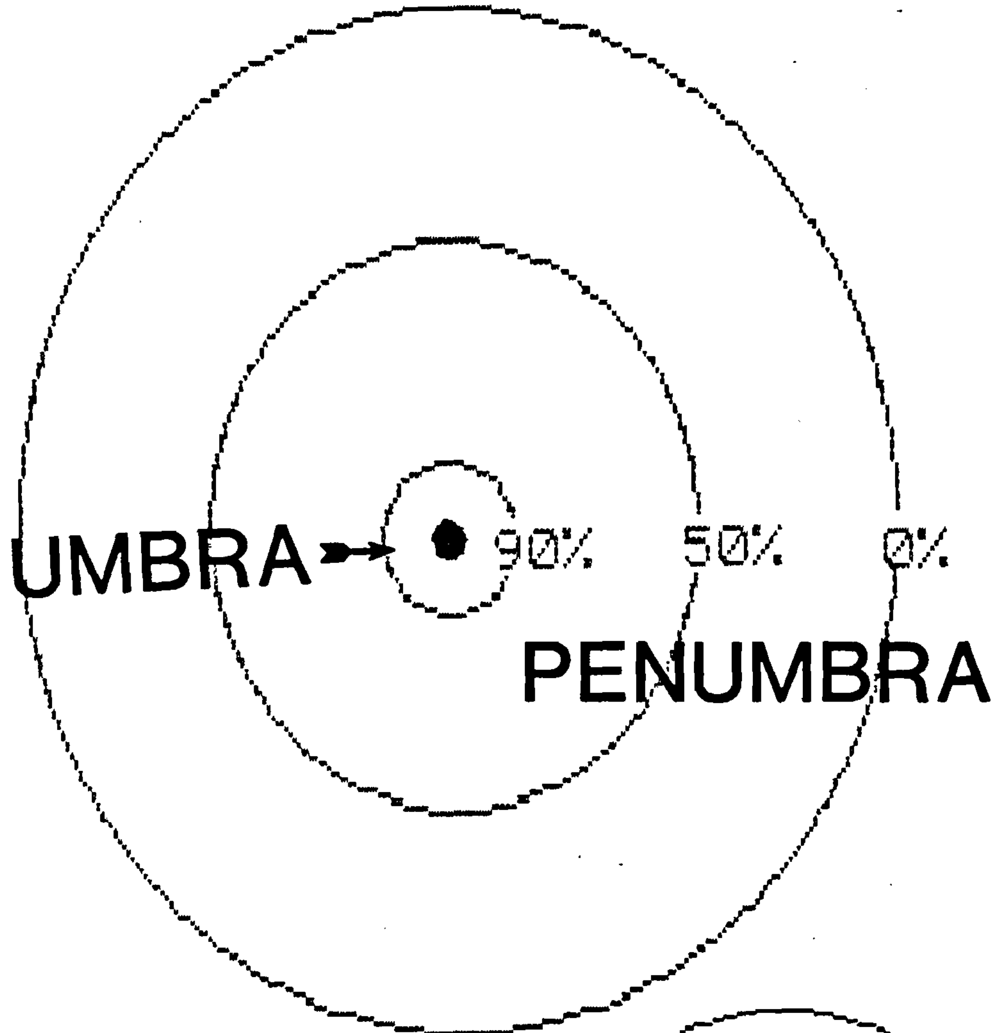
The program should now be running. The MAIN MENU lists the following operations:

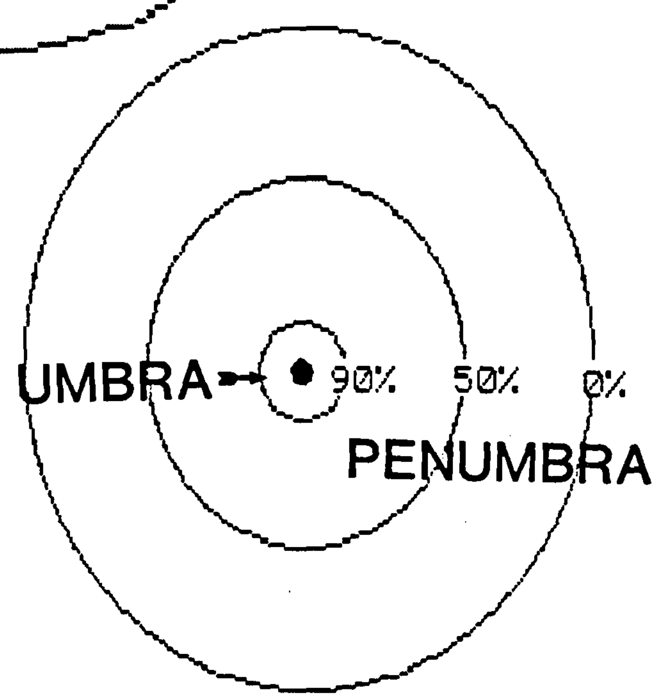
```
File  System  Time  Output Visibility  Run  Quit
```

Work from left to right in setting up the program for the solar eclipse on July 11, 1991.

```
File <ENTER>
Change Satellite File <ENTER> ECLIPSE.TXT
        <ENTER><ENTER><ENTER>
Load Satellite  Elements <ENTER> LO-19 <ENTER>
Keep Reading?  NO  <ENTER>
New Tracking Station <ENTER>  San Diego  <ENTER>
Keep Reading?  NO  <ENTER>
Tracking Station    Altitude  [0] <ENTER>
                    Hours from UTC [-07]
(You can enter your own location if you like.)

Time <ENTER>
Delta Time Mode <ENTER>
Starting Date (UTC) [07/11/91]     <ENTER>
Starting Time (UTC) [17:00:00]     <ENTER>
Length of Simulation [00:02:00:00] <ENTER>
Step Time (Minutes)  [1.000000 ]   <ENTER>

Output  <ENTER>
Single Satellite <ENTER>
Orthographic View <ENTER>  or  Ground Traks <ENTER>

Run <Enter>
```

If you are running the Orthographic view on a slower computer, it will take about 10 minutes to draw the North and South Americas. You might not want to wait any longer to run the pass. Simply hit the space bar and the pass will begin immediately.


UMBRA
90%
50%
0%
PENUMBRA


UMBRA
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50%
0%
PENUMBRA

Using Amateur Satellite and Weather Fax Systems in Secondary and University Classes

Robert J. Twiggs
Dr. K.R. Reister, N7MXF
Weber State University
Ogden, Utah

Abstract

The amateur radio community has taken advantage of the low cost of personal computers and pioneered advancements in low cost digital communications and image processing technology. In particular, the development of the weather facsimile systems and the OSCAR satellites which provide real-time global imaging data and worldwide store and forward communications. How can the national K-12 classrooms and universities utilize this technology now that the Apple II and Commodore computers are being replaced by MacIntosh and IBM PC compatible computers?

Introduction

The amateur radio community has been on the forefront of pioneering low cost radio communication systems for the last 87 years. With the development of the OSCAR satellites in the 1970's, the amateurs went into space. The initial communications in space were primarily by morse code and voice.

With the development of low cost personal computers, the amateurs quickly moved into digital communications and developed matching low cost packet communication technology.

The interest of school age children in amateur radio has declined significantly in proportion to the population over the last fifteen years. This decline can be attributed to the lack of interest by younger people in morse code and voice communications and the growing use of personal computers in the classrooms. These generations of students are attuned to fast-action, visual device interaction. What has the amateur radio community to offer this new generation of K thru university students?

The Questions to be Asked!

Is there a need in the U.S. education system to change what students are learning and how students learn it?

Does the amateur radio community have anything to offer to provide some of the needs of the educational community?

Does the amateur radio community need to be involved with the educational community?

Is now the time to network the amateur radio and educational communities?

What Are The U.S. Educational Needs?

The state of the U.S. educational system is of growing concern to almost everyone. The newspapers and television daily review studies and statistics of the test values of students with great alarm. "They can't read". "They can't do simple mathematics".

The employers are finding new employees poorly prepared in basic communications skills and math to the point of making them almost functionally illiterate. The universities find most new students lack basics skill to progress in entry level classes and require remedial classes before starting freshman classes.

What is the cause of this? Overloaded classrooms? Poorly trained and paid teachers? Lack of equipment? Poor discipline at home? One very major reason is lack of application of subjects at the time the material is taught!

Many schools purchased APPLE II and Commodore computers, but without a lot of educational software that relates to "real-world" computer applications. The schools are now replacing these computers with MacIntoshes and IBM PC compatible computers that match the "real-world", in office, plant and laboratory. This same transition is now being made at the university level too.

What can the amateur community provide for the educational system?

Can the Amateur Community Help?

The amateur radio community posses some very valuable assets that are needed in the educational classrooms. These assets are not only in the technical skills of radio communication, in particular satellite communications, but in life experience; time to assist teachers; becoming a mentor for the students; and being a member of the community that can provide donated equipment and financial support.

The amateur radio community has always shown a spirit of community support through radio communications in times of local and national emergencies. There is an emergency in the education system now!

The amateur radio community may not have always been welcome in the schools by administration and teachers with the misconception that, they were not needed or that "ham" radio could not offer students any educational benefit. With satellite communications, weather fax and communication by computer controlled digital packet radio, the educational community can begin to see a global picture in education associated with the amateur community.

The amateur will still have the same problem of going to the school directly to convince the administration and teachers to have him/her help them become involved in space age communication that can excite and expand the horizons in the classroom. The acceptance of amateurs in the schools can come by making an initial entry through a selected progressive school that is recognized as having a willingness to look at what the amateurs have to offer. This can be done by taking case studies to the school in the form of video, slide presentations and live demonstrations.

Demonstrating a live weather fax or receive only satellite station by students at a PTA meeting can have a very dramatic effect. Each local amateur club that has interests in satellite communications and weather fax system can make a goal to introduce such educational advantages into the classroom. Remember .... young students today are as adept with computers and video displays today as young student previously were with amateur radio a few generations ago.

Does the Amateur Community Need to be Involved?

The amateur radio community needs to and must be involved in the education systems today! The education system needs you! You have a great deal to offer!

Not only does the education system need the amateur radio community, but for the continued longevity of amateur radio, the amateur community must start generating more interest for students in amateur radio. Education is one of the major objectives of amateur radio. It is one of the requirements of the Federal Communications Commission to maintain the allocated amateur frequencies.

No new members and very little use of the frequencies means a loss of frequencies for future amateur radio generations. Create an interest in amateur radio (satellite communications, weather fax, computers, digital packet radio) with today's students and you can document your educational objective, significantly increase usage of the frequencies (reception of data in classrooms is usage), gain new generations of members and maintain the frequency allocations.

Is Now the Time to Get Involved?

In 1991 the power and graphics capabilities of the personal computer have made such significant advances coupled with the dramatic decreases in prices, that they have brought the space communication within reach of the classroom. In particular, the national attention now being focused on the need to make dramatic changes in education will allow amateurs to get the attention of the parent community, school administrators and the teachers.

You must seize this opportunity for the betterment of education and continued existence of amateur radio by showing a united force in front of the educational community, by showing your new technologies and energy to get teachers and students alike into the space educational environment.

What is the Program Plan of Action?

The amateur community has many assets such ARRL, AMSAT, and examples of dedicated teachers around the country. The professional, non-profit organizations such as ARRL, DRIG and AMSAT have as one of their many goals, introducing the amateur radio into the educational community. This goal becomes overshadowed with other activities directed to existing members.

The Environmental Research Institute of Michigan (ERIM) started a major teacher education program in 1989 with funding from a NASA grant to provide STEP (Space Technology Education Program) summer workshops for teachers. This two-week intensive workshop introduces the concepts of weather fax stations; how to solicit support and funding from the school district and the community to purchase a station for the classroom; how to use the system and the data in the classroom; and how to set up and maintain the station. This program has had outstanding results and is significantly promoting the technology developed by amateur radio community in the classroom.

What is to be done now?

1. **Form a non-profit organization that has one major objective ---- introduce, support and promote amateur radio technology in the educational system.**

2. **Seek funding and in-kind support for this organization through pledges from existing amateur organizations, amateur equipment manufactures, space and aerospace industry and government grant sources.**

3. **Set up an organization with direction that would come from a board of directors that represent significant, long term contributors.**

4. **Have this organization develop material such as video tapes and documented success stories to be used by local amateur radio clubs to promote this activity in**

the schools.

5. **Have this organization be a national resource center for curriculum, workshops, and data that could be used in the classroom with amateur stations.**

6. **Have this organization produce news bulletins for students and teachers to exchange information and sponsor regional and national conferences.**

7. **Have this organization establish gateways for schools to participate in world-wide packet communication between classrooms.**

8. **Have this organization represent the educational community in future planning and development of OSCAR satellites to assure that a portion of the space assets are devoted to education.**

9. **Have this organization represent the education community in influencing planning and development of future scientific satellites to have useful data transmitted directly to the classroom.**

Summary and Conclusions

Weber State University has greatly benefitted from its association with the amateur radio community and in particular with AMSAT-NA in expanding educational horizons for students in engineering technology programs. This association with radio amateurs in the development of the NUSAT I in 1985 and the development and launch of the Webersat (WO-18) in 1990 has had significant pay-off in terms of enhanced student education, international recognition in the space program and increased funding to further enhance the direct "hands-on" activities of students in "real-world" engineering work.

This benefit to Weber State is being returned to the educational community by sponsoring the ERIM workshops for teachers in 1991 on the Weber campus, promotion of weather fax and amateur radio stations in local schools and active solicitation of grant funding from government organizations to train teachers and demonstrate use of amateur satellite communications in classrooms nationally.

The 1991 AMSAT-NA Conference and the amateur radio community should adopt as a major 1992 goal to take the national leadership position to promote the formation of a separate organization that is dedicated to the promotion and support of amateur radio developed technology into the K-12 classrooms.

The Use of Satellites in Furthering Tertiary Electrical Engineering Education

JHN Van De Groenendaal, ZS6AKV

ABSTRACT

Amateur Radio and Satellites are being introduced in more and more schools and tertiary education facilities, not only as a study aid in science subjects but also in other academic disciplines. This paper reviews various opportunities for unjamming the curriculum and includes discussion on a number of case studies.

INTRODUCTION

The spirit of adventure lies buried in every man's soul. Strike the spark and ignite the soul and the impossible is accomplished. [1]

So it was on December 12, 1901 when the self-proclaimed Radio Amateur Guglielmo Marconi, bent intently over his crude receiving instruments and heard the letter "S" transmitted across the stormy Atlantic Ocean, from a station in Cornwall. That letter "S" changed the world and set in motion developments that even science fiction writers of that time had not written about.

The spirit of adventure made its mark sixty years later on December 12, 1961. The locale this time was an experimental aerospace base on the border of the Pacific Ocean. A group of radio amateurs saw launched into orbit the first Amateur Radio space satellite. Born in a burst of flames, the 4 kg, home made beacon satellite transmitted to the world that the spirit of adventure and quest that drove Marconi down the road of history was still goading the radio amateur in his eternal search after the mysteries of nature.

Now, another thirty years later, this spirit of adventure is finding its way into schools and universities offering educators new exciting opportunities to create enthusiasm and interest in the study of science and technology.

AMATEUR RADIO IN THE CLASSROOM

Amateur Radio and shortwave listening has been brought into the classroom in some USA schools and from all accounts has opened up new worlds of experience to children of different backgrounds.

It has been shown that special education students with learning and emotional disabilities as well as reluctant learners can succeed for the first time in their school career by mastering the Morse code, or by learning how to speak clearly. The brighter students can go on to obtain a Novice Amateur Radio license and from an early age develop ideas for new career choices.

"The marvelous thing about teaching Amateur Radio in a classroom is that you will be exposing young people to all kinds of new school experiences that the average child going through the school system today doesn't have a chance to learn about" Carole Perry told the 1989 ARRL National Educational workshop in the US. [2]

Shuttle mission, STS-35 (December 1990), also included Amateur Radio operation. Payload specialist Ron Parise is a licensed radio amateur and spent some of his off-duty time talking from the shuttle to radio amateurs worldwide.

In the US, many schools set up facilities to communicate with him and brought new experiences into the classroom.

In South Africa little interest was shown with the standard answer "it is during school time, we cannot fit it into our programme."

EXTRA CURRICULUM ACTIVITY

A few South African schools have introduced Amateur Radio and satellites into their after school activities programme. At Benoni High School one enthusiastic teacher runs an Amateur Radio club offering courses and various Amateur Radio and weather satellite projects.

During the first six months the club succeeded in turning some "strictly 8 to 2 students" to involved students. It is interesting to note that these students also improved their academic performance.

This teacher works alone with some support of past students who are now at university. Her colleagues? Too busy!

SKI-TREK

Several years ago the University in Guildford (UK) used one of their experimental Amateur Radio satellites, UOSAT OSCAR 11 to support the Transpolar ski-trek expedition that took a group of Russian and Canadian skiers from Russia across the North Pole to Canada.

The skiers carried a locator beacon transmitter which was picked up by the Sea and Air Rescue Satellites. From this information their location was determined and the information loaded into UOSAT OSCAR 11 onboard computer. The digitalker, an educational feature on UOSAT OSCAR 11, transmitted the information every two minutes. The skiers received this information on a small receiver and compared it with their navigational information.

Ski-trek turned into a worldwide school project. In South Africa only a few schools participated, but many parents involved their kids in the project at home. Some teamed up with local radio amateurs to get the information daily directly from the satellite, other relied on reports broadcast by the SABC on Mondays, Wednesdays and Fridays at 06:30. The information from the digitalker, longitude and latitude, was plotted on polar maps following the skiers' progress.

Some innovative teachers involved their geography classes and used large polar maps to plot the skiers' progress. These teachers recorded the information and played the tapes in the classroom for the pupils to decipher and interpret. Associated with this, several projects concerning the polar region were arranged.

The South African Radio League and SA AMSAT supported the project with regular reports about the activities of the skiers, their hardships and successes. These reports were transmitted on two 1 kilowatt AM transmitters in the 40 and 80 metreband. Edited versions were also included in the SABC 06:30 reports.

Currently the Johannesburg College of Education Centre for Gifted Children (in my opinion a poor choice of name, all children are gifted) are using weather satellites in some of their science teaching. They are planning to expand this to include Amateur Radio and Amateur Radio satellites as soon as one of the teachers has obtained his amateur license.

Thus far I have concentrated on schools because I believe that a child's formative years are the most important if the ultimate objective is to prepare scholars for Technikons and Universities is to be acheived. In many instances the curriculum is already jammed at primary school level. If not jammed, at least inflexible!

AMATEUR RADIO AND UNIVERSITY EDUCATION

At an Educators Conference [3] in the USA Robert M. May of the Tennessee State University said that one of the reasons why Amateur Radio is encouraged, is that the student interested in, and familiar with, the hobby will be more inclined to take a positive approach to classroom learning of electronic subjects. As part of its BS degree in Electonics Engineering Technology, the University offers an Amateur Radio course. With an Amateur Radio license the student has many more opportunities to apply his or her acquired knowledge practically and is likely to earn a better grade as a result.

Dr. Robin Braun at the University of Cape Town has introduced a similiar scheme and has his students involved in an ambitious satellite development project.

SOFTWARE ENGINEERING PROJECT AT THE UNIVERSITY OF THE WITWATERSRAND

In 1988 the Computer Science Department at the University of the Witwatersrand involved their third year students taking a Software Engineering course in a project to develop the onboard software regime for an orbiting space satellite.

The students were assembled in 12 groups of 5 and given access to radio amateurs who had experience with satellites.

The objectives of the exercise was to give students experience in working in groups, and of applying software engineering techniques in practice. Each group worked on a separate project using different equipment and different languages.

The fictitious amateur satellite was based on some of the parameters of the University of Surrey Amateur Radio Satellites UOSAT OSCAR 9 and 11.

The project was supported by the South African Amateur Radio Development Trust and the Southern African Amateur Radio Satellite Association (SA AMSAT).

The project was very successful. It involved many students in study of the practical aspects of satellites spending many hours at the Johannesburg Amateur Radio Centre Satellite ground station tracking and observing satellite performance.

SOUTH AFRICAN SATELLITE PROJECTS

As mentioned earlier the University of Cape Town has embarked on a long term project to develop and construct a Flying Post Box. [4] The Flying Post Box will serve as a mail transference and forwarding system for bulletin boards operating throughout South Africa. The intention is that it should be carried by a satellite that is roughly in a north/south orbit and that it will interrogate local bulletin boards for mail and carry it until it can download to the appropriate other bulletin board in another area.

The construction of the Flying Post Box has very exciting implications on the education of young undergraduates. Dr. Robin Braun told the 11th Amateur Radio Space Communications Conference held in Johannesburg in August, 1990 that he had found that the best students going through the system, not necessarily in academic terms, are those with electronics as a hobby.

The University of Stellenbosch and BSI are working on a satellite project "kleinsat" which may well provide UCT with a launch opportunity for their Flying Post Box.

SA AMSAT is currently working on a joint satellite project with other international Amateur Radio Satellite Groups. The satellite is code named AMSAT Phase 3D. The South African involvement includes a broadcast transponder which will operate on 29 MHz downlink using AM compatible SSB. The purpose of the transponder is to transmit technical and Amateur Radio related educational information to a wide audience. The system is being designed so that only mimimal ground receiving equipment will be required to receive a good signal. This is of particular importance in the African context. Once in orbit the system will provide endless opportunities for educational projects.

The development phase of this satellite also offers opportunities for Techikon and University students to become involved and supplement their studies with hands-on practical experience. A University of Pretoria student is currently designing and building a prototype high efficiency power amplifier as part of his post-graduate studies.

AMATEUR RADIO SATELLITES

A number of Amateur Radio satellites are in orbit providing a large number of educational activities. One of the most recent is Webersat, a microsat developed and built by students and staff of the Weber State University in conjunction with AMSAT North America.

The satellite carries a CCD camera. The University of Stellenbosch is planning to involve some of their students in projects using signals from Webersat.

The University of Surrey has two experimental Amateur Radio satellites in orbit and is working on a third one due for launch in 1992. The UoSATS, as they are known, all include experimental payloads offering a wide range of experimental opportunities.

AMSAT DL (Germany) is about to launch an experimental digital package as part of a Russian Amateur Radio Satellite. The system, called RUDAK, will offer experimental opportunities in the field of modulation techniques.

DOVE, Digital Orbiting Voice Encoder, is owned by AMSAT Brazil and once fully activated will offer primary school educators many opportunities for interesting classroom projects.

Many commercial weather satellites are available for classroom and experimental work. Schools in the UK make extensive use of these.

CONCLUSION

Amateur Radio and Amateur Radio satellites offer many educational opportunities. The largest obstacle however is the availability of readily usable information and tutorial material. SA AMSAT and the South African Amateur Radio Development Trust are working on the establishment of a Amateur Radio and Satellite Education Resources Centre. Progress is slow as funds are not forthcoming.

Currently most projects are not funded adequately and supported mainly by individuals during their leisure time.

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Space Education and the SEDSAT 1 Project

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Introduction

Education in America today is in a crisis state. According to the recent report from the National Education Goals Panel, test scores, after several years of gains during the 1980's, are declining. Money has not been the solution to the problem. The problems in education, especially secondary education, defy easy solution. This is because there are so many problems, that when lumped together, make solution very difficult. While there are no easy all encompassing answers, there are steps that we as a student group can take to help. We are in an advantageous situation to quantify what the problems are. We have spent the last twelve to seventeen years on the receiving end of the educational process and we know what it is like from the inside.

School is boring, that more than anything else, is the complaint of students in school today. School is boring because the subjects that are taught, and the way that they are taught, are inadequate. This was particularly true in the 1970's and early 80's. There has been some improvements recently. These improvements have not been widespread enough to impact the whole system. Many of these improvements have come because of the efforts of volunteers who see the poor state of education and are putting in their time and efforts to make a difference. This is especially true of people who are associated with what is coming to be termed "Space Education".

Traditionally, people involved in the amateur radio world have been very good in promoting education. Almost every amateur radio operator in America learned what was necessary to pass the FCC exam at a amateur radio club staffed with volunteers or from an individual who volunteered to help. Indeed, the FCC relies on the Volunteer Examiner system set up in cooperation with amateur radio groups to administer the testing of potential hams. This fine tradition of volunteerism has been extended into the Amateur radio satellite world by the efforts of volunteer groups such as AMSAT in building innovative, cheap and reliable communications satellites . It is the purpose of this paper to present ideas on how our group is using our SEDSAT 1 project to promote space education to help make school exciting and learning enjoyable.

Approach

Space exploration is the perfect vehicle for building an educational curriculum to make learning fun. The adventure, the wonder, and the scope of the final frontier make space education unique in its ability to get students interested in learning. Learning in traditional education today is extremely compartmentalized. This is an example of the classic "can't see the forest for the trees" dilemma. Math is taught separate from physics. History is taught separate from literature. English instruction is completely the most boring subject in the world. We learned for over eight years over and over how to diagram sentences. This is a talent that was soon rightly forgotten. Also, new developments in technology that are crucial to the future success of the student today are often not taught systematically in this country at all.

An approach that we would offer, uses space education as a vehicle in a holistic approach. Space exploration can encompass every subject in the world. The subject that is taught as calculus today was developed by physicist such as Newton to describe the motion of the planets. In later times this higher level math has been extended to be able to describe most processes in nature and is taught as physics. However, in the schools math is treated as a completely independent, non-connected subject. This approach is confusing to the student who wonders "just what in the world is this stuff really for". The same is true in other sciences. We never understood just how much the damage being done to the rain forests in south America effects the rest of the world until we were able to look down on the planet from the larger vantage point of space. Amateur radio both ground based and on satellites and the associated technologies can be used to teach analog and digital electrical engineering at both the introductory and advanced topic level in such a way as to show how both disciplines together operate to form a coherent whole which is not normally the case in school. This holistic approach can do much to remove the confusion and enhance the retention of knowledge which is the goal of education.

An Alternative Educational Paradigm

Education can be looked at as a complete system. In a holistic approach to education there is established what would be termed "interconnectedness". Within a holistic paradigm knowledge, when presented, is presented not as independent stand alone jewels of knowledge, but presented as a whole system, where the individual pieces fit together as in a puzzle where the relationships of one piece to another are clearly shown. As the knowledge in each area is presented and the connections with related subjects established and reinforced, insight is gained into the subjects in such a way that they are retained in memory in higher retention rates than the rote memorization that is standard in todays schools.

It is appalling that teachers routinely state to their students that if they remember only ten percent of what was taught them in a subject over the term of study, then they are doing good. That is wasteful of students time, teachers time and of our whole nations educational resources. Ten percent efficiency in learning is simply unacceptable but unfortunately the norm. Many of the memory systems that are sold by companies today stress the relationships between knowledge and use the relationships to "tag" memory in such a way as to increase memory retention. These methodologies need to be researched in more detail in order to integrate the useful methods into the scholastic curriculum.

SEDSAT 1, Amateur Radio, and a Space Education Methodology

SEDSAT 1 is a microsat class satellite potentially flying as a secondary payload as part of NASA's Small Expendable Deployer System (SEDS) flight demonstration project . SEDSAT 1 is being designed to be deployed into a 680 X 792 km orbit at a 39° inclination. SEDSAT 1 will be deployed from a McDonnell Douglas Delta II 7925 second stage by the SEDS via a 46 km tether.

It is the intention of the members of SEDS at UAH and our national organization to utilize the different aspects of the SEDSAT 1 satellite and its mission to teach science, math and engineering. It is our goal to develop, in cooperation with other organizations, educational packages both written and computer based, to communicate the principles surrounding our scientific mission, the engineering design of the satellite, and the communications systems and amateur radio aspects of the satellite. Ideally students at all levels would be encouraged to gain their amateur ticket as part of the learning process. We would like to wrap the various aspects of the learning process into a related whole in which the students could then continue on within the framework of their educational process to further broaden their education and then as they become more familiar with the big picture *then* specialize in their desired fields

Below is a list in the disciplines of math/science and engineering that can be addressed by using the SEDSAT 1 satellite, its mission, and amateur radio aspects. These are by no means the entire scope of what can be covered but will give an idea of the direction that we are interested in taking.

SEDSAT 1 and Science

Radio waves, light waves and the electromagnetic spectrum

Orbital mechanics and calculus/mathematics

Vectors/torque and dynamic systems

Earth remote sensing with SEASIS/Environmental Concerns

Geography/Geodesy

SEDSAT 1 and Engineering Sciences

SEDSAT 1 and communications

Analog Communications/QRP work

Digital Communications and Computers

Image Processing and Data manipulation

RF engineering and setting up a station

Basic Radio Knowledge

Amateur Radio Licensing

Below is a list of what we are accomplishing today and what we wish to pursue as ideas on integrating our efforts into school curriculums at the different levels. The above list

SEDSAT 1 and College Education

Scholastic credit for SEDSAT 1 work
Undergraduate and graduate research using SEDSAT 1
Teaching amateur radio and its principles

SEDSAT 1 and High School Education

Using SEDSAT 1 experiments and communications

Physics, calculus/math computer technology
Communications technology/Amateur radio
Environmental issues
Teaching amateur radio and its principles.

SEDSAT 1 and Elementary and Junior High School Education

Teaching about the earth in relation to the solar system
Teaching about the earth and its environment
Teaching about the environment in space
Teaching about why satellites stay in orbit
Teaching Amateur Radio and its principles

Building citizenship

Amateur radio public service
Emergency communications traffic and emergency preparedness
Amateur radio operators as ambassadors of international good will
Environmental awareness

The last category on building citizenship through the traditional amateur radio public services can be a valuable tool to instill in students of all ages that they can take part and make a contribution to society. Too often in our modern age students are told that their efforts will not significantly influence society, that the game is rigged and you can't win. The long tradition of public service by amateurs is well worth passing on to the next generation.

Conclusions

Some of the goals of this paper are already in progress. Several members of the SEDSAT 1 team at UAH have received credit toward engineering and science degrees by working on our satellite. Also, students at other Universities such as Weber State and the National Cheng Kung University in Taiwan have received or will receive credit for working on this project. We, like AMSAT and the ARRL are a volunteer organization. We do what we do in space education for two reasons. One is that we perceive that the future of our species on this earth depends on our ability to reach out into the vastness of space to bring back the benefits of this last frontier to earth. The other is that, as students, we see the shortcomings of our educational system from a victims perspective. Students in America for the past thirty years have been political footballs kicked around by various interest groups seeking to impose their way and mold us into their image. It is time to stop and reexamine the structure and methods used to educate students in our country and return to what education was meant to accomplish, prepare us for the future.