$12.00

AMSAT

RADIO AMATEUR SATELLITE CORPORATION

PROCEEDINGS OF THE

AMSAT-NA

FIFTH SPACE SYMPOSIUM AND ANNUAL MEETING

NOVEMBER 6-8

1987

SOUTHFIELD, MICHIGAN

Cliff Buttschardt K7RR
950 Pacific Street
Morro Bay CA 93442

Proceedings of

AMSAT-NA Fifth Space Symposium and Annual Meeting

November 6-8, 1987
Southfield, Michigan

Published by the
American Radio Relay League
225 Main Street
Newington, CT 06111

AMSAT-NA Fifth Space Symposium

Held in conjunction with the 1987 Annual Meeting in Southfield, Michigan
November 6-8, 1987

Committee:

Bob Anderson W8KZM
John Champa K8OCL
Steve Culp K8QKY
Rich Ensign N8IWJ
Jan Jellema W8SWN
Larry Koziel K8MU *Chairman*
Doug Wilson KA8IGS

Contents

SPACECRAFT TECHNOLOGY TRENDS IN THE AMATEUR SATELLITE SERVICE

Dick Jansson
AMSAT-NA

ABSTRACT

Small communications satellites have been employed by the Amateur Radio community for over twenty five years. These satellites have been used by tens of thousands of radio amateurs for recreation, education and scientific investigation. The Amateur satellite program today is international in scope with nine countries having contributed space flight hardware to the overall effort. A total of 14 satellites have been fabricated in the OSCAR program resulting in 29 spacecraft-years of orbital experience.

This paper will address the history of the spacecraft developed for the Amateur Satellite Service with emphasis on technology trends in the program. Particular emphasis will be placed upon the mass, cost, system capability and construction phase duration for each of the fourteen satellites of the OSCAR series. The Amateur satellite program has not simply adopted technology from other larger satellite programs. In many cases entirely unique design concepts were employed, required because of the small size of the spacecraft, the very limited power available or the limitation of fiscal resources. The development of high efficiency linear communications transponders and the design of highly integrated command, control and telemetry equipment are two examples. For many years these techniques have been of little value to designers of larger spacecraft, who have alternatives. With the new interest in lightweight satellites at low cost, these techniques may take on renewed applicability.

INTRODUCTION

Small communications satellites have been employed by the Amateur Radio community for over twenty five years. These satellites have been used by tens of thousands of radio amateurs for recreation, education and scientific investigation. In recognition of the potential value of these activities, the International Telecommunications Union established, in 1971, the Amateur Satellite Service; a separate service from the Amateur

Radio Service but with common objectives. The Federal Communications Commission has followed suit in its Rules and Regulations, Part 97, Subpart H.

Spectrum has been allocated to the Amateur Satellite Service throughout the HF, VHF, UHF and microwave bands. The Amateur satellite program today is international in scope with nine countries having contributed space flight hardware to the overall effort. A total of 25 satellites have been fabricated in the world-wide Amateur Satellite program resulting in 29 spacecraft-years of orbital experience to date. One of the satellites failed to achieve orbit due to a launch vehicle failure and one awaits launch on the new European ARIANE-4.

This paper will address the history of the spacecraft developed for the Amateur Satellite Service with emphasis on technology trends in the program. Particular emphasis will be placed upon the mass, cost, system capability and construction phase duration for each of the fourteen satellites of the OSCAR series. The Amateur satellite program has not simply adopted technology from other larger satellite programs. In many cases entirely unique design concepts were employed, required because of the small size of the spacecraft, the very limited power available or the limitation of fiscal resources. The development of high efficiency linear communications transponders and the design of highly integrated command, control and telemetry equipment are two examples of these technologies. For many years these techniques have been of little value to designers of larger spacecraft, who have alternative technology options. With the new interest in lightweight satellites at low cost, these techniques may take on renewed applicability.

In the process of developing spacecraft of this nature, new strategies for environmental testing, component selection, materials selection, system redundancy and program management had to be developed. Some of these new strategies are driven by fiscal restraints, while others by manpower resources, these approaches differ significantly from conventional spacecraft programs.

HISTORICAL BACKGROUND

The launch of the first artificial satellite, Sputnik I, excited the imaginations of a great many people around this globe. The world of Amateur Radio ("ham" radio) is one that historically has attracted devotees that have been filled with curiosity, investigation and "imagineering", all to create new methods and applications in the realm of radio communications. These two statements, seemingly unconnected, converged about two years following the launch of Sputnik I, with a group of California amateurs, incorporated as Project OSCAR, initiating a program to build an OSCAR (Orbital Satellite Carrying Amateur Radio). After two years of their efforts, OSCAR I was launched on 12 December 1961 as a "piggy-back" secondary payload aboard an Air Force Thor-Agena launch vehicle carrying the Discovery XXXVI payload. These events have been suitably documented by Davidoff and others, starting with the visions of a magazine writer.[1]

Oscar I was but the first of some 25 satellites, built by radio amateurs around the world, that have either been orbited or are planned to be launched. Fig. 1 chronicles the relentless pursuit of radio amateurs toward achieving highly reliable global communications with complete freedom from the effects of ionospheric propagation phenomena. The 40 years of past and future OSCAR activity shown provide the background of our experience and lay the plan for our future expectations. Fig. 2 is a log of the operating history of each of these satellites, presented with a logarithmic abscissa covering time from 1.2 days to 31.7 years. Note also that there are eleven Russian radio amateur satellites that have been launched, the RS and Iskra series. As we have very little information on their construction and properties, further efforts to include them in this discussion is not practical.

AMSAT

Starting with OSCAR 5, a new organization was formed for the exploitation of amateur radio satellites. Called the Radio Amateur Satellite Corporation, it is more commonly known as AMSAT, a successor to Project OSCAR in launching amateur satellites.

AMSAT has grown into an international organization and spun off a number of affiliate organizations in other countries. Most of the work done on amateur satellites in the last fifteen years has been done as international efforts, with one or more national group defining the basic spacecraft. This consortium has also provided the systems design and control and defined the subsystem interfaces. Substantial design flexibility exists in the subsystems, as long as their interface requirements are met, and the execution of these subsystems have been delegated to even other groups. Phase III satellites provide a good example of this process. The central consortium has been between (as we know it now) AMSAT-NA (AMSAT North America) and our West German colleagues, AMSAT-DL. Subsystems have been fabricated by Bulgarians, Japanese, Australians, South Africans and other national AMSAT groups. Even the spaceframe assembly in suburban Washington, DC, looked like a small United Nations.

This decentralized, all volunteer army does have its drawbacks in managing a program, but the dividends are that the program can draw on the talents of highly capable and motivated persons.

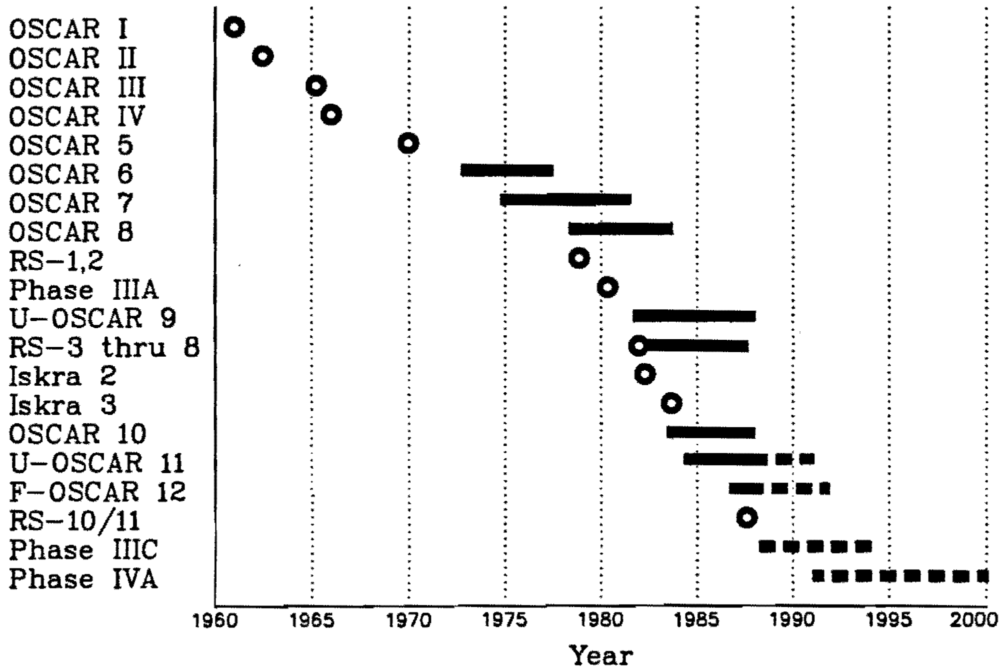


Fig. 1. Amateur Satellite Flight History

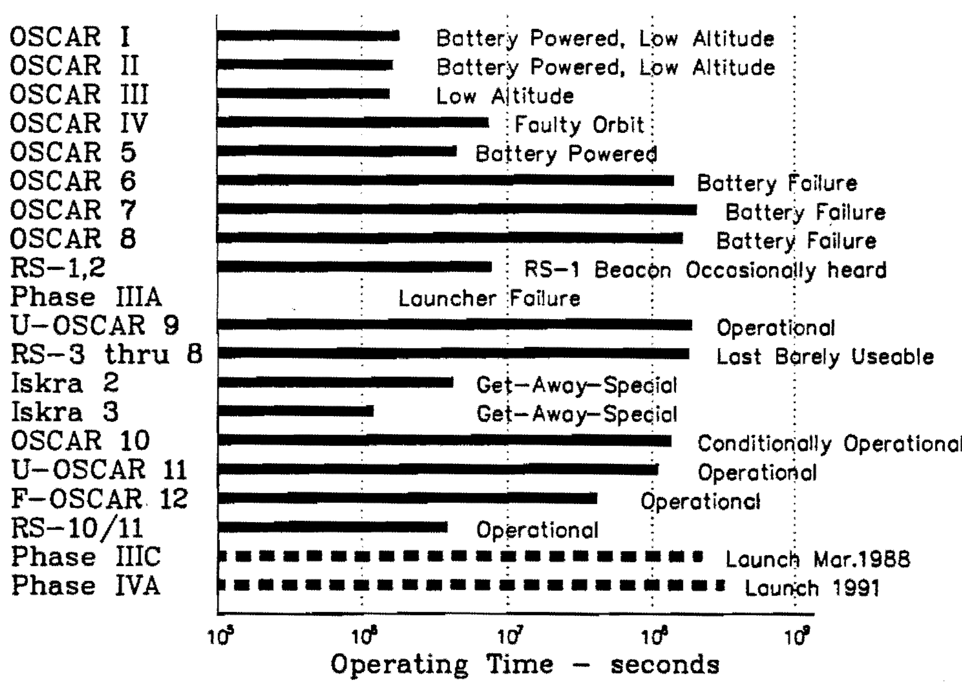


Fig. 2. Amateur Satellite Flight Log

Many of these volunteers are aerospace professionals on their own right, but the aura of an amateur spacecraft attracts them to contribute their time and talents to the program.

OSCAR Program Phases

The many spacecraft constructed by radio amateurs can be roughly classified by their intended function into four Phases. Phase I designs comprise low earth orbit (LEO), short lifetime beacon satellites, such as OSCARs I, II, III, 5 and Iskra 1 and 2. Phase II designs are also LEO (but not as low an altitude), long lifetime satellites with active transponders and experiments, such as OSCARs 6, 7, and 8, UoSAT OSCARs 9 & 11 and RS 1-11. Phase III satellites are designed to function in elliptical Molnia-type orbits at high altitudes, for long lifetimes and with wide area transponder coverage. Examples of Phase III satellites are the ill-fated Phase IIIA, OSCAR 10, and the soon to be launched Phase IIIC. Phase IV satellites are now in the study and design phase and crown this development cycle with geosynchronous "constant" position orbits providing 24 hour/day communications over nearly half the globe per satellite. OSCAR IV was ahead of its time by 2.5 decades with a Phase IV mission, that we now plan for the early 1990s.

OSCAR SATELLITE CHARACTERISTICS

As would be expected in a progression of satellite designs covering 2.5 decades, substantial advancements have been made in the features and capabilities of the OSCARs. Correspondingly, satellite mass, cost and complexity have increased. OSCARs I and II were literally assembled in California home workshops in the originator's garages. Even substantial elements of OSCAR 10 were concocted in home workshops and kitchen ovens, although that spacecraft was too large for a normal home workshop and required a more formal assembly laboratory. The Phase IVA spacecraft will be just too immense to place in anyone's shop, much less get through the doorways of all but the most special of commercial buildings. These size examples only illustrate our progress.

Fig. 3 illustrates this spacecraft growth from OSCAR I to Phase IVA, with the increase of nearly 100 (actually 19.5 dB, for those who think in logarithmic terms) in spacecraft orbital mass. Similarly, power consumption, in our own miserly power budget terms, has grown by two to three decades, as shown in Fig. 4, although that data is considerably skewed by mission objectives and the available power sources employed.

OSCAR Payloads

To further grasp the degree of evolution of the OSCAR satellites Fig. 5 shows several measures of the capabilities of these

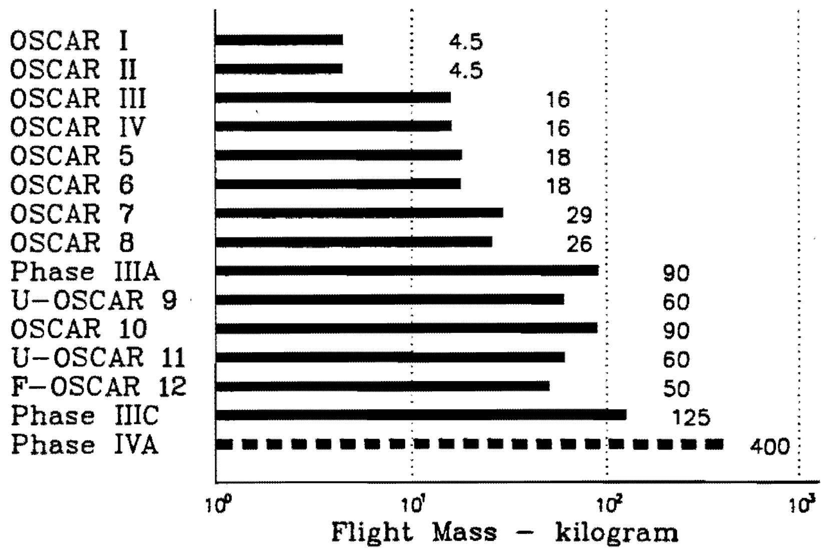


Fig. 3. Amateur Satellite Flight Mass

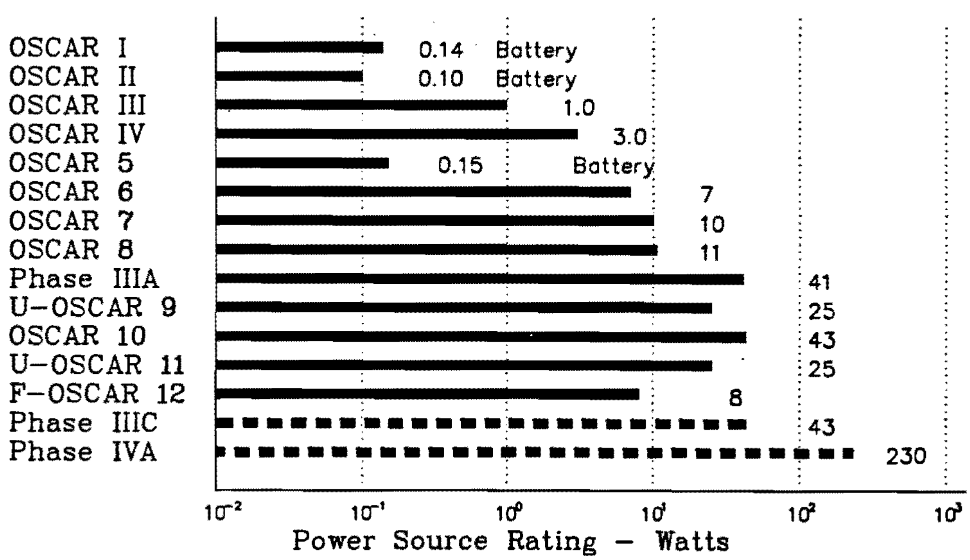


Fig. 4. Amateur Satellite Power Rating

	Telemetry Channels	Command Channels	Computer Memory kByte	Highest Frequency MHz.
OSCAR I	1	0		144
OSCAR II	1	0		144
OSCAR III	2	0		145
OSCAR IV	2	2		432
OSCAR 5	7	2		144
OSCAR 6	24	21		435
OSCAR 7	96	70		2304
OSCAR 8	6	5		435
Phase IIIA	64	OBC	16	435
U-OSCAR 9	105	OBC	32	10 GHz
OSCAR 10	64	OBC	16	1270
U-OSCAR 11	156	OBC	368	2400
F-OSCAR 12	62	40	48	436
Phase IIIC	64	OBC	32	2401
Phase IVA	~128	OBC	~640	2402

Note: OBC is On Board Computer

Fig. 5 Amateur Satellite Capabilities

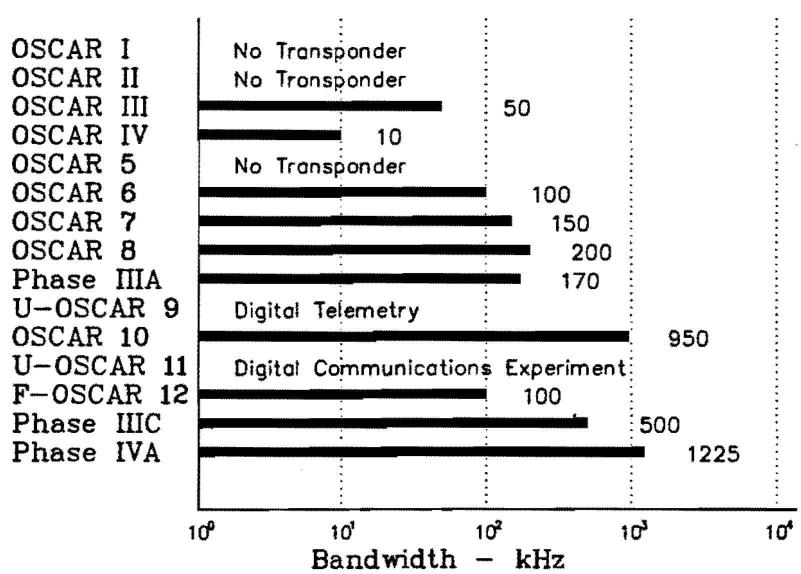


Fig. 6 Compounded Transponder Bandwidth

missions. Measures are in terms of the relative sophistication employed for information telemetry, control capabilities and transponder highest frequencies. In recent years the degree of control cannot be related to the number of channels employed as microprocessor on-board-computers (OBC) have changed that meaning, instead the measure is given in terms of the RAM memory carried aboard.

While more than 25 years ago we spoke about just being able to copy the single channel CW beacon of OSCAR I, these days, even in LEO satellites (Fuji OSCAR 12) we speak in terms of copying the packet bulletin board system (PBBS) messages and leaving stored messages for other amateurs at other locations on this globe. This FO-12 activity has been witnessed, and viewed in awe, as this paper was being prepared. Meanwhile, the AFC locked phase-shift-keyed (PSK) modem automatically tracked the down-link information through all of its signal Doppler shift, and the computer kept right on flashing all of the traffic onto the screen as the satellite passed.

In Fig. 5 the information regarding highest frequency is a bit misleading, as while OSCAR 7 had a 2304 MHz beacon aboard, it could not be turned on for legal reasons, dictated by the FCC. For Phase IIIC and Phase IVA we are planning to employ this kind of 13 cm equipment in real transponder service. The principal transponder of Phase IV will be several band segments (separate transponders) of 24 cm uplink with 13 cm downlink, fairly advanced even for many of today's amateurs, but a very real need for that mission. These communications links are feasible today, and will be common place at the time of the expected Phase IVA launch.

This advancement in communications transponder capabilities is more suitably illustrated in Fig. 6, showing the total compounded bandwidths of all transponders aboard the respective satellites. While the total bandwidth for OSCAR 10 looks large, and it was actually flown with that capability, a single transistor failure in the 800 kHz wide Mode L (24 cm uplink, 70 cm downlink) transponder reduced the gain and operationally effective bandwidth of that unit to about 100 kHz, making the real total for OSCAR 10 about 270 kHz. The upcoming launch of Phase IIIC, with 500 kHz bandwidth presents a real improvement over predecessors, and the 1.22 MHz bandwidth for Phase IV represents a substantial improvement over Phase IIIC. Most of the transponders have been linear translators, faithfully retransmitting their input signals. Some recent transponders have deliberately not been linear. The digital tranponding functions of the DCE of the UoSAT OSCAR 11 and the Phase IIIC RUDAK packet system are examples.

To conclude this discussion on the prime payloads of the OSCAR satellites, the communications transponders, a useful measure of capability is shown in terms of a form of "gain-bandwidth" product. Fig. 7 shows our version as a "power-bandwidth" product, EIRP-bandwidth in Watt-kiloHertz, to be specific. This measure accounts for transmitter antenna gain, transmitter power and bandwidth, all expressed as a single product. It can be seen that the plans for Phase IVA present a stupendous decade growth over even the inflated value for OSCAR 10. Not normalized in this process, however, are the mission requirements. The lower EIRP-B.W. for Fuji OSCAR 12 does not demean its performance, as it is a long-life LEO satellite and produces quite strong signals despite its lower transponder output. Conversely, the Phase III and IV satellites need higher powers and antenna gains to provide usable signals from their 36,000 km altitudes.

Attitude Control and Station Keeping

As the missions of the OSCAR satellites have become more sophisticated, so too have the methods employed for attitude control. Transponder antennas, even fairly simple ones, have directivity characteristics, and spacecraft attitude control is important to maintain useful communications links. Fig. 8 shows this progression of spacecraft control, running from no control on the earliest, to simple bar magnets, and further on to a complex computer controlled magnet system for active spin and attitude control. This last system is used on the Phase III satellites and senses Earth and Sun positions, computer processing the data and controlling three sets of magnets for spacecraft spin and attitude.[2] The UoSAT program also uses magnetic torquing, but in conjunction with gravity gradient booms and magnetometry for attitude sensing. The Phase IV spacecraft will employ transponders with highly directive antennas that will require very precise attitude control in the body stabilized mode at geosynchronous altitudes. We hope to employ a simple, low cost reaction control system for this Phase IV mission.

As the attitude control needs have become more demanding, the microprocessor computer has made meeting these demands feasible. Pointing requirements have dictated that we are able to measure our position in space and the location of the Sun and Earth. While these needs are not at all new to the space industry, some of the solutions employed and proposed are unique. It should be noted that the space industry probably has as many solutions for position determination as there are satellites, this kind of measurement has had no really universal solution. Suffice, there are probably very few missions, even of the low-cost small satellite field that will not require some sort of attitude control, even passive.

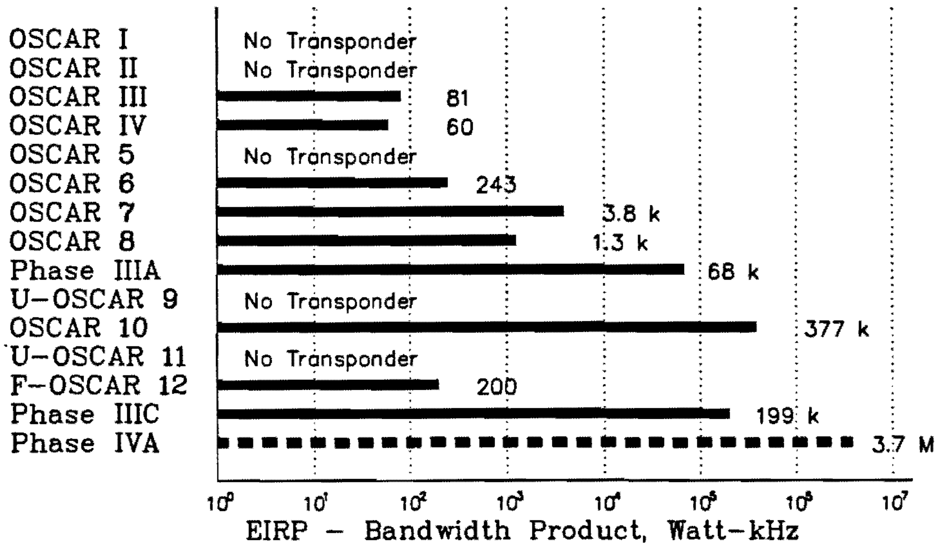


Fig. 7 Amateur Satellite Transponder System Performance

	Orbit Type	Attitude Control
OSCAR I	LEO	None
OSCAR II	LEO	None
OSCAR III	LEO	None
OSCAR IV	GTO	Spin
OSCAR 5	LEO	Spin, Passive Magnets & Lossy Dampers
OSCAR 6	LEO	Spin, Passive Magnets & Lossy Dampers
OSCAR 7	LEO	Spin, Passive Magnets & Lossy Dampers
OSCAR 8	LEO	Spin, Passive Magnets & Lossy Dampers
Phase IIIA	Molnia	Spin & Computer Operated Magnets
U-OSCAR 9	LEO	Gravity Gradient Boom
OSCAR 10	Molnia	Spin & Computer Operated Magnets
U-OSCAR 11	LEO	Gravity Gradient Boom & Active Magnets
F-OSCAR 12	LEO	Spin, Passive Magnets & Lossy Dampers
Phase IIIC	Molnia	Spin & Computer Operated Magnets
Phase IVA	Geo	Earth Oriented Body Stabilized With Reaction Control System

Fig. 8 Amateur Satellite Attitude Control

OSCAR SATELLITE COSTS AND EFFORT

The discussion to this point has generally been on very quantifiable terms of satellite design and performance. Entering the arena of the cost of an OSCAR satellite and how long it took to build become subjects that are difficult to grasp. One must first understand that while AMSAT's satellite builders may be well paid and respected professionals in their own diverse fields, they are truly volunteers when it comes to building OSCAR satellites. Evaluating a fair-market-value for the labors of tirelessly applied volunteer efforts is next to impossible. Further, many companies in the aerospace industry knowingly contributed to the programs in many diverse ways, such as authorization of computer time resources for satellite design efforts, specialized components and many other countless contributions.

Fig. 9 shows that while we have assembled satellites for very nominal monetary amounts of out-of-pocket funds, the trend of costs are escalating nearly five decades while the mass only grew two! These increases all despite the application of innovative solutions to normally expensive problems. One cost that is now becoming substantial is that of a launch position. Most of the early OSCARs were launched for no fees at all, as there were usually excess launcher capacity available, or the launcher was new and experimental, as was the case of the ARIANE that was to launch the Phase IIIA spacecraft in 1980. The loss of that launcher was a hardship to the ESA program, and an absolute disaster to the amateur satellite program. As launching facilities have become more experienced and and launches more routine we have been expected to underwrite some share of the integration and launch costs. This trend is expected to continue as space programs mature.

Another impact to the cost picture is illustrated by the OSCAR 10 effort. A substantial amount of the work needed was done in duplicate (e.g. the spaceframe) and this subsequently reduced the costs for its later sister spacecraft, Phase IIIC.

Fig. 10 gives some insight to the elapsed calendar time for the several OSCAR programs. Buried in this information is the trend that second and third models of a particular program have required less time to achieve, not a terribly surprising situation. The experience factor has been substantial; hence the Phase IIIA effort was 5.5 years, OSCAR 10 was 2.5 years, and Phase IIIC only two years. A two year program seems to be the minimum, although some programs, through the application of super-human efforts have produced complex spacecraft, such as UoSAT OSCAR 11, in as short a period as 6 months.

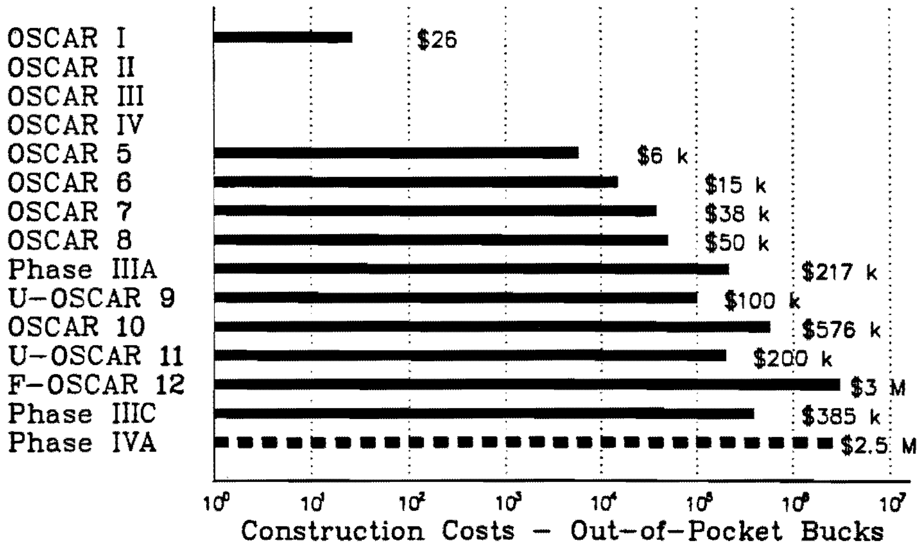


Fig. 9 Amateur Satellite Costs

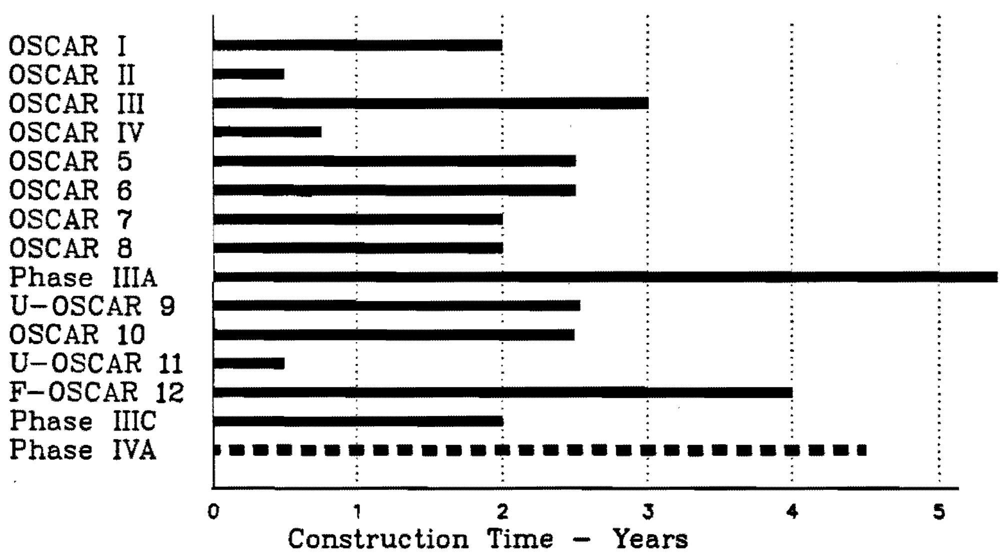


Fig. 10 Amateur Satellite Construction Time

OSCAR PROGRAM EXECUTION

This subject of constructing complex hardware projects with mostly volunteer labor cannot be left without commenting on the immensity of the differences in the management techniques that need to be applied. AMSAT's procedure may seem harsh and leaderless to some, the process really sorts out those individuals who will perform with a major amount of self motivation, and those who are just along for the ride. This later group does not last very long on an AMSAT program. This yoke of volunteerism places demands on an AMSAT program manager that pale those placed on a manager of an all professional effort.

Technical management on a low cost spacecraft program also requires inventiveness in the process of evaluating the suitability of components to do their job. Decisions also must be made on just how much testing of various system blocks is needed to provide a flight worthy confidence, without the cost overkill of a NASA or DOD program.

Component testing varies from a full stress and test burn-in, to a simple value check measurement at assembly. The drivers on deciding these criteria are the confidence in the class of component and its failure mechanisms. In some cases, by purchasing MIL-STD components, there is no individual component testing done at all, except at the subassembly level.

Testing of subassemblies primarily are just those of an extensive room temperature burn-in and functional test to sort out component and circuit infant mortalities. Environmental testing is relegated to the overall spacecraft integration level of assembly. The success record provides some substantiation to these philosophies. Useful life termination of early spacecraft, such as OSCAR 6, 7 and 8, have been related to high battery temperature problems. This is a thermal design problem that has been solved on later programs by obtaining the services of qualified personnel in the design phases of the program, long before the fact of the failure mode.

CONCLUSIONS

AMSAT's proven track record of successful spacecraft has given the confidence that we can build a geostationary class of satellite. We have to be very careful, however, as the size, cost and complexity of this kind of program may grow beyond that which can be handled as a volunteer program constructing a "small satellite".

ACKNOWLEDGMENT

I would like to thank Jan King, Vice President for Engineering, AMSAT-NA, for the opportunity to practice some of the really fun aspects of my profession over the last decade; opportunities that were not available to me in my vocational pursuits. Further, this association with Jan has followed me into retirement, providing me the challenge and fun of staying abreast of spacecraft technology, all of which is gratefully appreciated.

REFERENCES

1. Martin Davidoff, The Satellite Experimenter's Handbook, The American Radio Relay League, Newington, CT, 1984.
2. Gordon Hardman, "The Integrated Housekeeping Unit", 1st USU Conference on Small Satellites, Logan, UT, 1987.

ABSTRACT

NUSAT II Satellite Development

by
William G. Clapp
Weber State College
Ogden, Utah 84408-1703

NUSAT I was the first satellite ejected from a Get-Away-Special canister on the NASA orbiter Challenger. This ejection occurred on April 29, 1985, and marked the beginning of a new era of satellite designs which could be inexpensively placed in orbit by the NASA Shuttles. Over 1500 two-way communications were completed before NUSAT I burned up because of its short life low orbit. The FAA radar experiments were not completed as intended because of the unanticipated high density radar signals found at that altitude.

The success of NUSAT I has provided the opportunity for Weber State College to design and launch another satellite. Funding has been provided by the State of Utah under the Centers of Excellence Grants to develop a second satellite to complete the experiments started by NUSAT I. The Center for Aerospace Technology (CAST) at Weber State College was organized to facilitate projects of this nature. Significant improvements have been implemented on the NUSAT II design that should greatly improve the chances of completing the FAA radar experiments.

All of the development for NUSAT II has been accomplished by students under the supervision of industry and faculty advisors. Over 100 students have contributed over 300 hours each in completing the graduation requirement for senior projects. Twenty-five volunteer industry advisors have contributed hundreds of hours advising the student efforts. Weber State College is attempting to create an ideal environment for training technology students.

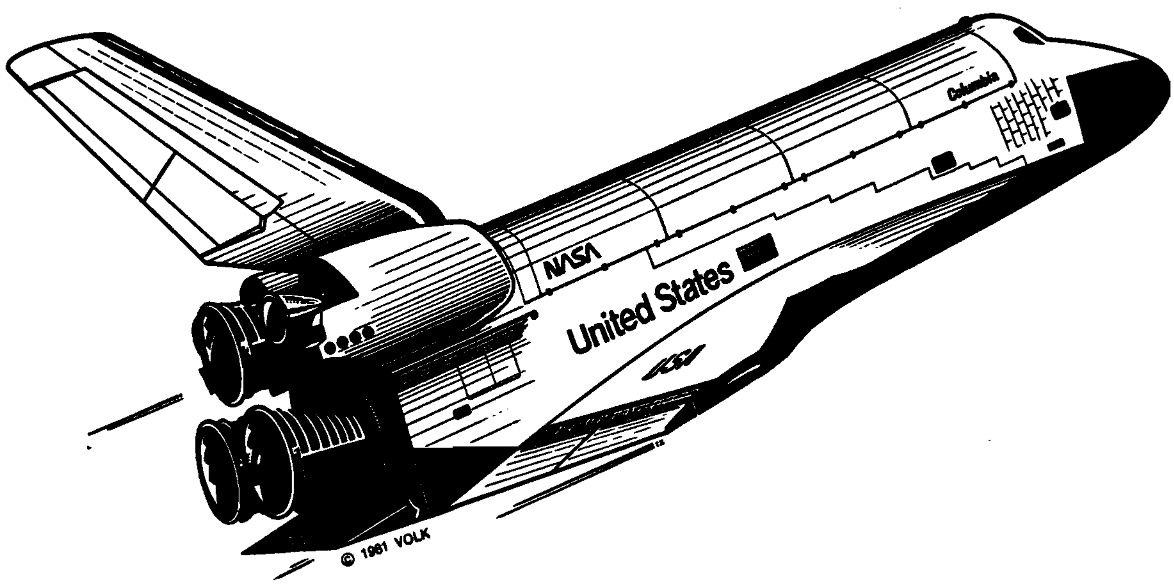
The NUSAT II airframe is considerably larger than NUSAT I. The increased size will allow additional systems to be included in the design. The prototype airframe has already been built and structurally tested. The NUSAT II airframe has been purchased by Richland Community College and being considered by another organization. The larger airframe design was approved by NASA because of the success of the launcher mechanism that was designed by students in the Automotive and Manufacturing Department at Weber State College. The launcher mechanism has successfully launched two satellites out of a small Get-Away-Special (GAS) canister on the shuttle.

The electronic subsystems will be integrated into the airframe starting in the Fall of 1987. The launch date will probably be postponed until the last part of 1988 or early 1989 because of the new NASA shuttle launch schedules.

FAST SCAN AMATEUR TELEVISION

FOR THE SPACE SHUTTLE

PROPOSED BY
THE MOTOROLA AMATEUR RADIO CLUB
(SCHAUMBURG, ILLINOIS CHAPTER)
MAY 1, 1987



Submitted by:
Andrew Bachler N9AB
Technical Writing Services
Motorola Inc.
1301 E. Algonquin Rd
Schaumburg, Illinois 60196

ABSTRACT

Previous amateur radio experiments from the space shuttle used 2 meter FM as the communications link. Advancing to UHF fast scan television is a much more challenging endeavor requiring from 35-50 dB of extra ERP to overcome the higher path losses and wider bandwidths. FM television can provide excellent television pictures at very modest carrier to noise levels. However; FM television also requires wider bandwidths, higher path losses, increased equipment complexity, and more stringent high power transmitting equipment; than the more common AM television on the 70 cm band.

1. PURPOSE:

To further the use of amateur radio on manned space missions by providing practical real time television communications. Amateur radio on the shuttle can *directly* touch several thousands of people with a live experience from space.

2. OBJECTIVES:

1. Television Uplink — Television sent to the shuttle from ground stations to be viewed by the crew and recorded on video tape. Can be unattended operation.

2. Television Downlink — Television sent from the shuttle to ground stations. Can be unattended operation.

3. 2-Way Television Exchange — Actual face to face communications between an orbiting astronaut and a ground station.

4. Duplex Communications — Television transmission (either uplink or downlink) while simultaneously receiving immediate feedback from a separate sound talkback channel.

3. LINK PARAMETERS

Link budget calculations were made using the following parameters:

3.1 Frequency: 70 cm, 33 cm, 23 cm. The 70 cm band is the lowest frequency which can be used for amateur television, while the 23 cm band is the highest frequency at which the required transmit power is readily available to the amateur community. FM television was not considered on the 70 cm band due to the wide bandwidth requirements.

3.2 Shuttle Antenna Gain: 0 dBi. Due to unknown spacecraft orientations, and expected antenna restrictions we chose 0 dBi. However, any antenna gain from the shuttle would greatly aid the links. If proper orientation can be expected for reasonable times, then antenna gains of approximately 4 dBi provide a very usable footprint. The JPL "drooping dipole" antenna is a consideration since it provides a useful pattern of approximately 4.5 dBi and it is circularly polarized. If dedicated astronaut time is expected, then a hand-held gain antenna could be pointed out a window at target stations.

3.3 Shuttle Antenna Temperature: 290 degrees K. The antenna temperature depends upon the placement and pattern of the antenna. We estimate that the antenna will essentially "see" the temperature of the earth.

3.4 Shuttle Receiver Temperature: 110 degrees K. The receiver temperature estimate is based on the use of a low noise high gain preamplifier, bandpass filter and intercabling losses. Line losses and preamplifier temperatures at the higher frequencies will increase, however filter requirements (and associated losses) will be less.

3.5 Shuttle Transmit Power: 10 Watts. Only low shuttle transmit power is expected. However, much higher levels can be easily achieved if allowed.

3.6 Ground Station Transmit Power: 1500 Watts (Peak)-70 cm, 500 Watts-33 cm, 250 Watts-23 cm. High transmit powers are required to provide the acceptable uplink performance. These levels are characteristic of "high power" amateur stations.

3.7 Ground Station Antenna Gain: 17 dBic. At these frequencies, antenna systems providing 17 dBi of circular polarization are easily achievable. *Higher gain antennas should be used only if the accuracy of the pointing and tracking system can accommodate the resultant narrower beamwidths.*

3.8 Ground Station Feedline Loss: 1 dB-70 cm, 1.8 dB-33 cm, 2 dB-23 cm. These losses are characteristic of available feedlines and jumper cables.

3.9 Ground Station Antenna Temperature: 75 degrees K. For all three bands the sky noise above 5 degrees of elevation will typically be under 20 degrees K. Thermal leakage from sidelobes should keep the equivalent antenna noise temperature under 75 degrees K.

3.10 Ground Station Receiver Temperature: 75 degrees K-70 cm, 100 degrees K-33 cm, 125 degrees K-23 cm. Low noise mast mounted preamplifiers are assumed.

3.11 VSB AM Bandwidth: 5 MHz. Typical i-f bandwidth of a modern consumer color television set is assumed.

3.12 Modulation Index: 1. A modulation index of 1 assures excellent quality video once the FM improvement carrier threshold is reached, while also providing a tolerable bandwidth.

3.13 FM Bandwidth: 20 MHz. Bandwidths narrower than Carson's rule approximation can be used with acceptable picture quality degradation. However, larger bandwidths are readily available with commercial TVRO receivers.

3.14 FM Full Improvement Threshold: 10 dB. Excellent picture quality will result through FM enhancement if at least 10 dB carrier to noise is maintained. Minimum picture quality is reached at approximately 7 dB carrier to noise.

3.15 Polarization Loss: 3dB. Assuming linear polarization on the shuttle, circular polarization on the ground results in a 3 dB loss regardless of the polarization of the received signal. Polarization losses of 20 dB or more can occur on cross polarized linear to linear and RHCP to LHCP transmissions.

3.16 Antenna Pointing Error: Uplink 3 dB, Downlink 1 dB. We estimate that the antenna pointing error can be kept to these values, except for high elevations near zenith, if a concentrated effort is made to minimize the following sources of error. (Fortunately, when antenna pointing error is most severe the path loss is near minimum.)

1. Calibration: This error is the actual offset from a true heading or elevation. Minimizing this error requires accurate determination of reference points such as true north and 0 degree

elevation. In addition, the entire antenna structure must be plumb to maintain accuracy for all directions and elevations. A reasonable goal for calibration error is +/- 2 degrees.

2. Resolution: Some popular commercially manufactured antenna rotating systems have readout indications of 5 degrees and nonlinearities as much as 10 degrees. For these cases a separate readout system should be constructed. A goal for resolution error is approximately +/- 2 degrees.

3. Tracking: The ability to move the antenna to match the position of the shuttle is a function of the slew-rates of the rotators and the relative motion of the spacecraft. At high elevations, most commercially available rotators lose the ability to keep up near zenith. Tracking errors can be very significant during these portions of a pass. In addition, many rotating systems have "stops" which occasionally require the need to go the "long way around".

4. Location: Due to orbital changes as part of the primary mission, the spacecraft is often not where the amateur's information predicts it to be. This appears to be mainly a problem of timing and not the apparent track in the sky. If timing is off by as little as 15 to 20 seconds, pointing errors near zenith of 30 to 60 degrees can result. The use of a beacon and more up to date Keplerian data from NASA would tend to minimize this error.

3.17 Blockage, Margin, Etc. Error: 3 dB. A carrier to noise margin is necessary to compensate for miscellaneous and variable link losses. A nominal value of 3 dB appears to be a reasonable estimate.

4. EQUATIONS

The carrier to noise equation used (in dB) is:

$$C/N = 10 \log P + 136.15 - 20 \log F - 20 \log D + GS + GG$$
$$- 10 \log (TE+TR) - 10 \log BW - LF - PE - PL - ML$$

where

P is peak power in watts
F is frequency in gigahertz
D is slant range in kilometers
GS is shuttle antenna gain in dB
GG is ground station antenna gain in dB
TE is effective noise temperature of receive antenna (including feedline)
TR is noise temperature of receiver
BW is receiver noise bandwidth in Hz
LF is transmit station line loss in dB
PE is pointing error in dB
PL is polarization loss in dB
ML is margin loss in dB

4.1 The weighted video signal (p-p) to noise (rms) ratio for a vestigial sideband AM system is the sum of the carrier to noise ratio, AM noise weighting factor, and p-p/rms conversion factor; minus the downward modulation factor, 87.5 % modulation factor, and 100/140 IRE picture factor. In dB this is stated as:

$$S/N_{(p\text{-}p/rms)} = C/N_{(rms/rms)} + 10.3 + 9 - 6 - 1.2 - 2.9$$

$$= C/N_{(rms/rms)} + 9.2$$

where

- 10.3 dB is the noise weighting factor for AM
- 9 dB is the rms/rms to p-p/rms conversion factor
- 6 dB is the downward modulation loss
- 1.2 dB is the 87.5 % modulation loss
- 2.9 dB is the 100/140 IRE ratio loss

4.2 The weighted video signal (p-p) to noise (rms) ratio for an FM system (above the FM threshold) is the sum of the carrier to noise ratio, the FM improvement, bandwidth correction factor, the emphasis improvement, the FM noise weighting, and the p-p/rms conversion factor. In dB this is stated as:

$$S/N_{(p\text{-}p/rms)} = C/N_{(rms/rms)} + 10 \log 3(.714\ fpk/fm)^2$$

$$+ 10 \log BW/2fm + 12.9 + 12.8 + 9$$

where

- $10 \log 3(.714\ fpk/fm)^2$ is the FM improvement for the luminance signal
- 10 log BW/2fm is the bandwidth correction factor
- 12.9 dB is the emphasis improvement
- 12.8 dB is the noise weighting factor for FM
- 9 dB is the rms/rms to p-p/rms conversion factor

and where

- 0.714 is the ratio of the video component to the peak composite signal
- fpk is the peak deviation of the FM carrier (MHz)
- fm is is the maximum frequency of the baseband (4.2 MHz)
- BW is the receiver bandwidth (MHz)

5. CALCULATIONS AND GRAPHS FOR TYPICAL LINK PARAMETERS

Tables 1-4 provide calculated weighted video signal (p-p) /noise (rms) ratios for typical slant ranges, using the indicated link parameters. Figure 1 compares the relative performance of these calculations.

6. OTHER CONSIDERATIONS

6.1 Narrow Band FM Of Video Carrier: In AM systems the transmitted carrier can be narrowband frequency modulated (+/- 5 KHz deviation) and monitored with a separate narrow bandwidth receiver to provide an audio channel with a 20-25 dB carrier to noise improvement over the wideband video transmission.

6.2 Frequencies Of Operation: The precise operating frequencies should be coordinated through AMSAT and ARRL. If duplex operation is anticipated, then harmonic related frequencies must be avoided.

Table 1. 70 cm Vestigial Sideband AM Uplink

ENTER FREQUENCY, GHZ:	0.439
ENTER BANDWIDTH, MHZ:	5
PEAK POWER WATTS:	1500
FEEDLINE LOSS, DB:	1
GND STN ANTENNA GAIN, DBI:	17
SHUTTLE ANTENNA GAIN, DBI(0):	0
POINTING ERROR, (3 DB):	3
POLARIZATION LOSS, (3 DB):	3
MARGIN LOSS, (3 DB):	3
EXTERNAL TEMP, TE:	290
RECEIVER TEMP, TR:	110
MODULATION INDEX (0 FOR AM):	0

DISTANCE KM	WEIGHTED SIGNAL/NOISE RATIO DB	
300	48.7	**P5 EXCELLENT**
400	46.2	
500	44.3	
600	42.7	
700	41.3	
800	40.2	
900	39.2	
1000	38.3	
1100	37.4	
1200	36.7	
1300	36.0	
1400	35.3	
1500	34.7	
1600	34.2	
1700	33.6	**P4 GOOD**
1800	33.1	
1900	32.7	
2000	32.2	

Table 2. 33 cm FM Uplink

ENTER FREQUENCY, GHZ:	0.910
ENTER BANDWIDTH, MHZ:	20
PEAK POWER WATTS:	500
FEEDLINE LOSS, DB:	1.8
GND STN ANTENNA GAIN, DBI:	17
SHUTTLE ANTENNA GAIN, DBI(0):	0
POINTING ERROR, (3 DB):	3
POLARIZATION LOSS, (3 DB):	3
MARGIN LOSS, (3 DB):	3
EXTERNAL TEMP, TE:	290
RECEIVER TEMP, TR:	110
MODULATION INDEX (0 FOR AM):	1
FM THRESHOLD, TH DB:	10

DISTANCE KM	WEIGHTED SIGNAL/NOISE RATIO DB	
300	61.9	P5 EXCELLENT
400	59.4	
500	57.5	
600	55.9	
700	54.5	
800	53.4	
900	52.4	
1000	51.4	
1100	50.6	
1200	45.6	
1300	38.7	
1400	32.5	P4 GOOD
1500	27.1	P3 FAIR
1600	22.2	
1700	17.8	P2 POOR
1800	13.8	P1
1900	10.2	
2000	6.9	

Table 3. 23 cm FM Uplink

ENTER FREQUENCY, GHZ:	1.2
ENTER BANDWIDTH, MHZ:	20
PEAK POWER WATTS:	250
FEEDLINE LOSS, DB:	2
GND STN ANTENNA GAIN, DBI:	17
SHUTTLE ANTENNA GAIN, DBI(0):	0
POINTING ERROR, (3 DB):	3
POLARIZATION LOSS, (3 DB):	3
MARGIN LOSS, (3 DB):	3
EXTERNAL TEMP, TE:	290
RECEIVER TEMP, TR:	110
MODULATION INDEX (0 FOR AM):	1
FM THRESHOLD, TH DB:	10

DISTANCE KM	WEIGHTED SIGNAL/NOISE RATIO DB	
300	56.3	P5 EXCELLENT
400	53.8	
500	51.8	
600	49.8	
700	36.4	
800	25.7	P3 FAIR
900	17.1	P2 POOR
1000	9.9	P1
1100	3.9	P0

CARRIER MORE THAN 3 DB BELOW MINIMUM NOISE THRESHOLD

Table 4. 70 cm Vestigial Sideband AM Downlink

ENTER FREQUENCY, GHZ:	0.435
ENTER BANDWIDTH, MHZ:	5
PEAK POWER WATTS:	10
FEEDLINE LOSS, DB:	0.5
GND STN ANTENNA GAIN, DBI:	17
SHUTTLE ANTENNA GAIN, DBI(0):	0
POINTING ERROR, (3 DB):	1
POLARIZATION LOSS, (3 DB):	3
MARGIN LOSS, (3 DB):	3
EXTERNAL TEMP, TE:	75
RECEIVER TEMP, TR:	75
MODULATION INDEX (0 FOR AM):	0

DISTANCE KM	WEIGHTED SIGNAL/NOISE RATIO DB	
300	33.8	**P4 GOOD**
400	31.3	
500	29.4	
600	27.8	**P3 FAIR**
700	26.4	
800	25.3	
900	24.2	
1000	23.3	
1100	22.5	
1200	21.7	**P2 POOR**
1300	21.1	
1400	20.4	
1500	19.8	
1600	19.2	
1700	18.7	
1800	18.2	
1900	17.8	
2000	17.3	

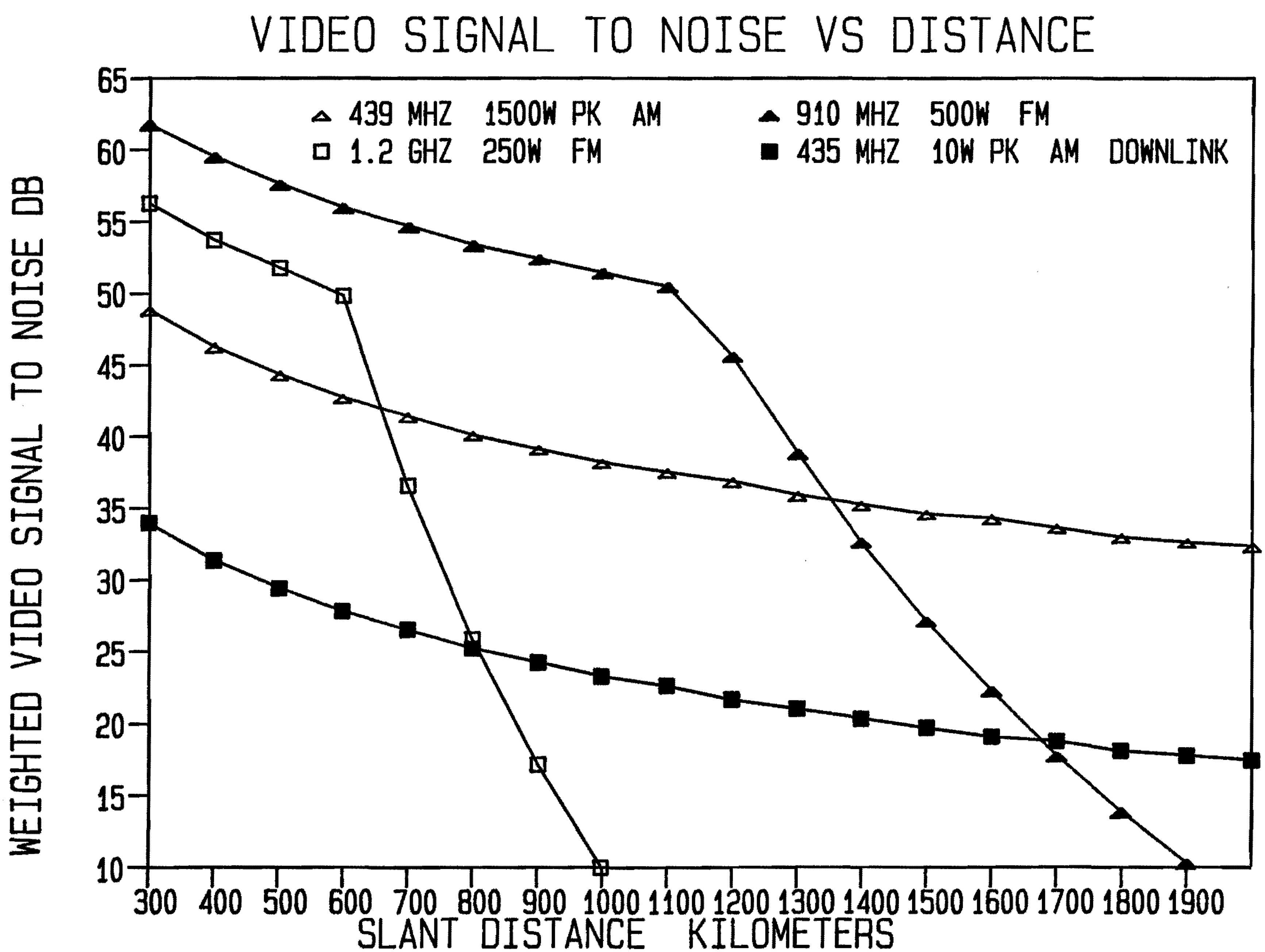


Figure 1. Calculated Weighted Video Signal to Noise for Typical Distances

6.3 Duplex Operation: Full duplex operation (simultaneous transmission and reception using different frequencies) is a very efficient and desirable means of communications. UHF video transmissions and a separate 2 meter FM talkback channel is recommended.

6.4 Operating Procedures: Well publicized operating procedures must be chosen to reduce uplink interference and increase communications efficiency. Possible uplink operating procedures include:

1. Scheduled calls only
2. Selective geographical areas only
3. Selective call sign prefixes (or suffixes) only
4. Time limit for each station's uplink transmission
5. Use of antenna windows, which allows the shuttle to pass through the beamwidth of a fixed positioned antenna.

Local areas can coordinate their own specific times and sky antenna pointing windows for participating nearby stations.

6.5 Power Consumption: Approximate power requirements are:

RECEIVE MODE	WATTS	TRANSMIT MODE	WATTS
television set	3	video monitor (if used)	3
video recorder	5	video camera	3
misc. (preamplifier, sync detect, separate FM rec, video buffers, etc.)	1	transmitter	25
		misc. (ID generator, etc.)	1
total	**9**	**total**	**32**

6.6 Video Recorder: A small portable video recorder is essential to document uplink communications. If a video downlink is planned then an 8 mm camcorder is a possibility. It is recommended that the recorder be automatically enabled upon reception of signal carrier in coincidence with synchronization pulses.

6.7 Television Set/Video Monitor: A small lightweight portable television set is required to view uplink transmissions. Video and audio outputs are required to drive the recorder (and any other video monitors). A video input can be used to monitor detected transmitted video during downlinks. If FM is used, then a separate receiver is required. If AM is used, then the television should be crystal controlled on the desired frequency. A television set which can receive cable television channel 60 can directly be used to receive standard 439.250 MHz amateur television. A separate low noise GaAS fet preamplifier and bandpass filter should be located as close as possible to the antenna. In AM systems, a power splitter (after the preamplifier and filter) can route receive signals to the television set and to a separate narrow bandwidth FM carrier receiver if used.

6.8 International Video Standards: Several incompatible international television standards are in use. It is desirable that the single shuttle station be able to respond to more than one standard.

6.9 Video Quality Levels: Numerous studies and recommendations are available which describe picture quality for various commercial services. However, since this is an amateur radio operation, we chose to use the accepted amateur picture quality reporting system. Figure 2 shows examples of this five grade amateur system for AM television. In FM television, "sparklies" start to occur at approximately 40 dB weighted S/N, and as a result the picture degrades much more rapidly then AM television which is impaired only by "snow".

6.10 Expected Participation By Radio Amateurs: Only a small percentage of the radio amateur population is involved in fast scan amateur television. The participation shrinks even more due to the power level requirements. At present, FM television on the higher frequencies, using high power is extremely rare. However, several stations can quickly be established or upgraded to meet ground station amateur television requirements. Downlink participation (especially on 70 cm) is easy to implement and should be relatively widespread.

6.11 Rules and Regulations: The following three concerns involve the Amateur-Satellite Service rules and regulations:

1. Frequencies available. (Part 97.415) Downlink transmissions from the shuttle are allowed only on one of the three frequency bands of interest (435- 438 MHz). However, the available bandwidth on this satellite subband is insufficient for normal fast scan television. A waiver to extend the bandwidth is required.

2. Earth operation. (Part 97.403) No limitations apply to television uplink transmissions since signals from the ground stations will not automatically be retransmitted back to earth.

3. Notification required. (Part 97.423) Various FCC notifications are required concerning space operation.

6.12 Other Modes Of Operation (SSTV, Packet, 2 MTR FM): Fast scan television operation should be supplemented with two meter FM voice operation. Packet radio operation (using separate uplink and downlink frequencies) would serve as a useful beacon, while allowing widespread participation by the amateur radio community. SSTV operation is not recommended, in order to concentrate on fast scan television.

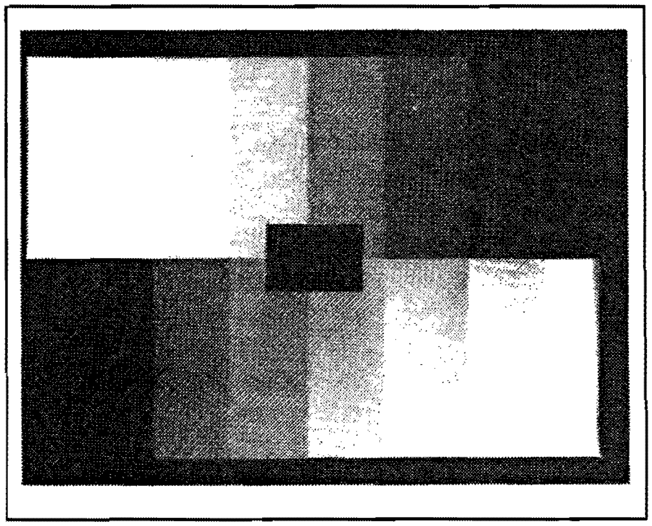
6.13 Use of Ground Command Stations: During unattended operation, designated ground command stations can select modes of operation, video standards, etc. Ground command stations must abide by the Amateur Satellite Service rules and regulations.

6.14 Beacon (Unattended Operation): Since only limited astronaut time is expected, it is extremely desirable to have some form of unattended or beacon operation. This increases the amount of recorded data, and a downlink transmission provides verification of tracking methods. Beacon operation can be a fast scan downlink, packet radio operation, sequenced uplinks and downlinks etc.

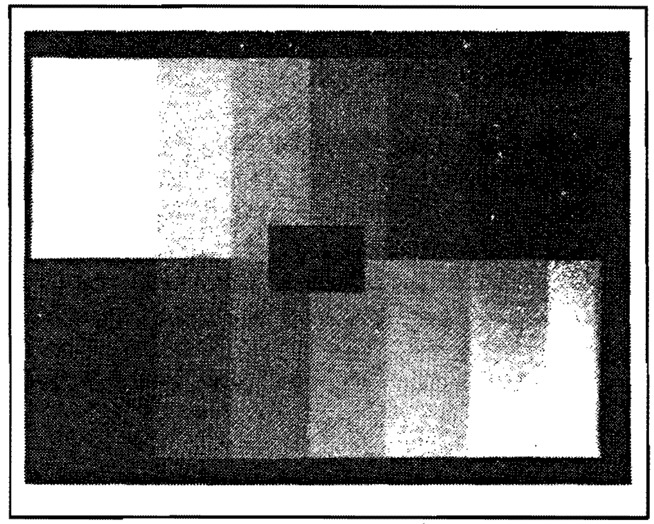
6.15 Coverage Area Reduction By Square Of Radius: Since the coverage area is proportional to the square of the range, it is imperative that the usable range of the television link be maximized.

6.16 Orbit Parameters: Current Keplerian elements must be available to assure accurate tracking with the required antenna beamwidths.

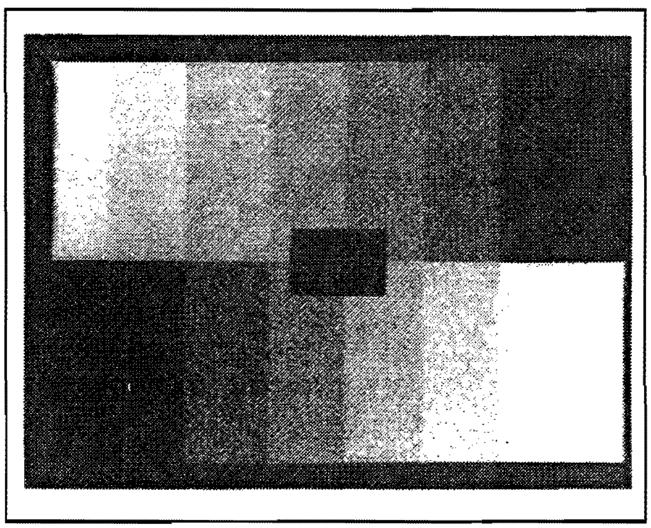
6.17 Television Audio: Some form of television audio must be used to fulfill the desired duplex operation. In FM systems, a standard 6.2 or 6.8 MHz subcarrier can be used. In AM systems, the normal 4.5 MHz +/-25 KHz FM subcarrier can be used, the video carrier can be modulated +/-5 KHz, or both.



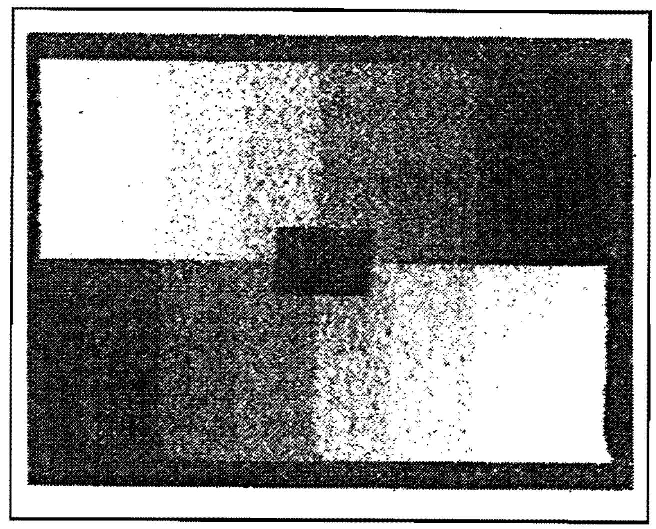
P5 Excellent
(34 dB)



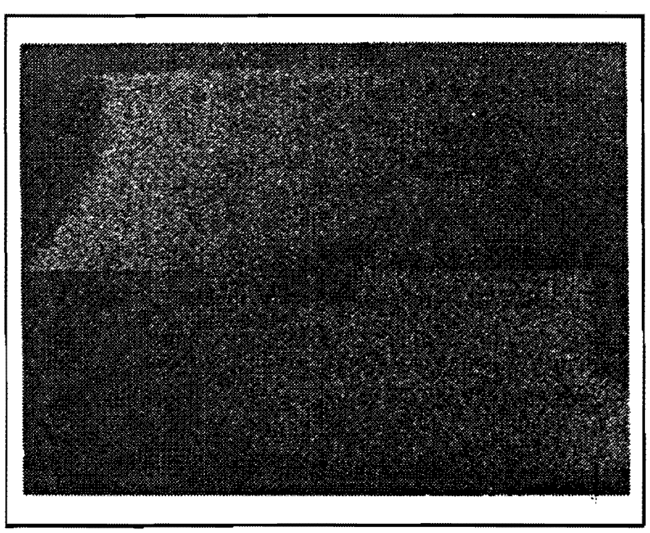
P4 Good
(28 dB)



P3 Fair
(22 dB)



P2 Poor
(16 dB)



P1 Barely Perceptible
(10 dB)

Figure 2. Typical Amateur Picture Quality Reporting System

7. COMPARISON WITH ART ANZIC (NASA — LEWIS RESEARCH CENTER) PROPOSAL

This proposal acknowledges the work done by Art Anzic of the NASA Lewis Research Center on his pioneering "PROPOSED FAST-SCAN TV EXPERIMENT FOR SAREX A". The following lists link parameters which differ between the two proposals:

7.1 Shuttle Antenna Gain: We chose to reduce the antenna gain from the shuttle from 3 dBi to 0 dBi. Although this may seem rather insignificant it can be a very important factor on FM systems which do not maintain threshold during the entire pass. If antenna gain is used, then the link calculations must respond to the resulting footprint, and the shuttle antenna receive temperature must increase.

7.2 Minimum Acceptable Video S/N: Amateur applications can tolerate video signal to noise ratios much lower than 35 dB on AM television systems. Since this is a very subjective topic we prefer to use the customary amateur television picture quality reporting system. In addition, a video recording of expected results was produced and is available for evaluation of picture quality.

PICTURE QUALITY LEVEL	APPROXIMATE WEIGHTED S/N
P1 Barely perceptible	10 dB
P2 Poor	16 dB
P3 Fair	22 dB
P4 Good	28 dB
P5 Excellent	34 dB

7.3 Pointing, Polarization, Blockage, Margin Errors: These errors can be extremely significant and can easily reduce the FM threshold coverage area by a factor greater than 8. Loss between linear and circular polarization is 3 dB. Blockage and pointing errors are not easily defined and are dependent upon variables such as:

1. Availability and accuracy of automatic tracking facilities
2. Accuracy of Keplerian elements
3. Antenna beamwidth
4. Rate of change of the target
5. Shuttle antenna pattern
6. Shuttle orientation

Pointing errors on a downlink should be less than on an uplink due to the immediate visual feedback.

7.4 Ground Station Antenna Gain and Line Loss: Usable antenna gain is limited by the ability to track the fast moving target. Therefore link comparisons between different frequencies must use the same maximum ground station antenna gain. A practical limit is approximately 17 dBi which corresponds to a beamwidth of approximately 28 degrees. Similarly, line loss comparisons must be based on using the same type of line regardless of the increased losses suffered at the higher frequencies.

7.5 Receiver Noise Figure: The total receiver noise figure is the sum of the equivalent antenna temperature, feedline noise temperature, bandpass filter noise temperature, and the actual receiver noise temperature converted to dB. Practical numbers vary slightly between different frequency bands. A substantial advantage exists on a downlink due to the the ground station's lower antenna temperature and a much less stringent bandpass filter requirement.

7.6 FM Improvement: Very substantial signal to noise improvement can be experienced on FM systems once the carrier to noise threshold is maintained. However, below this minimum threshold, the signal to noise ratio degrades much more rapidly than in an AM system. The signal to noise (p-p/rms) FM improvement is a function of the modulation index, bandwidth correction factor, pre-emphasis, and p-p/rms conversion factor. For a modulation index of 1, Art Anzic used an improvement of 13.8 dB (emphasis was not included). Our total non-weighted improvement is 27.3 dB.

7.7 Video Noise Weighting: Objective instrument measurements use noise weighting circuits to simulate subjective results with human observers. Video noise weighting applies to video transmitted by either AM or FM systems. However, due to electrical characteristics of the de-emphasis circuits used in FM systems, the weighting factors differ slightly. Art Anzic used a weighting factor of 10.2 dB, but applied it only to FM systems. We chose 10.3 dB for AM systems and 12.8 dB for FM systems.

7.8 rms/rms to p-p/rms Conversion: The FM improvement factor used in Art Anzic's proposal converts the video signal to noise value from an rms/rms ratio into a p-p/rms ratio. However, a similar conversion was not made in the AM systems. We added a common rms/rms to p-p/rms correction factor of 9 dB to both systems.

8. ADDITIONAL REFERENCE MATERIAL

8.1 Computer Program

All link calculations were made using a simple BASIC program. The program first calculates carrier to noise, for typical slant ranges, and then converts this value into a predicted weighted video signal to noise (p-p/rms) ratio for either an AM or FM transmission. The link parameters are easily customized for individual stations. Table 5 is a listing of this program.

8.2 Video Tape

A VHS video tape is available which simulates the expected television results for a typical "good" shuttle pass for the following conditions:

1. High Power 23 cm FM Uplink
2. High Power 33 cm FM Uplink
3. High Power 70 cm Vestigial Sideband AM Uplink
4. Low Power 70 cm Vestigial Sideband AM Downlink

The video tape also illustrates the amateur television picture quality reporting system.

9. CONCLUSIONS

9.1 Amateur Television Uplink Is Possible

A successful amateur television uplink to the space shuttle can be accomplished on any of the three bands investigated. However, the degree of success varies greatly as illustrated in figure 3 and discussed in the following:

Table 5. BASIC Computer Program Listing

```
10 '*********************************************************************
20 '  THIS PROGRAM CALCULATES WEIGHTED VIDEO S/N FOR TYPICAL SHUTTLE
30 '  SLANT DISTANCES.  LINK PARAMENTERS ARE USER CHOSEN.
40 '  WRITTEN IN GW-BASIC FOR IBM-PC OR MS-DOS COMPATIBLE COMPUTERS
50 '
60 '* *(USE BASICA ON IBM-PC TO PREVENT ERRORS IN GRAPHICS ROUTINES)* *
70 '
80 '  BY DON BEASON AND ANDY BACHLER                               4/22/87
90 '*********************************************************************
100 '
110 '
120 DIM HOR(20),VER(20),X(20),Y(20)
130 CLS:LOCATE 5,1:KEY OFF
140 LOG10E=.434294482#
150 DEF FNLOG10(V)=LOG(V)*LOG10E
160 INPUT" ENTER FREQUENCY, GHZ:        ",F
170 INPUT" ENTER BANDWIDTH, MHZ:        ",B
180 INPUT" PEAK POWER WATTS:            ",P
190 INPUT" FEEDLINE LOSS, DB:           ",LF
200 INPUT" GND STN ANTENNA GAIN, DBI:   ",GG
210 INPUT" SHUTTLE ANTENNA GAIN, DBI(0):",GS
220 INPUT" POINTING ERROR, (3 DB):      ",PE
230 INPUT" POLARIZATION LOSS, (3DB):    ",PL
240 INPUT" MARGIN LOSS, (3DB):          ",ML
250 INPUT" EXTERNAL TEMP, TE:           ",TE
260 INPUT" RECEIVER TEMP, TR:           ",TR
270 INPUT" MODULATION INDEX (0 FOR AM):  ",M
280 IF M=0 THEN GOTO 300
290 INPUT" FM THRESHOLD,TH DB:           ",TH
300 GOSUB 610
310 PRINT"DISTANCE KM", "WEIGHTED SIGNAL/NOISE RATIO DB"
320 C=0
330 FOR D=300 TO 2000 STEP 100
340     C=C+1
350     CN=(10*FNLOG10(P)) + 136.15 -(20*FNLOG10(F)) - (20*FNLOG10(D))+ GG + GS
        -(10*FNLOG10(TE+TR)) - (10*FNLOG10(B*1000000!)) - LF -PE -PL -ML
        'CALCULATES C/N
360     IF M=0 THEN SN=CN+10.3 +9 -6 -1.2 -2.9 :GOTO 430 'CALCULATES AM S/N
370     FM=(10*FNLOG10(3*(.714*M)^2)) + 10*FNLOG10(B/8.399999) 'FM IMPROVEMENT
        AND BANDWIDTH CORRECTION FACTOR
380     IF CN>TH THEN 390  ELSE 400
390     SN=CN+FM+12.9:GOTO 410 'EMPHASIS IMPROVEMENT
400     IF CN<=TH THEN SN=(CN+FM+12.9) -((CN+FM+12.9)/3) * (TH-CN) 'REDUCES S/N
        WHEN C/N IS BELOW FULL THRESHOLD.
410     SN=SN+12.8+9 'ADDS FM WEIGHTING AND P-P/RMS CONVERSION
420     IF CN < TH-6 THEN PRINT " CARRIER MORE THAN 3 DB BELOW MINIMUM NOISE
        THRESHOLD" :GOTO 470
430     PRINT D,
440     HOR(C)=D:VER(C)=SN:X(C)=90+INT(D*.264):Y(C)=162-INT(SN*2.4)
450     PRINT USING"##.#";SN
460 NEXT D
470 LOCATE 22,7:LINE INPUT;"DO YOU WANT TO SEE A GRAPHIC REPRESENTATION OF THESE
    VALUES?__";Q$
480 IF LEFT$(Q$,1)="N" OR LEFT$(Q$,1)="n" THEN GOTO 500
```

Table 5. BASIC Computer Program Listing (Cont'd.)

```
490 GOSUB 970
500 LOCATE 22,60:PRINT"                    "
510 LOCATE 10,7:PRINT"SELECT OPERATION (1-3)"
520 LOCATE 13,9:PRINT"1  MODIFY EXISTING PARAMETERS"
530 LOCATE 15,9:PRINT"2  ENTER ALL NEW PARAMETERS"
540 LOCATE 17,9:PRINT"3  EXIT THE PROGRAM"
550 Q=0
560 LOCATE 20,11:INPUT "YOUR CHOICE__";Q
570 IF Q<1 OR Q>3 THEN BEEP:LOCATE 20,24:PRINT"     ":GOTO 550
580 IF Q=1 THEN GOTO 300
590 IF Q=2 THEN GOTO 130
600 END
610 'subroutine for verifying entries and corrections
620 CLS
630 LOCATE 3,10:PRINT"your parameters are...:":PRINT
640 PRINT"    1 FREQUENCY                  :";F;" GHz"
650 PRINT"    2 BANDWIDTH                  :";B;" MHz"
660 PRINT"    3 PEAK POWER                 :";P;" WATTS"
670 PRINT"    4 FEEDLINE LOSS              :";LF;" DB"
680 PRINT"    5 GND STN ANTENNA GAIN       :";GG;" DBI"
690 PRINT"    6 SHUTTLE ANTENNA GAIN       :";GS;" DBI"
700 PRINT"    7 POINTING ERROR, (3 DB)     :";PE;" DB"
710 PRINT"    8 POLARIZATION LOSS, (3DB)   :";PL;" DB"
720 PRINT"    9 MARGIN LOSS, (3DB)         :";ML;" DB"
730 PRINT"   10 EXTERNAL TEMP, TE          :";TE;" K"
740 PRINT"   11 RECEIVER TEMP, TR          :";TR;" K"
750 PRINT"   12 MODULATION INDEX (0 FOR AM):";M
760 IF M=0 THEN GOTO 780
770 PRINT"   13 FM THRESHOLD, TH           :";TH;" DB"
780 LOCATE 20,7:LINE INPUT;"DO YOU WANT TO CHANGE ANY PARAMETERS?(Y/N)__";Q$
790 IF LEFT$(Q$,1)="N" OR LEFT$(Q$,1)="n" THEN GOTO 960
800 LOCATE 22,7:INPUT;"WHICH PARAMETER (USE NUMBER 1-13)__";WO
810 IF WO<1 OR WO>13 THEN BEEP: LOCATE 22,44:PRINT"    ":GOTO 800
820 PRINT:LOCATE 24,7
830 IF WO=1 THEN INPUT" ENTER NEW FREQUENCY, GHZ:        ",F:GOTO 620
840 IF WO=2 THEN INPUT" ENTER NEW BANDWIDTH, MHZ:        ",B:GOTO 620
850 IF WO=3 THEN INPUT" NEW PEAK POWER WATTS:            ",P:GOTO 620
860 IF WO=4 THEN INPUT" NEW FEEDLINE LOSS, DB:           ",LF:GOTO 620
870 IF WO=5 THEN INPUT" NEW GND STN ANTENNA GAIN, DBI:   ",GG:GOTO 620
880 IF WO=6 THEN INPUT" NEW SHUTTLE ANTENNA GAIN, DBI(0):",GS:GOTO 620
890 IF WO=7 THEN INPUT" NEW POINTING ERROR, (3 DB):      ",PE:GOTO 620
900 IF WO=8 THEN INPUT" NEW POLARIZATION LOSS, (3DB):    ",PL:GOTO 620
910 IF WO=9 THEN INPUT" NEW MARGIN LOSS, (3DB):          ",ML:GOTO 620
920 IF WO=10 THEN INPUT" NEW EXTERNAL TEMP, TE:           ",TE:GOTO 620
930 IF WO=11 THEN INPUT" NEW RECEIVER TEMP, TR:           ",TR:GOTO 620
940 IF WO=12 THEN INPUT" NEW MODULATION INDEX (0 FOR AM):  ",M:GOTO 620
950 IF WO=13 THEN INPUT" NEW FM THRESHOLD,TH DB:            ",TH:GOTO 620
960 CLS:RETURN
970 'GRAPHING ROUTINE
980 SCREEN 2
990 KEY OFF
1000 CLS
1010 LINE (90,10)-(90,170)
1020 LINE (90,170)-(620,170)
```

```
1030 FOR I= 170 TO 20 STEP -24
1040    LINE (87,I)-(93,I)
1050 NEXT
1060 LOCATE 4,8:PRINT"60"
1070 LOCATE 7,8:PRINT"50"
1080 LOCATE 10,8:PRINT"40"
1090 LOCATE 13,8:PRINT"30"
1100 LOCATE 16,8:PRINT"20"
1110 LOCATE 19,8:PRINT"10"
1120 LOCATE 12,2:PRINT"VIDEO"
1130 LOCATE 13,2:PRINT"S/N"
1140 LOCATE 14,2:PRINT"dB"
1150 FOR I= 90 TO 620 STEP 132
1160    LINE (I,168)-(I,172)
1170 NEXT
1180 LOCATE 23,27:PRINT"500"
1190 LOCATE 23,43:PRINT"1000"
1200 LOCATE 23,60:PRINT"1500"
1210 LOCATE 23,76:PRINT"2000"
1220 LOCATE 24,38:PRINT"DISTANCE (KM)"
1230 FOR I=1 TO C-1
1240    PSET (X(I),Y(I)):CIRCLE STEP (0,0),4
1250    IF I=1 THEN GOTO 1270
1260    LINE (X(I-1),Y(I-1))-(X(I),Y(I))
1270 NEXT I
1280 LOCATE 25,5:LINE INPUT"HIT <ENTER> TO CONTINUE";Q$
1290 CLS
1300 SCREEN 0
1310 RETURN
```

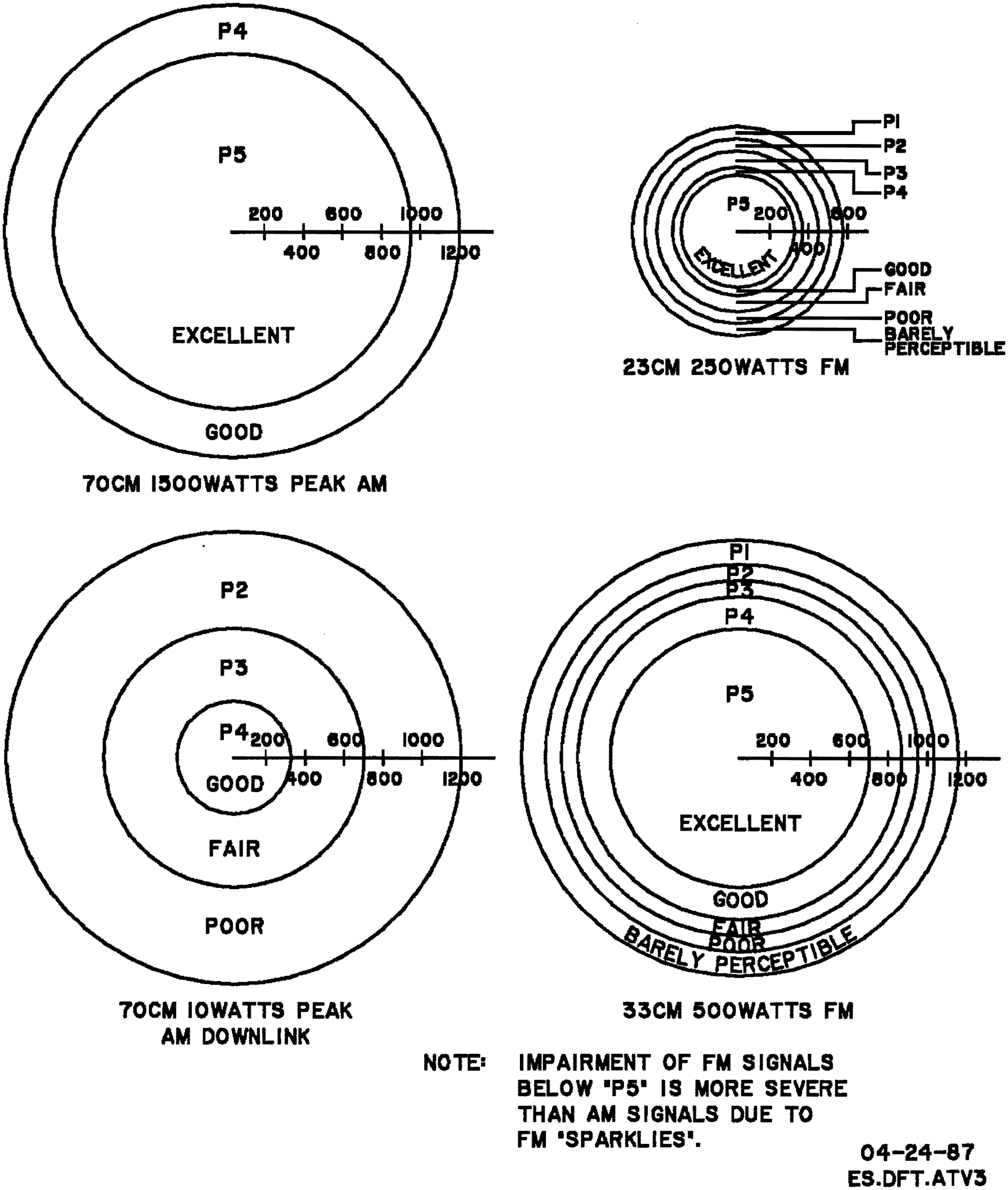


Figure 3. Typical Map Ranges (Statute Miles)
Altitude = 200 Miles

4-23-87

- 23 cm FM: Although some success is possible, 1.2 GHz FM is absolutely the worst choice for an uplink. The propagation losses are the highest, transmit power is the most difficult to obtain, and the bandwidth requirements are severe. Even with the capabilities of a well equipped "high power" amateur station, the signal can not maintain threshold for more than about 1/3 of an overhead pass. This reduces the usable coverage to approximately 1/9 of the area "seen" by the shuttle.

- 33 cm FM: This band is substantially better than 23 cm, due to approximately 3 dB less propagation loss and the addition of 3 dB of available transmit output power. Excellent ("sparklie" free) pictures can be expected for more than 60 % of an overhead pass, and the corresponding coverage is approximately 37% of the total possible area. However, the system is very vulnerable and fails to maintain threshold for the entire pass. At present, stations meeting the necessary requirements for this band are probably non-existant.

- 70 cm AM: Standard AM television on this band is definitely the best choice for an uplink to the space shuttle. *It is the only system which is designed not to fail during part of each pass.* Available "high power" stations can provide excellent pictures for 80% of an overhead pass and good pictures at the extreme ranges. Modest stations can provide excellent to fair pictures for entire passes. Required equipment is less complex and readily available. Numerous stations are now available which can meet the requirements for a successful uplink to the shuttle using 70 cm AM television.

9.2 Television Downlink Is Possible

Only 70 cm can provide television downlink from the shuttle. Usable pictures (refer to figure 4), with only 10 watts of peak power from the shuttle, are possible for each entire pass. Additional power linearly improves the picture quality. Widespread participation using this mode is expected. Narrowband frequency modulation of the picture carrier can provide an effective auxiliary audio downlink channel which can be received with very modest systems.

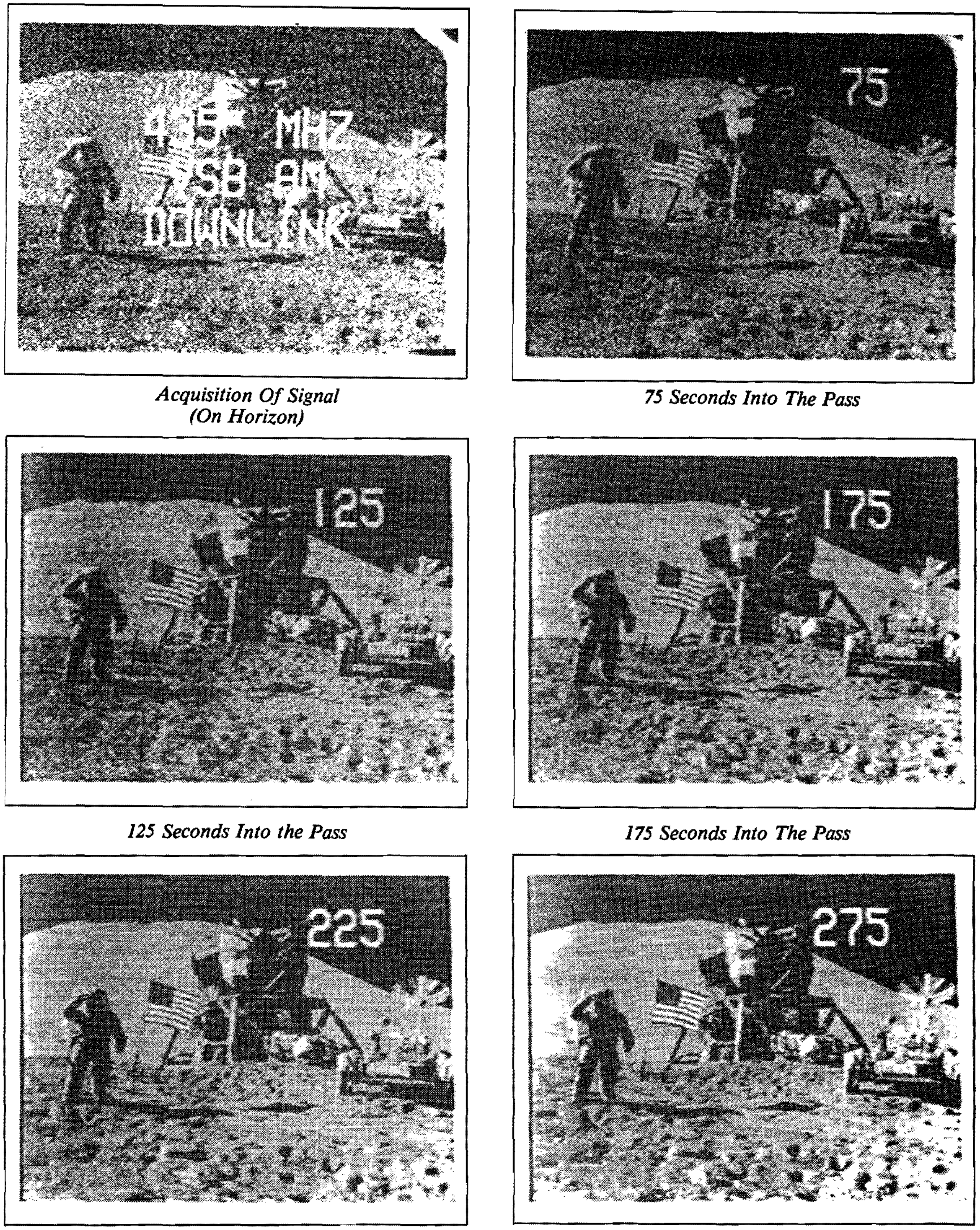
9.3 Equipment Requirements and Availability

FM systems on 23 and 33 cm must be able to achieve the continuous duty ERP used in the uplink calculations in order to reach FM threshold and provide any reasonable success. The requirements using 70 cm AM are much less severe. Peak effective radiated powers much less than the recommendations can be used, however, the picture quality will degrade correspondingly. Amateur television stations on 23 and 33 cm are much less common than stations on 70 cm. In the United States, amateur FM television is exceedingly rare.

10. RECOMMENDATIONS

We strongly recommend the following:

- **70 cm AM television uplink on "standard" amateur TV frequencies.** Publicized recommended operating procedures and separate downlink audio will eliminate interference during "demonstration" contacts. Only a small selective and sensitive television set is required on the shuttle. However, a portable video recorder allowing some unattended operation and documentation of the received pictures should be included. If only extremely limited participation is desired, then 33 cm FM uplink should be considered. An uplink on 23 cm should be avoided due to its very high potential for failure.



Acquisition Of Signal (On Horizon)

75 Seconds Into The Pass

125 Seconds Into the Pass

175 Seconds Into The Pass

225 Seconds Into The Pass

275 Seconds Into The Pass (Near Zenith)

Figure 4. Simulated 70 cm AM Downlink Picture Quality (Photograph Courtesy of NASA)

4-23-87

- **70 cm AM television downlink.** Since very usable pictures can easily be received during an entire pass, a 70 cm downlink should be used to allow widespread participation in the fast scan television experiment. The use of a downlink also allows the demonstration of a 2-way fast scan television exchange. Basically, a video camera and a simple interface box to the space qualified Motorola® UHF MX300™ Handie-Talkie® is all that is required on the shuttle. (Refer to figure 5.)

- **2 meter FM capability.** Retention of the 2 meter link ensures very widespread participation in the mission, allows other modes of operation such as two-way voice exchanges and packet radio, and enables duplex operation with a television transmission and a simultaneous audio talkback.

11. SUMMARY

Amateur fast scan television can be sent to and received from an orbiting space shuttle. Conventional vestigial sideband AM television on 70 cm is absolutely the best choice for this communications link. Higher propagation losses, wider bandwidths requirements, and practical transmit power limitations associated with FM television on 23 and 33 cm dictates a large degree of failure and should be avoided.

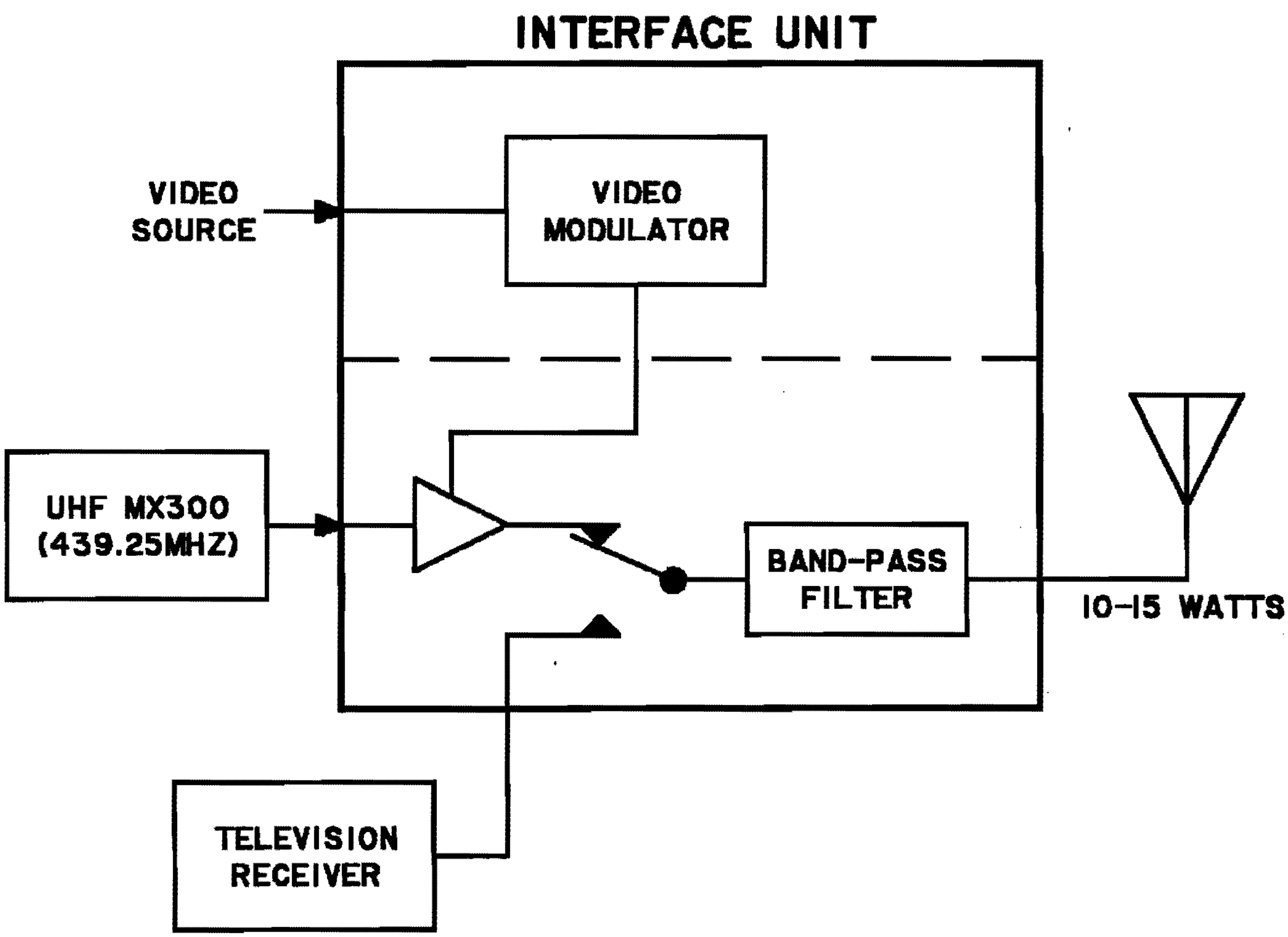


Figure 5. Fast Scan Amateur Television (ATV) System

FAST SCAN AMATEUR TELEVISION FOR THE SPACE SHUTTLE

EXPERIMENTAL DATA SUPPLEMENT

Submitted by:
Andrew Bachler N9AB
Motorola Amateur Radio Club
September 10, 1987

1. INTRODUCTION

In May 1987, the proposal **FAST SCAN AMATEUR TELEVISION FOR THE SPACE SHUTTLE** was distributed. The proposal consists of a written document, a supplemental software program, and a supplemental video tape. Practical experimental data is now available which verifies and reinforces calculations and conclusions in the proposal.

On August 15, 1987 a high altitude helium balloon was launched by Bill Brown, WB8ELK. The payload on this balloon included a 100 mW 2 meter FM beacon transmitter and an amplitude modulated 1 Watt ATV transmitter operating on 439.25 MHz. The video input to the television transmitter consisted of two computer generated graphics scenes. During the ascent of the balloon, geometric line-of-sight reached 250 statute miles and free space propagation critera was achieved.

Supplement Table 1. Predicted Results Using Calculations in Proposal

ENTER FREQUENCY, GHZ:	0.439
ENTER BANDWIDTH, MHZ:	5
PEAK POWER WATTS:	1
FEEDLINE LOSS, DB:	0.25
GND STN ANTENNA GAIN, DBI:	20
BALLOON ANTENNA GAIN, DBI(0):	2.1
POINTING ERROR, (3 DB):	1
POLARIZATION LOSS, (3 DB):	3
MARGIN LOSS, (3 DB):	3
EXTERNAL TEMP, TE:	290
RECEIVER TEMP, TR:	290
MODULATION INDEX (0 FOR AM):	0

DISTANCE MI	WEIGHTED SIGNAL/NOISE RATIO DB	
50	34.6	P5
75	31.1	P4
100	28.6	
125	16.7	P3
150	25.1	
175	23.7	
200	22.6	
225	21.6	P2
250	20.6	
275	19.8	

To within the accuracy of the amateur television picture reporting system and the ability to estimate system parameters, the *results of the experiment were exactly as predicted using the calculations described in the proposal.*

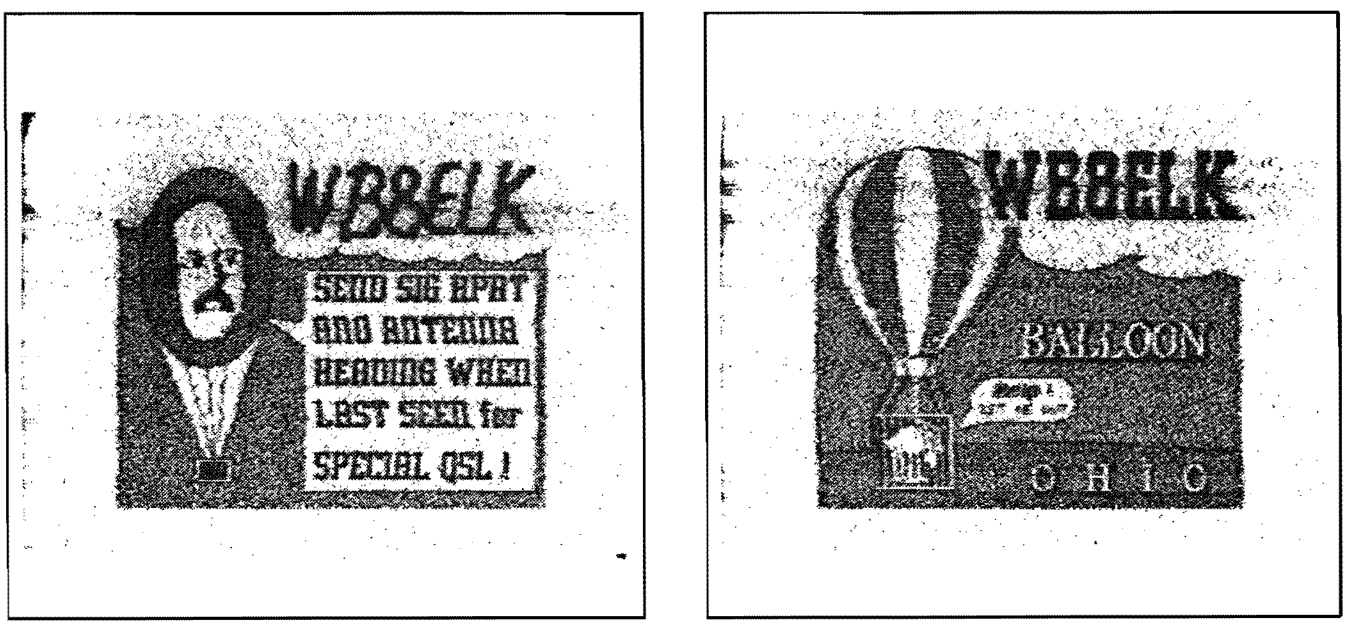
2. LINK PARAMETERS

After minor customizing modifications, the computer program in the proposal was used to calculate the expected received video picture quality. Supplement table 1 lists the parameters used and the expected results:

3. RECORDED RESULTS

Supplement Figure 1 "approaches" the video quality received during the WB8ELK balloon flight experiment. Some degradation of the pictures occurred during the video recording/playback generation, hard copy video printing process, and the reproduction process. However, the quality of the figures are within one "P" unit from the actual received signal. Upon reviewing the prints and applying the amateur television reporting system, it can be stated that the pictures fall within the "P2" (poor) definition, while the actual received television picture approached the "P3" (fair) quality level. This agrees very closely with the 250 mile calculated level of 20.6 dB.

Not illustrated in supplement Figure 1, but very noticeable during the actual experiment, was deep fading caused by antenna cross polarization due to the changing orientation of the payload package. Stations using circular polarized antennas did not experience the deep fades. The use of fast scan television allowed several seconds of complete clear pictures between the fades, however had slow scan television been used, not a single complete frame would have been received.



Supplement Figure 1. Experimental Results

4. CONCLUSIONS

The experimental results from the WB8ELK balloon flight strongly confirm the 70 cm AM television calculations in the proposal. The results also provide additional insight into the usability of a 70 cm television link with the shuttle. In the proposal, we recommended a minimum of 10 Watts of video from the shuttle. This higher power level coupled with the lower antenna temperatures expected from an elevated antenna, assures good to excellent pictures from the shuttle at close ranges. In the worst case (using 10 Watts) when the shuttle is at the extreme range and near the horizon, the quality of the pictures would be very similar to the included figures. Uplink ground stations using 100 to 1500 watts can easily provide good to excellent pictures to the shuttle over an entire pass.

QRP EME

by Ray Soifer, W2RS

The ever-improving state of the art in 2-meter EME has finally reached a point at which QRP stations, defined for this purpose as those having a single Yagi and less than 200 watts, can participate. So far, W2RS has had ten contacts with five different stations, using a single 32-19 Boomer and a Mirage B1016 solid-state amplifier. W5UN has worked single-Yagi stations having as little as 80 watts. This paper analyzes my results to see if anything can be learned that might help more small stations to be successful, and also help larger stations to complete contacts with QRP'ers. Since there are many more small stations than large ones, the smaller the stations one is capable of working, the more DX it will be possible to add to one's totals.

The operating conditions at W2RS are typical of many in suburban locations. The station is located on a plot of about one-third acre, which with its numerous trees does not afford a large open area for antennas. The aforementioned Boomer is mounted on the roof of the house, approximately 30 feet above ground, and is pointed at the horizon without elevation control. This provides two major ground reflection lobes, one at approximately 3.5° elevation, the other at about 10.5°.

When I first worked W5UN in November 1985, the output was about 130 watts at the antenna. After tweaking and minor improvements (adding forced-air cooling, replacing lossy connectors, etc.), I now measure 180 watts output at the amplifier and 150 watts at the antenna; the feedline is 65 feet of Belden 9913. The remaining station equipment consists of an ARR SP144VDG GaAsFET preamp (the preamp in the Mirage is not used), a Kenwood TR-9000 transceiver, and an Autek QF-1 audio filter. I have tried an ARR converter into the FT-102 HF transceiver in place of the TR-9000; no meaningful difference in EME reception resulted.

As mentioned at the outset, I have worked five stations with this setup: W5UN, KB8RQ (with the 32 Boomers), VE7BQH, SM7BAE and N5BLZ. Leaving aside the two 32-Yagi "superstations", analysis of the contacts with the three "smaller" stations indicates that ground gain and libration peaks are each playing an important role. Path calculations leaving out ground gain, but taking into account the actual sky noise and lunar position at the time of each contact, result in predicted signal-to-noise ratios (in a 100 Hz bandwidth) of -7 dB, -4 dB and -6 dB at VE7BQH, SM7BAE and N5BLZ, respectively.

Assuming a normal residential and industrial ground as per the ARRL Antenna Book, the lowest (3.5°) lobe of my vertical pattern theoretically should exhibit ground gain of about 5 dB and total effective gain of about 18 dBd, while the next higher lobe should produce effective gain of about 17 dBd. The EME results achieved, both transmitting and receiving, bear out these figures at least approximately.

Incidentally, I would argue from prior experience that a good operator skilled in weak-signal work may well be capable of doing better than the "conventional" effective-bandwidth assumption of 100 Hz, perhaps even down to the actual bandwidth occupied by the signal (60 Hz at a speed of 15 WPM). Such an improvement would add 2.2 dB to the signal-to-noise ratio compared with that obtained in a bandwidth of 100 Hz (occupied by a CW signal at 25 WPM).

However, one should not infer from this that even slower speeds would produce better results. Most of my EME tapes show frequent peaks of signal strength lasting one to three seconds, undoubtedly caused by libration. Some of these are quite pronounced: N5BLZ reported that my signals peaked at 5 dB above his noise level. Unlike the experience at higher frequencies where the peaks are shorter in duration, much usable information can be passed during libration peaks at 144 MHz. At 15 WPM, the sequence "RO" takes 1.8 seconds to send; at 18 WPM, my full call sign takes 3.1 seconds. There is clearly a tradeoff between speed and bandwidth; my experience to date indicates that 15 to 18 WPM is probably the optimal range if one is going to try to take advantage of libration. Of course, during a given schedule the QRP station should always try to mirror the sending speed used by the other operator, since that is probably the speed for which his "cerebral signal processor" is currently set.

Ground gain appears to be playing a critical role in having my signals heard by the other stations, but man-made noise picked up by my antenna is the other side of the coin as it probably is for other stations in suburban areas. Glen Rock, NJ, is about 20 miles from the center of New York City; while most of the surroundings are single-family homes, a major state highway and two small industrial parks are all within one mile of the QTH, each contributing its share of noise. I generally cannot detect sun noise at 144 MHz, although it is quite pronounced at 432 MHz with comparable equipment (single KLM-16LB and GaAsFET) due to the lower level of man-made noise at 70 cm. Measurements at 144 MHz show a wide variation in antenna noise, from about 400K at the quietest time and beam heading to over 5,000K at the worst. Most readings cluster between 500K and 1,500K; the median value is 1,100K and the mean is 1,400K.

In general, noise is least between 0100 and 0600 local time and is lower in northerly directions (positive declination) than southerly owing to the locations of my principal noise sources, but these generalizations do not always hold true. Local man-made noise should definitely be considered when scheduling EME attempts with a QRP station; I have missed contacts with every one of the five stations when they heard me but I was unable to hear them due to a high local noise level. However, ultimately I did hear them, and in general hear more from other stations (typically having 1,500 watts output) than they do from me despite my noise level.

I have not attempted to elevate the antenna, although this would probably result in less man-made noise being heard. The tradeoff for this, of course, would be a loss of ground gain, which from the foregoing analysis would probably prove fatal for EME contacts with most of the stations I have worked. For a one-Yagi station, adding elevation control may not make sense unless enough power is available to make up the loss of ground gain when aiming skyward.

Perhaps the most important element in QRP EME is persistence on the parts of both operators in each schedule. Numerous tries are generally required before a successful contact results, since all conditions must be right. I have been extremely fortunate in working with all five operators, who wanted to work me as much as I did them and who would not quit until we made it. Special thanks are due to W5UN, who got me going in EME; to KB8RQ, whose Apple IIe moon tracking software keeps me going; and to VE7BQH, who does such a great job of scheduling stations for me as he does for so many others.

I am continuing to run schedules with more large stations. From the experience gained so far, I believe that I (and others with comparable stations) can work anyone with approximately 23 to 24 dBd of antenna gain, given enough schedules and a little luck. More stations in this category are coming on the air continually. The smallest station worked to date, VE7BQH, estimates his antenna gain in the range of 22.7 dBd. As more QRP operators gain the necessary experience, more records will fall and more DX will be worked. Hopefully, some of what we are learning from these QRP EME tests will be of value to all as well.

Spread Spectrum Ranging for Phase IV
and
Nonlinear Filtering for Orbit Determination in Phase III-C and Phase IV

by
Phil Karn and Bob McGwier

Abstract

In this paper we discuss aspects of spread spectrum signals and their use in ranging for orbit determination in satellites. In addition, we propose to use some suboptimal but realizable nonlinear estimators, notably the iterated exponential forgetting second order extended Kalman Filter and Smoother, for using these ranging observations to do orbit determination. The nonlinear estimators will be in use on Phase III-C in addition to the well tested least squares algorithm developed by Phil Karn. The results will be compared in order that we may perfect the filtering scheme for other satellites, as it has several advantages over the least squares techniques. These include (1) the ease of adding new observations of the range as they become available and (2) the theoretical large improvement in the covariance of the error possible with the optimal but nonrealizable nonlinear filter.

Orbit Determination and Satellites

One of the most important tasks facing us in the deployment of the Phase III-C satellite next spring and the Phase IV satellite which is possible for the early part of next decade, is the need for us as amateur satellite enthusiasts, to develop our own techniques for determining just exactly what orbit our spacecraft occupies after deployment. The need for this is paramount as we must perform our own maneuvering burns for insertion into our final orbit in both the Molniya (Phase III-C and D?) and for geosynchronous satellites (Phase IV). The primary method for acquiring observations of the state of the satellite is that of ranging. It is exactly what the name implies. You make observations from stations with known ground locations of the time of flight of a signal up to the satellite and back. Given the constant and known speed of light, this gives us a means of measuring the *range* of the satellite from the known ground station. This will de done in a slightly different way as far as system block diagrams go in III-C and Phase IV satellites. In Phase III-C, in order to prevent unauthorized use of the transponder, the signal is sent on a command uplink, received and regenerated in the spacecraft and transmitted back to the ground. After removing the known bias due to the time taken to regenerate the signal in the spacecraft, the time of flight determines the range to some estimated accuracy. In Phase IV, it is hoped the transponder used will be very wideband and the means of accessing it will provide the necessary security as well as the frequencies involved. Again the security will be primarily physical but without the necessary removal of somewhat ill determined biases. The primary biases will be inaccurate ground station location and the delay through the filters in the transponder.

Spread Spectrum Signals

A widely used technique for ranging in satellite systems is the use of direct sequence spread spectrum signals. It usually consists of a carrier begin modulated by a PN or *pseudo-noise* sequence. A PN sequence generator is a generator of a pseudo-random binary sequence at a rate known as the chip rate R_c that is very large and will occupy a bandwidth that is also large compared with an average voice bandwidth signal. This PN sequence is modulated onto a carrier by phase shifting keying. The efficacy of this technique for ranging comes from several properties of the system. First, because the signalling rate R_c is high the time a single bit takes to transmit is small. We maintain a PN sequence that does not repeat itself (in a way to be specified later) until well after the entire round trip has been made. A good technical description of spread spectrum signals in general may be found in two very good books by Dixon[1] and Holmes[2]. A typical direct sequence spread spectrum transmitter for ranging is given in block diagram form in Figure 1. On the receiving end an *exact* replica of the PN-sequence or code must be generated and synchronously maintained at the receiver in order that the spreading can be properly removed and the carrier recovered. A block diagram of a spread spectrum receiver for this purpose is given in also in Figure 1. The synchronization techniques must be very good indeed and maintain the generation of the copy of the transmitted signal to within a fraction of a single bit of the received signal if we design the sequence correctly. We will deal only with linear code sequence generators and only with maximal length code sequences. Figure 2 shows a simple code sequence generator. The properties we wish to exploit are those found by considering the autocorrelation of one of these bits sequences. That is, we take the bit sequence generated by one of these generators and place it against all offsets of the same sequence. We then count the number of bit agreements and subtract the number of disagreements. For *all* sequences of the type we will consider, if the offset is other than zero, the relative autocorrelation (agreements - disagreements) will be -1. For the zero offset, the autocorrelation will be the length of the sequence. The length of the sequence is easy to compute and we will return to this in a moment. First let us consider the simple the stage shift register in figure 2 to illustrate the autocorrelation property. Also consider table 1 of the sequence which begins with a 111 fill in the three stages of the register in figure 2. The entire length of the sequence is $2^3 - 1$ and for all other n-stage registers we consider, the sequences will also be of length $2^n - 1$. The autocorrelation is nothing more than lining up the shifted sequence and the reference and computing the number of agreements minus the number of disagreements. Notice that all of the nonzero offsets have correlations of -1 and only the zero offset has bigger and is 7 $(2^3 - 1)$ and fits the description we mentioned before. This falls off gradually as we slide off the bit so that it is possible to use this to lock on and track the incoming code and this is what we will do in practice. It is this property of the autocorrelations that allows us to determine roundtrip times. When we take another much larger shift register and do the same kind of process of comparing the offsets of the code to the received signal we will be able to tell quickly when we are lined up with the incoming bits from the satellite. This offset is given in numbers of bits. Knowing the speed of light and the number of bits per second (the chip rate), we can determine a round trip time. Suppose we are sending the code at 256,000 bits per second. Then the one bit time in terms of the distance traveled by light in that time is

$$\frac{c}{R} = \frac{2.99725 \times 10^8 \text{ m/sec}}{256000 \text{ bits/sec}} = 1170 \text{ meters} \tag{1}$$

Using statistical means (pun intended), we may reduce this to a much smaller number with high confidence in the result. We will use these range observations, given from several different sites on the globe, as the input to our next topic.

Orbit Determination and Nonlinear Filtering

Orbital motion, like many other physical systems, may be described by an ordinary differential equation. In this case, an equation which relates the acceleration on the satellite body to its position and velocity. These equations may be solved analytically or numerically. In the case of orbital motion about an oblate planet, with a dense atmosphere and a large satellite (Earth), the analytical solution appears intractible. However, we are fortunate to be able to describe the gravitational field, and the mean drag on our craft due to residual atmosphere to a specified accuracy. The unmodeled terms in the gravitational field and the irregularities in the atmosphere will be treated as random excitations to the acceleration terms for the spacecraft. We then observe the state of the spacecraft through a nonlinear function of its position and the current time. This function is the range of the spacecraft from a specified ground station. The time dependence of the function comes from the fact that we do not (and do not wish to) limit ourselves to one ground station observer. Of course, the method in the case of the ranging system described in the previous section is limited to an error that is determined by the length of a bit in the pseudorandom sequence in the case of both Phase III and Phase IV satellites. Using many observations and an adaptation of the Strong Law of Large Numbers to this problem, we can reduce the error over many observations to a small fraction of the error of a single observation. Let us consider the differential equation that determines the mean behaviour of the satellite in orbit about the Earth.

The equation of motion we wish to use is derived from the potential of the Earth's gravitational and drag due to residual atmosphere. The potential due to the Earths gravitational field is a fairly complicated function due to the fact that the Earth is not a homogeneous sphere. It is a nonhomogeneous oblate spheroid. It is possible to expand the gravtitational field into harmonic series and use quite successfully the largest terms in the series expansion for the Earth's potential. This will be our approach. We will not present the exact form we intend for the potential but leave it in functional form alone.

$$\text{Earth potential } = \Phi(x, y, z) \tag{2}$$

and the acceleration on an a satellite due to the gravitational field of the earth at a point x, y, z above its surface is

$$\frac{d^2 r_g}{dt^2} = \nabla\Phi \tag{3}$$

The effects of lift and drag will be lumped and will be a function of the velocity of the spacecraft and we will assume a mean "shape" for the spacecraft and take an averaged approach to describing this term. Errors in this approach will be lumped with inadequacies in the gravitational model into a random excitation to the dynamical system. Our final equation of motion will have a functional form which will involve both position and velocity in an equation giving the acceleration on the satellite.

$$\frac{d^2 r}{dt^2} = f(x, y, z, \dot{x}, \dot{y}, \dot{z}) \tag{4}$$

will be the mean differential equation neglecting any random perturbations described above. We will assume that this random perturbation is white, Gaussian noise and only affects the acceleration terms of our dynamical system. Suppose that at times $t_k, k = 1, 2, 3\ldots$, we observe the spacecraft range from known ground station locations $(x_k, y_k, z_k), k = 1, 2, 3, \ldots$. We will assume that our observation model looks like

$$O_k = ((x - x_k)^2 + (y - y_k)^2 + (z - z_k)^2)^{\frac{1}{2}} + V_k \tag{5}$$

and we will let

$$\mathbf{h}_k(\mathbf{x}) = ((x - x_k)^2 + (y - y_k)^2 + (z - z_k)^2)^{\frac{1}{2}} \tag{6}$$

Where (x, y, z) is the true position of the spacecraft at time t_k, and V_k is the error we make in determining the range to spacecraft using our ranging technique. We assume that we have taken out all major biases and thus V_k is a mean zero process. A not unreasonable model for this error "noise" in practice is Gaussian and mean zero. The variance will be determined by a number of factors including as the major component what the "bit" time is in our pseudorandom sequence. We will represent the second order differential equation as a six dimensional first order differential equation and at the same time show our representation of the random excitation. Velocity below will be (u, v, w) and position will be (x, y, z). The "stochastic" differential equation for orbital motion we use is

$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \\ \dot{u} \\ \dot{v} \\ \dot{w} \end{pmatrix} = \begin{pmatrix} u \\ v \\ w \\ f_x(x,y,z,u,v,w) \\ f_y(x,y,z,u,v,w) \\ f_z(x,y,z,u,v,w) \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ 0 \\ w_x \\ w_y \\ w_z \end{pmatrix} \tag{7}$$

where the subscripted f's stand for the x, y, and z components of the acceleration on the satellite. This immediately lends itself to a formulation as an extended Kalman filter in the forward time direction. Suppose that we have an estimate based on all the observations up to time t_k the time including the $k-th$ range observation. We will give the equations for the iterated extended Kalman filter with exponential forgetting. These may be found in Gelb[3]. Let

$$\mathbf{F}(\hat{\mathbf{x}}) = \begin{pmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ \frac{\partial f_x}{\partial x} & \frac{\partial f_x}{\partial y} & \frac{\partial f_x}{\partial z} & 0 & 0 & 0 \\ \frac{\partial f_y}{\partial x} & \frac{\partial f_y}{\partial y} & \frac{\partial f_y}{\partial z} & 0 & 0 & 0 \\ \frac{\partial f_z}{\partial x} & \frac{\partial f_z}{\partial y} & \frac{\partial f_z}{\partial z} & 0 & 0 & 0 \end{pmatrix} \tag{8}$$

$\mathbf{F}$ is sometimes called the Jacobian matrix of the vector valued function (u, v, w, f_x, f_y, f_z). Likewise we will let $\mathbf{H}$ be the Jacobian matrix of the observation function.

$$\mathbf{H}(\hat{\mathbf{x}}) = \left((x - x_k) \quad (y - y_k) \quad (z - z_k) \quad 0 \quad 0 \quad 0 \right) \tag{9}$$

Let $\hat{\mathbf{x}}_{k+1}^-$ and P_{k+1}^- be the solution to the Cauchy problem

$$\frac{d\hat{\mathbf{x}}}{dt} = \begin{pmatrix} u \\ v \\ w \\ f_x \\ f_y \\ f_z \end{pmatrix}$$

$$\frac{d\mathbf{P}}{dt} = \mathbf{F}(\hat{\mathbf{x}}(t))\mathbf{P}(t) + \mathbf{P}(t)\mathbf{F}^T(\hat{\mathbf{x}}(t)) + Q$$

at the timepoint t_{k+1}, where the solution interval is $[t_k, t_{k+1}]$, the time interval between the k-th and $k+1$-st observation. Q is the covariance matrix of the random terms driving

(7). The initial conditions are $\hat{\mathbf{x}}_k^+$ and P_k^+ respectively. At each observation time t_k, we do the following iterative procedure. Define $\mathbf{x}_{k,0}^+ = \mathbf{x}_k^-$

$$K_{k,i} = \mathbf{P}_k^- \mathbf{H}_k^T(\hat{\mathbf{x}}_{k,i}^+) \left[\mathbf{H}(\hat{\mathbf{x}}_{k,i}^+) \mathbf{P}_k^- \mathbf{H}_k^T(\hat{\mathbf{x}}_{k,i}^+) + R_k \right]^{-1} \tag{10}$$

$$\hat{\mathbf{x}}_{k,i+1}^+ = \hat{\mathbf{x}}_k^- + K_{k,i} \left[O_k - \mathbf{h}_k - \mathbf{H}_k(\hat{\mathbf{x}}_{k,i}^+)(\hat{\mathbf{x}}_k^- - \hat{\mathbf{x}}_{k,i}^+) \right] \tag{11}$$

$$\mathbf{P}_{k,i+1}^+ = s \left[I - K_{k,i} \mathbf{H}_k(\hat{\mathbf{x}}_{k,i}^+) \right] \mathbf{P}_k^- \tag{12}$$

This procedure is repeated for $i = 0, 1, 2, \cdots$ until either there is no significant change in the the estimated state and covariance or until some maximum number of iterations have been done. s in the above is the exponential forgetting factor. If $s = 1$ then this is a "standard" extended Kalman filter and no forgetting is done. The size of the covariance will decay until some threshold is reached and the gain $K_{k,i}$ will get smaller. If $s > 1$ the older observations are exponentially discounted and the size of s determines this discount rate. This prevents the filtering from "turning off" and not taking more advantage of the later observations. This set of equations *completely* determines the filtering process for the orbit determination. It is our belief and the experience of ourselves and others that this is necessary for increased convergence of the estimates here and for stability of the estimates. This is a tool to prevent "divergence" in the filtered estimate.

Unlike some problems where we are attempting to get filtered estimates in real time, we have all the observations available to us up until the time of the final observation and the processing will be done "offline". Statistically, to achieve the minimum covariance of the error we will need to also do a "backward" estimates and then smooth our filtered estimates. The equations are similar to the filtering equation and are given below. Let $\hat{\mathbf{x}}_k^+$ be the final iterate of the filtering process at each observation time from above. We must store all these values and the final iterates of the covariance matrices which we will likewise call $\mathbf{P}_k^+$. Let $\hat{\mathbf{x}}_b(\tau)$ and $\mathbf{P}_b$ be the solution to

$$\begin{aligned} \frac{d\hat{\mathbf{x}}_b(\tau)}{d\tau} &= -\mathbf{f}(\hat{\mathbf{x}}(T-\tau), T-\tau) - \mathbf{F}(\hat{\mathbf{x}}(t-\tau), T-\tau)(\hat{\mathbf{x}}_b(\tau) - \hat{\mathbf{x}}(T-\tau)) \\ \frac{d\mathbf{P}_b(\tau)}{d\tau} &= -\mathbf{F}(\hat{\mathbf{x}}(t-\tau), T-\tau)\mathbf{P}_b(\tau) - \mathbf{P}_b(\tau)\mathbf{F}^T(\hat{\mathbf{x}}(t-\tau), T-\tau) \end{aligned} \tag{13}$$

for τ in the interval $[T - t_{k+1}, T - t_k]$ and the initial conditions are $\hat{\mathbf{x}}_{b,k+1}^+$ and $\mathbf{P}_{b,k+1}^+$ repectively, the backwards filtered update at the observation time t_{k+1}. At the next (previous) observation t_k the solutions are at $\tau = T - t_k$ called $\hat{\mathbf{x}}_{b,k}^-$ and $\mathbf{P}^- b, k$ repectively. We update these with the observations as follows

$$\hat{\mathbf{x}}_{b,k}^+ = \hat{\mathbf{x}}_{b,k}^- + K_{b,k} \left[O_{N-k} - \mathbf{h}_{N-k}(\hat{\mathbf{x}}_{N-k}) - \mathbf{H}_{N-k}(\hat{\mathbf{x}}_{N-k})(\hat{\mathbf{x}}_{b,k}^- - \hat{\mathbf{x}}_{N-k}) \right] \tag{14}$$

$$K_{b,k} = \mathbf{P}_{b,k}^- \mathbf{H}_{N-k}^T(\hat{\mathbf{x}}_{N-k}) \left[\mathbf{H}_{N-k}(\hat{\mathbf{x}}_{N-k}) \mathbf{P}_{b,k}^- \mathbf{H}_{N-k}^T(\hat{\mathbf{x}}_{N-k}) + R_{N-k} \right]^{-1} \tag{15}$$

$$\mathbf{P}_{b,k}^+ = \left[I - K_{b,k} \mathbf{H}_{N-k}(\hat{\mathbf{x}}_{N-k}) \right] \mathbf{P}_{b,k}^-, k = 0, 1, \ldots, N-1 \tag{16}$$

where the $\mathbf{h}_{N-k}$ and $\mathbf{H}_{N-k}$ are obtained from the forward filter. At each time step backwards we compute

$$\hat{\mathbf{x}}(t_k \mid T) = ((\mathbf{P}_k^+)^{-1} + (\mathbf{P}_{b,k}^+)^{-1})^{-1} \left[(\mathbf{P}_k^+)^{-1}\hat{\mathbf{x}}_k^+ + (\mathbf{P}_{b,k}^+)^{-1}\hat{\mathbf{x}}_{b,k}^+\right] \tag{17}$$

This is the final smoothed estimate for each time t_k. Given the state at any one of these times, we may compute the standard Keplerian elements from a few transformations which we will not give here (see Escobal[4]). The level of sophistication here is quite high and the demands on hardware are quite exacting. Work on the design of the hardware continues. We believe this will yield usable (accurate) orbits for our satellites.

[1] **Spread Spectrum Systems**, R.C. Dixon, Wiley Interscience.

[2] **Coherent Spread Spectrum Systems,** J. K. Holmes, Wiley, 1982.

[3] *Applied Optimal Estimation*,A. Gelb et. al., M.I.T. Press, 1974.

[4] **Methods of Orbit Determination**, Pedro Escobal, Prentice-Hall, 1969.

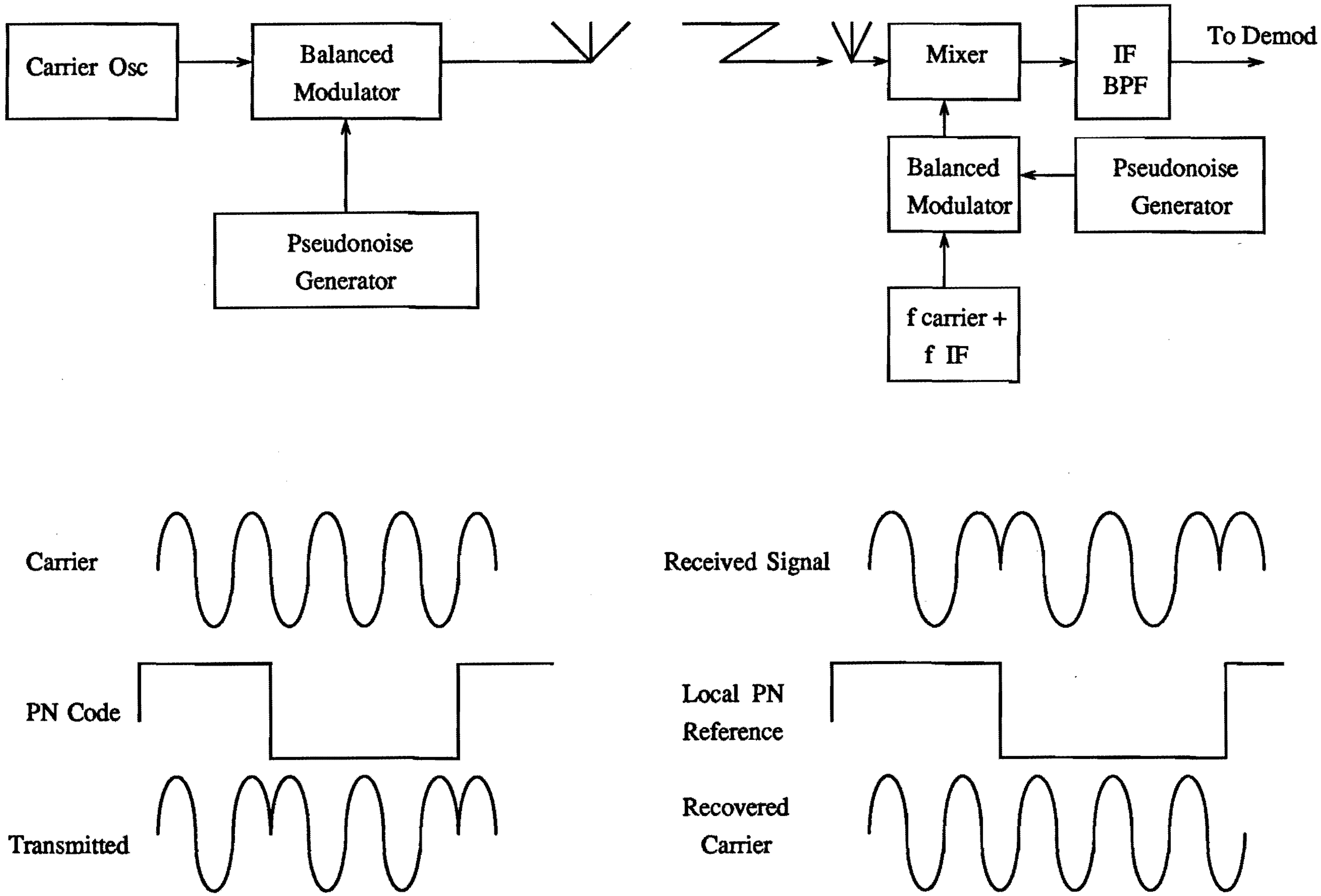
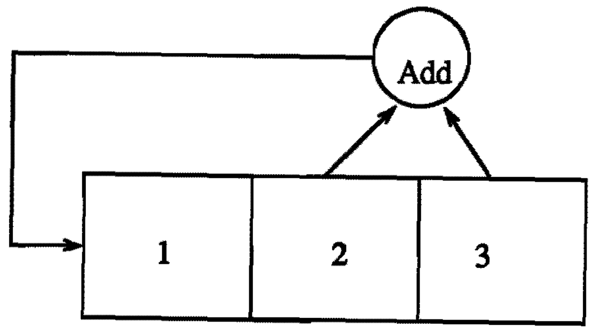

Carrier Osc
Balanced Modulator
Pseudonoise Generator
Mixer
IF BPF
To Demod
Balanced Modulator
Pseudonoise Generator
f carrier + f IF
Carrier
PN Code
Transmitted
Received Signal
Local PN Reference
Recovered Carrier

Figure 1



Three stage shift register yielding maximal length sequences (7)
Add is a modulo 2 adder.

Figure 2

Reference sequence: 1110010

Shift	Sequence	Agreements	Disagreements	A–D
1	0111001	3	4	−1
2	1011100	3	4	−1
3	0101110	3	4	−1
4	0010111	3	4	−1
5	1001011	3	4	−1
6	1100101	3	4	−1
0	1110010	7	0	7

TABLE 1

The FO-12 Mailbox System

Moriyoshi Ohara (JK1VXJ)

Masaya Fukasawa (JR1FIG)

Youichi Kikukawa (JR1ING)

Abstract

Fuji/OSCAR-12 contains a store-and-forward communication facility, called a mailbox. This paper describes hardware and software design of the digital system.

Background

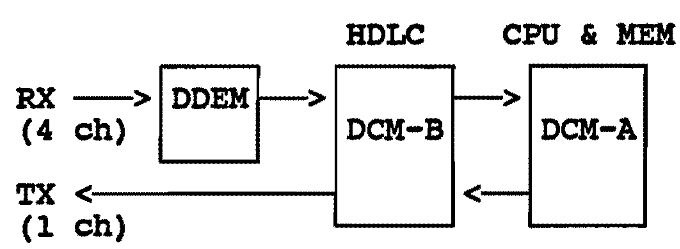
Mailbox service is one of the major features in the FO-12, which is the first Japanese amateur satellite, launched by NASDA (National Aerospace Development Agency) on 13 August 1986. When we started the functional design of the satellite in 1983, the mailbox was chosen mainly for three reasons. Firstly, store-and-forward methods were expected to be a suitable application for low orbit satellites, like FO-12. Secondly, we thought packet communication would become a very popular method in terrestrial communications, so that a lot of people would be able to use this facility. Lastly, implementaion of such digital system onto a satellite was a challenging project.

The FO-12 digital mode was designed not to be too difficult for the majority of potential users when they use the mailbox. We did not expect what kind of technology would be available or would become popular for ground stations when the satellite became available. However, the communication rate of 1200 bps and AX.25 protocol were seemed to be very feasible for common amateurs. Thus, we chose them.

FO-12 Hardware

Overview

The digital system of FO-12 consists of DDEM, DCM-A, and DCM-B as shown below. The DDEM (Data Demodulator) has four demodulators for general service. HDLC controllers for each uplink and one downlink are contained in the DCM-B



(Digital Communication Module - B). The DCM-B is made from three cards (size: 6.85 inch x 8.74 inch) and 144 ICs. The DCM-A (Digital Communication Module - A) is a computer system for both the mailbox and housekeeping. It has ten cards (size: 6.30 inch x 5.91 inch) and 329 ICs. There are four uplink channels. Each of them can be shared by several uplinks. On the other hand, we have only one downlink channel, used for all transmission in the digital mode.

Memory

One of our concerns in this system was the memory. We should consider its capacity, power consumption, packaging, memory error, and reliability. The mass of the FO-12 is so small that the power available for the computer would be less than 3.5 W, and that volume for it should be less than a cube, of which sides were about 180 mm. Besides we roughly estimated one million bytes would be required. As the result, DRAM chips of 256 kbit were chosen. We used four 256 kbyte memory cards in the FO-12. Some characteristics are listed below.

- 1. One bit ECC in every memory cycle
- 2. Four independent memory cards
- 3. DRAM only, no ROM nor SRAM

To keep data integrity, one bit error correction is made in all memory cycles. The four memory cards are functionally interchangeable to provide 4-way redundancy, so that we did not need SRAM chips to achieve high reliability. IPL was implemented by wired-logic, not by a ROM program.

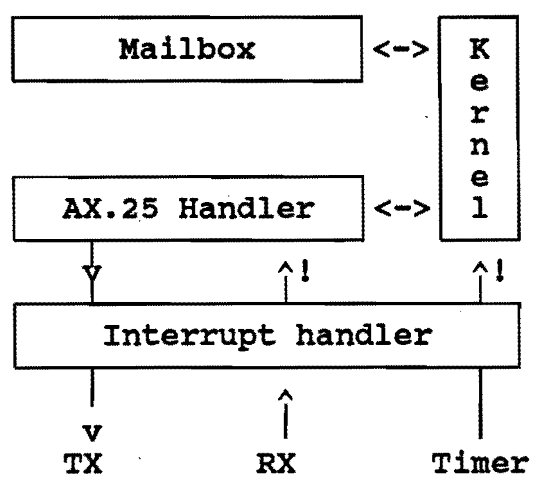
CPU

We selected the NSC800 microprocesor for the FO-12, based on the some considerations. First of all, its power consumption should be very low. There were three such candidates: CDP1802, 8085, and NSC800. The NSC800 has the worst reliability against radiation among them. However it is better than other CPUs in the following two points: (1) The NSC800 can execute more powerful instructions. (2) A lot of tools were available for this CPU, including an in-circuit-emulator, an emulator on DOS, and a high speed assembler. To write complicated and optimized software, these two points were considered very important.

FO-12 Software

Overview

The following figure shows the structure of the FO-12 software system. The mailbox interprets commands from users and manages its file system. Multilink AX.25 is controlled by the AX.25 handler.



This system was written in Z80 assembly language in order to get the most of computing performance from our microprocessor, as well as to minimize the code size.

One of the difficulties in our software is how to design a multiuser mailbox system, including multilink AX.25 handler, on the onboard computer with relatively low processing power (Z80 software compatible CPU with 1.7MHz).

Especially the mailbox requires multitask processing capability, which sometimes results in large overhead. We designed light task control mechanism in the kernel to minimize the overhead.

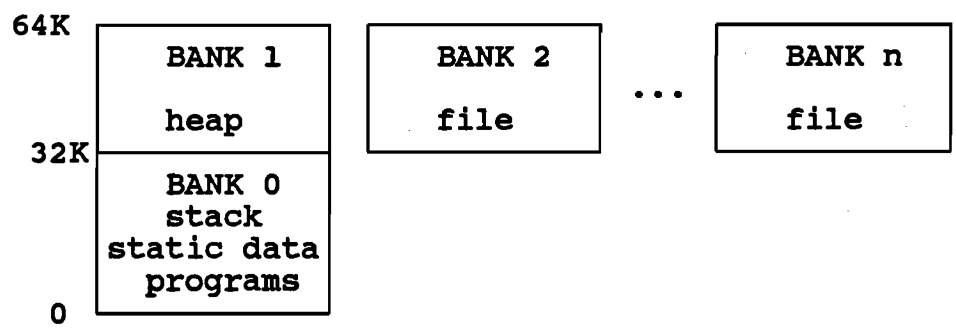
Kernel - task control -

A lot of general purpose operating systems use time slicing method to implement multitask. Instead we sliced software modules into several pieces of tasks from the beginning. Each task processes a straightforward job, and does not occupy the processor for a long time. It is invoked by another task or an interrupt handler, and terminated by itself. In this approach we do not need time slicing, so that we can get some benefits. Firstly task management became very light. Additionally tasks may not be re-entrant, should be only reusable.

The kernel manages the task invocation. There are two kinds of service routines for it. One is immediate task invocation request, and another is delayed task invocation request. The second one is, for example, used to implement T1/T2/T3 timers in AX.25. When tasks want to transfer their job to other tasks, or to wait for certain time, they call those routines. There is a task queue, in which ready-to-run tasks are stored. When the current task finishes its job, the kernel is called, and invokes the next task on FCFS basis.

Kernel - Memory Management -

The CPU NSC800 can only access 64 KByte area directly. To access 1 MByte memory, we have a bank selection mechanism, as shown in the following figure. However it takes longer time to access memory with bank selection than to access memory conventionally. Therefore we had to consider how to allocate programs and data in large memory space. As the result, upper banks (BANK2...n) are normally hidden, and store files (user's messages). On the other hand, BANK1 is called heap area, which stores frequently used data, such as work area and communication buffers. Programs, static data, and stack are allocated in the BANK0. The BANK0 and the BANK1 are normally visible from the CPU. Both the heap and file areas are managed in the same way. Each area is divided into several fixed length areas, which are called records. Unused records are linked to a free list. Using service routines of the kernel, programs can get/return records dynamically.



AX.25 handler

We implemented AX.25 level 2 version 2 protocol in the FO-12. The AX.25 handler can control 16 simultaneous links, and supports fully transparent mode. Functions of the AX.25 handler are as follows:

1) Accept frames from an interrupt handler.

2) Discard unacceptable frames, which are addressed to others, version 1 frames, or "digipeated" frames, etc.

3) Search source address in an active link table using hash-method, a create new link if the address is not found in the table and the frame is a valid SABM frame.

4) Alter link state and make a suitable response frame, according to current link state and control field in the received frame.

5) If necessary, send a response frame by pushing it into a transmission queue.

6) If necessary, activate a timer to wait for next action, which is to be dispatched after timeout of each timer.

7) If valid I-field is received, pass it to a mailbox task via the kernel.

8) Assemble frames, coming from a mailbox task, and send it to an interrupt handler.

As described above, AX.25 handler itself is a single-task, sequential routine. It runs without knowing other link activity.

Multilink feature owes to multitask kernel and data structure. Because every task switching should be explicitly done by each routine, we paid considerable attention to dividing each module into enough short tasks. An interrupt handler passes HDLC frames with correct FCS to the AX.25 handler. Data transfer is made by dispatching frame-processing task. This method made the AX.25 handler process one frame at the same time, and reduce complexity of the software. It seems practical because the AX.25 handler does not need to know which uplink channel the frame comes from. The system defined parameters for the current AX.25 handler is as follows:

1) T1 timer	5.1 s
2) T2 timer	1.2 s
3) T3 timer	20 min (see note)
4) Retries	10 times
5) TX frame length	128 bytes
6) RX frame length	200 bytes
6) Number of outstanding frames (TX)	1
6) Number of outstanding frames (RX)	7 max.

Note: When T3 expires, the link will be cut without any polling. The user is out of satellite's sight on T3 timeout.

These values were chosen in order to decrease overloading on the downlink channel, instead of trying to get maximum efficiency of the link. We imagined it might be the case that many users would read lots of messages and cause downlink overload. However, since there are only limited numbers of users at this time, we can reconsider these parameters to increase speed of data-transfer rate.

Mailbox

The mailbox consists of two parts: a file system and a parser. The file system stores messages, exchanged among users. It has plane structure with a single file table.

Another part, a command parser, scans characters in received frames, and interprets commands (i.e. F, R, M, K, etc). This parser program is also divided into several parts in order to implement our multitask mechanism. Similar to the AX.25 handler, the program code is used by all users, but data area for each user is dynamically allocated. The data area is called a parsing descriptor, containing each user's current state.

A kill (file erase) command brought us a technical issue, which single user systems do not have. That is file system consistency in multiuser systems. For example, while someone is reading a file, it should not be erased by other users. In our implementation, the K command does not erase files immediately, only marks them as killed. Then they become unreadable, though contents are still in memory. Users who begin to read a file before marked can continue. Marked files are deleted while no user is using this system.

Summary

We implemented a store-and-forward communication system in the FO-12. The hardware has relatively large memory with high reliability. The software was designed to support our multiuser mailbox system efficiently.

Acknowledgment

We wish to thank a lot of people who gave us valuable information to design the FO-12. Especially, TNC source code for Xerox 820 written by Mr. Philip Karn (KA9Q), and TNC-2 source code by Mr. Howard Goldstein (N2WX) were very helpful for our design. Furthermore, TNC firmware by Mr. Ronald Lakes (WA8DED) was very useful as a debug tool.

Attitude Control and Phase IV Geosynchronous Satellites

by
Steve Boschert, Dave Cowdin, Gordon Hardeman, Dick Jansson,Lou McFadin
Bob McGwier,Steve Robinson, Mark Shriver, Laurie Wiggins, Jeff Zerr

Abstract

We development the theoretical tools needed to derive our attitude control needs for Phase IV.

Introduction

In a geosynchronous satellite, we have a very high orbit and are able to have 24 hour a day coverage from this satellite. Having the benefits of a satellite in a geosynchronous orbit places greater demands on the design and implementation of such a craft for several reasons. First, it is very expensive to get to a geosynchronous orbit so satellite construction and design must be done with great care or your large investment will be squandered. Second, large antenna arrays are not possible given the launchers available to us and the facilities available to us for construction. Thus, to get good signal to noise ratios we need to have high gain antennas on (typically) UHF, preferably higher. This means we will have small beamwidths to contend with. This is the primary reason for the high precision attitude control systems. These are our "antenna rotors" as well as (more importantly) the thing that keeps us pointed toward the life giving sun.

For Phase IV type satellites we propose to build a three axis stabilized craft and to have reaction control system and momentum storage facilities for the fine adjustment attitude controls. We will use a change in the stored momentum so located that they allow us to control the attitude of our spacecraft relative to a fix observer on the surface of the earth. The spin rate of the satellite will be once per sidereal day so that the antennas always point at approximately the same observer.

It will be necessary for us to develop the mathematical tools for studying the rigid body dynamics of spacecraft so that we determine the adequacy of the proposed system for fine attitude control, to determine what demands will be placed on a reaction control system (RCS) for gross attitude control, and to derive the needs for sensor technology to determine when attitude adjustment is needed. The reason for needing attitude control is that the spacecraft is subject to external perturbations. Once we have a dynamical model for the spacecraft, and have modeled the perturbations incident upon it, we can derive the dynamical model for the reaction of the spacecraft to our attitude control system. This will enable us to derive the "control laws" which are the formulae for determining "how much control" to apply. After deriving general equations for several needed quantities, we will apply the necessary mathematical tools to derive the results for our particular application.

PHYSICS

The linear momentum of a particle is defined as the product of its mass and its velocity. Let dm represent a small element of mass in a rigid body and $\mathbf{V}$ the velocity of the element. The linear momentum of a rigid body can be written in the form

$$\mathbf{P} = \int_m \mathbf{V} dm \tag{1}$$

where m is the mass point. If we have an inertial reference frame (think center of mass of the earth), and C is the center of mass of the rigid body (1) becomes

$$\begin{aligned} \mathbf{P} &= \int_m \mathbf{V}_C + \omega \times \mathbf{r} dm \\ &= m\mathbf{V}_C + \omega \times \int_m \mathbf{r} dm \end{aligned} \tag{2}$$

where $\mathbf{V}_C$ is the velocity of the center of mass in the inertial reference frame, and ω is the angular velocity of the body about the center of mass and $\mathbf{r}$ is the displacement of the particle "dm" from the center of mass. This equation simplifies to

$$\mathbf{P} = m\mathbf{V}_C \tag{3}$$

since in this case $\int_m \mathbf{r}dm = 0$ by definition of center of mass.

The angular momentum of a particle dm about the center of mass C is defined as the moment about C of the linear momentum of the mass element

$$\mathbf{h}_C = \mathbf{r} \times \mathbf{V}dm \tag{3}$$

or

$$\begin{aligned} \mathbf{H}_C &= \int_m \mathbf{r} \times \mathbf{V}_C + \omega \times \mathbf{r}dm \\ &= \int \mathbf{r}dm \times \mathbf{V}_C + \int_m \mathbf{r} \times (\omega \times \mathbf{r})dm \\ &= \int_m \mathbf{r} \times (\omega \times \mathbf{r})dm \end{aligned} \tag{4}$$

again using the center of mass reductions. Let the angular velocity be written in vector component notation

$$\omega = \omega_x\mathbf{i} + \omega_y\mathbf{j} + \omega_z\mathbf{k}. \tag{5}$$

Then we get

$$\begin{aligned} \mathbf{H}_C = \quad & [I_{xx}\omega_x - I_{xy}\omega_y - I_{xz}\omega_z]\,\mathbf{i} \\ & + [-I_{xy}\omega_x + I_{yy}\omega_y - I_{yz}\omega_z]\,\mathbf{j} \\ & + [-I_{xz}\omega_x - I_{yz}\omega_y + I_{zz}\omega_z]\,\mathbf{k} \end{aligned} \tag{6}$$

where

$$\begin{aligned} I_{xx} &= \int_m (y^2 + z^2)dm \\ I_{yy} &= \int_m (x^2 + z^2)dm \\ I_{zz} &= \int_m (x^2 + y^2)dm \end{aligned} \tag{7}$$

are the products of inertia of the body about the axes X, Y, Z respectively and

$$\begin{aligned} I_{xy} &= \int_m xy\,dm \\ I_{xz} &= \int_m xz\,dm \\ I_{yz} &= \int_m yz\,dm \end{aligned} \tag{8}$$

are the products of inertia. The axes about which the products of inertia are zero are called the principle axes of inertia or principle axes of rotation. For a coordinate system, fixed in the rigid body (x, y, z of any particle doesn't change with time), the moments and products of inertia are of course constants. In a convenient matrix notation,

$$\mathbf{H}_C = \begin{pmatrix} H_x \\ H_y \\ H_z \end{pmatrix} = \begin{pmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{xy} & I_{yy} & -I_{yz} \\ -I_{xz} & -I_{yz} & I_{zz} \end{pmatrix} \begin{pmatrix} \omega_x \\ \omega_y \\ \omega_z \end{pmatrix} \tag{9}$$

The kinetic energy of a rigid body is defined as

$$T = \frac{1}{2} \int_m \mathbf{V} \cdot \mathbf{V} dm \tag{10}$$

and in our case using the same coordinate system as above we get

$$T = \frac{1}{2} m V_C^2 + \frac{1}{2} \left[I_{xx}\omega_x^2 + I_{yy}\omega_y^2 + I_{zz}\omega_z^2 - 2\omega_x\omega_z I_{xz} - 2\omega_y\omega_z I_{yz} - 2\omega_x\omega_y I_{xy} \right] \tag{11}$$

The first term is the kinetic energy of translation and the second is the kinetic energy of rotation, which in matrix formulation is

$$T_{\text{rot}} = \frac{1}{2} \begin{pmatrix} \omega_x & \omega_y & \omega_z \end{pmatrix} \begin{pmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{xy} & I_{yy} & -I_{yz} \\ -I_{xz} & -I_{yz} & I_{zz} \end{pmatrix} \begin{pmatrix} \omega_x \\ \omega_y \\ \omega_z \end{pmatrix} \tag{12}$$

Equations of motion are based on Newton's second law, which states that the rate of change of linear momentum of a particle is equal to the force acting on it. We *must* measure motion relative to an inertial reference frame. Consider a particle of mass m which is being acted upon by a force $\mathbf{F}$. According to Newton

$$\mathbf{F} = \frac{d}{dt}(m\mathbf{V}) = m\dot{\mathbf{V}} = m\mathbf{a}. \tag{13}$$

The angular momentum of the particle relative to an arbitrary point P is

$$\mathbf{h}_P = \mathbf{r} \times m\mathbf{V}. \tag{14}$$

The time derivative of the angular momentum is

$$\dot{\mathbf{h}}_P = \dot{\mathbf{r}} \times m\mathbf{V} + \mathbf{r} \times m\dot{\mathbf{V}} \tag{15}$$

so that we obtain

$$\begin{aligned} \dot{\mathbf{h}}_P &= \dot{\mathbf{r}} \times m(\dot{\mathbf{R}}_P + \dot{\mathbf{r}}) + \mathbf{r} \times \mathbf{F} \\ &= -\dot{\mathbf{R}}_P \times m\dot{\mathbf{r}} + \mathbf{r} \times \mathbf{F}. \end{aligned} \tag{16}$$

By definition, the moment of force $\mathbf{F}$ about P is

$$\mathbf{M}_P = \mathbf{r} \times \mathbf{F}. \tag{17}$$

Substituting (16) into (15) we get upon algebra

$$\mathbf{M}_P = \dot{h}_P + \dot{\mathbf{R}}_P \times m\dot{\mathbf{r}}. \tag{18}$$

The force and momentum equation of motion were derived for a single particle but are easily generalized to rigid bodies. We can write the force equation of motion as

$$\mathbf{F} = \int_m \mathbf{a}\, dm = \int_m [\mathbf{a}_P + \omega \times \mathbf{r} + \omega \times (\omega \times \mathbf{r})] dm \tag{19}$$

where $\mathbf{F}$ is the resultant of the external forces. If we assume that P is at the center of mass C, this greatly reduces to

$$\mathbf{F} = m\mathbf{a}_C. \tag{20}$$

The equation of motion about P is derived likewise and we get

$$\mathbf{M}_P = \dot{\mathbf{H}}_P + \int_m \dot{\mathbf{R}}_P \times \dot{\mathbf{r}}\, dm \tag{21}$$

and again if $P = C$, we get a simplification to

$$\mathbf{M}_C = \dot{\mathbf{H}}_C. \tag{22}$$

That is, the moment of external force about the center of mas is the time rate of change of angular momentum of the rigid body about C. Expressing the angular momentum in coordinate notation $\mathbf{H}_C = H_x\mathbf{i} + H_y\mathbf{j} + H_z\mathbf{k}$ we get

$$\begin{aligned} F_x &= m\ddot{x}_C \\ F_y &= m\ddot{y}_C \\ F_z &= m\ddot{z}_C \\ M_x &= \dot{H}_x + \omega_y H_z - \omega_z H_y \\ M_y &= \dot{H}_y + \omega_z H_x - \omega_x H_z \\ M_z &= \dot{H}_z + \omega_x H_y - \omega_y H_x \end{aligned} \tag{23}$$

Assuming that the axes coincide with the principal axes of rotation, the components of the angular momentum are reduced to

$$H_q = I_{qq}\omega_q \text{ where } q = x, y, z \tag{24}$$

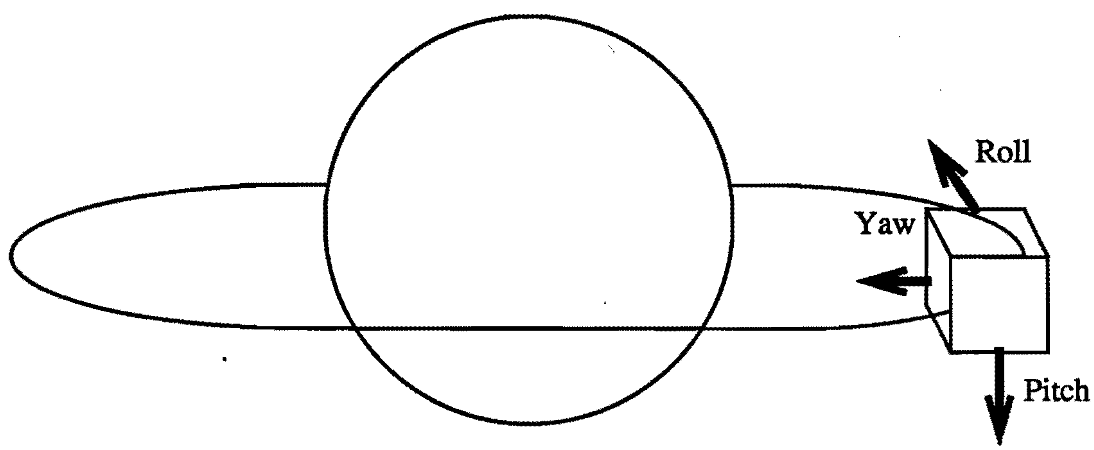
and

$$\begin{aligned} M_x &= I_{xx}\dot{\omega}_x + \omega_y\omega_z(I_{zz} - I_{yy}) \\ M_y &= I_{yy}\dot{\omega}_y + \omega_x\omega_z(I_{xx} - I_{zz}) \\ M_z &= I_{zz}\dot{\omega}_z + \omega_x\omega_y(I_{yy} - I_{xx}). \end{aligned} \tag{25}$$

These are known as Eulers moment equations.

ATTITUDE STABILIZATION

In geosynchronous satellites, attitude control/stabilization systems fall into two main categories: spin stabilized and three axis stabilized. Spin stabilization is based on the gyroscope stiffness due to rotation of all or part of of the body of the craft. The serious drawback of this approach for a Phase IV satellite is that it requires a platform on which the antennas are mounted and pointed at the earth. This platform is "despun" relative to the body of the spacecraft at a rate that just offsets the spin of the spacecraft. If the RF equipment is on this platform, then power must be supplied across the spinning interface. Otherwise RF must be piped across the spinning interface. In either case very high reliability interfaces must be provided in addition to high reliability bearing sets. This option is just too expensive for Phase IV spacecraft. The other option, three axis stabilization is normally done with three reaction wheels who work to keep the total angular momentum with respect to a ground observer at zero and the spin around the pitch axis of the spacecraft at once per sidereal day. This is a much simpler system overall than the spinner but still requires very high realiability bearing sets in in the reaction wheels which have to be able to spin at very high RPM's. In our case, we hope to replace these small wheels spinning at high RPM with, with momentum storage devices based on other principles so that we don't have to have these expensive wheels. The analysis of their functionality is otherwise identical. The disadvantages of the three axis approach is that we must have a very high reliabiblity thermal control system as one side of the spacecraft will be baking and the other will be freezing. This is being handled by other members of our team and will involve nice technology in heat piping.The coordinate system used in attitude control is shown in Figure 1.



The inertially fixed coordinate system $X_0Y_0Z_0$ is used to determine orbital position of the satellite. The attitude motion of a spacecraft is most commonly described in terms of an airplane three axis system, roll, pitch, and yaw. The roll axis X is along the orbit velocity vector. The yaw axis is Z, is along the vector from the center of mass of the spacecraft to the center of mass of the earth. The pitch axis Y is normal to the orbit plane so as to get a right handed coordinate system. The axes of the XYZ system has its origin at the center of mass of the spacecraft. It is rotating with respect to $X_0Y_0Z_0$ at an angular rate of once per sidereal in a three axis stabilized system. The perturbed attitude of the spacecraft coordinate system is obtained from the nominal attitude by the following rotations: ψ about the Z axis, θ about the once displaced Y axis, and ϕ about the twice displaced X axis. The angles ψ , θ, and ϕ are called the yaw, pitch, and roll errors, repsectively.

THREE AXIS STABILIZATION

As mentioned before, control torques are applied along the axes of the three axis stabilization system. We are proposing to use the equivalent of a zero momentum system with reaction wheels along each axis. For this section, assume that the thrusters have done their work and we are in the region of small error in the attitude angles and attitude angular velocity errors are also assumed small. We will accomplish a linearized analysis of the three axis stabilization system under these hypotheses. We have the facilities to solve the complete nonlinear systems numerically. However, for the process of "sizing" our needs, we may use this analysis freely as we will state explicitly what the cost of these assumptions are and how they affect the analysis later. Under the scenario of small initial error in all six states in our dynamical system, the effect of linearization will be small. We will express all angular velocities in a standard way, in terms of the orbital rate ω_0 and the attitude error angles as follows

$$\begin{aligned}\omega = \begin{pmatrix}\omega_x\\ \omega_y\\ \omega_z\end{pmatrix} &= \begin{pmatrix}1 & 0 & -\sin(\theta)\\ 0 & \cos(\phi) & \cos(\theta)\sin(\phi)\\ 0 & -\sin(\phi) & \cos(\theta)\cos(\phi)\end{pmatrix}\begin{pmatrix}\dot\phi\\ \dot\theta\\ \dot\psi\end{pmatrix}\\ &\quad - \omega_0\begin{pmatrix}\cos(\theta)\sin(\psi)\\ \cos(\phi)\cos(\psi)+\sin(\phi)\sin(\theta)\sin(\psi)\\ -\sin(\phi)\cos(\psi)+\cos(\phi)\sin(\theta)\sin(\psi)\end{pmatrix}\\ &\doteq \begin{pmatrix}\dot\phi-\omega_0\psi\\ \dot\theta-\omega_0\\ \dot\psi+\omega_0\phi\end{pmatrix}\end{aligned} \tag{26}$$

The total angular momentum of the system can be written as

$$\mathbf{H} = \mathbf{H}_L + \mathbf{H}_B \tag{28a}$$

where

$$\begin{aligned}\mathbf{H}_L &= (\,h_x \quad h_y \quad h_z\,)^T\\ \mathbf{H}_B &= (\,I_{xx}\omega_x \quad I_{yy}\omega_y \quad I_{zz}\omega_z\,)^T\end{aligned} \tag{28b}$$

ar the angular momentum of the momentum storage and spacecraft respectively. As before $I_{..}$ are the moment of inertia, $\omega_.$ are the angular velocities with respect to $X_0Y_0Z_0$. Going back to our moment equations of before, plugging and chugging with these values for $\mathbf{H}_L$ and $\mathbf{H}_B$ and *using small errors and linearization* we get

$$\mathbf{M} \doteq \begin{pmatrix} \dot{h}_x + I_{xx}(\ddot{\phi} - \omega_0\dot{\psi}) + h_z(\dot{\theta} - \omega_0) - h_y(\dot{\psi} + \omega_0\phi) \\ \quad - (I_{zz} - I_{yy})\omega_0(\dot{\psi} + \omega_0\phi) \\ \dot{h}_y + I_{yy}\ddot{\theta} + h_x(\dot{\psi} + \omega_0\phi) - h_z(\dot{\phi} - \omega_0\phi) \\ \dot{h}_z + I_{zz}(\ddot{\psi} + \omega_0\dot{\phi}) + h_z(\dot{\phi} - \omega_0\psi) \\ \quad - h_x(\dot{\theta} - \omega_0) - (I_{yy} - I_{xx})\omega_0(\dot{\phi} - \omega_0\psi) \end{pmatrix} \tag{29}$$

The external moments arise from three major sources: gravatitational gradient, solar radiation pressure, and control torques from the attitude control system. Let call these torques $\mathbf{M}_G$, $\mathbf{M}_s$, and $\mathbf{M}_c$. We will neglect the moon, Jupiter, solar gravity, etc. and say that

$$\mathbf{M} = \mathbf{M}_G + \mathbf{M}_s + \mathbf{M}_c \tag{30}$$

Let's take them each in turn.

DISTURBANCE TORQUES

Gravity Gradient Torque

Gravity Gradient Torques are caused by the fact that in reality a spacecraft is *NOT* a point mass but has mass at differing distances from the center of mass of the earth. We have used gravity gradient torques as a stabilization tool in UOSAT-1 and UOSAT-2, the University of Surrey, England's OSCAR 9 and 11 satellites.

Let dm be a small blob of mass in the spacecraft. Let $\mathbf{R}_0$ be the vector from the center of mass of the earth to the center of mass of the spacecraft and let $R_0 = \| \mathbf{R}_0 \|$. Let $\mathbf{r}$ be the vector from the center of mass of the spacecraft to the blob dm. Let $\mathbf{R}$ be the vector from the center of mass of the earth to the particle dm, and let $R = \| \mathbf{R} \|$. We know that

$$\begin{aligned} \mathbf{F} &= \frac{\mu_e \mathbf{R} dm}{R^3} = \mu_e \frac{\mathbf{R}_0 - \mathbf{r}}{\| \mathbf{R}_0 - \mathbf{r} \|^3} dm \\ &= \mu_e \frac{\mathbf{R}_0 - \mathbf{r}}{R_0^3} dm \left[1 + \frac{3\mathbf{r} \cdot \mathbf{R}_0}{R_0^2} + O\left(\frac{r^2}{R_0^2}\right)\right] \\ &\doteq \mu_e \frac{\mathbf{R}_0 - \mathbf{r}}{R_0^3} dm \left[1 + \frac{3\mathbf{r} \cdot \mathbf{R}_0}{R_0^2} \right] \end{aligned} \tag{31}$$

We have used $r/R_0 << 1$. Noting that $\int \mathbf{r} dm = 0$, because $\mathbf{r}$ is measured from the center of mass of the craft, and using (31) to get the gravitational moment the resultant of summing all these forces (integrating over dm) is

$$\begin{aligned} \mathbf{M}_G &= \int \mathbf{r} \times \mathbf{F} dm \\ &= \frac{3\mu_e}{R_0^5} \int (\mathbf{r} \times \mathbf{R}_0)(\mathbf{r} \cdot \mathbf{R}_0)\, dm \end{aligned} \tag{32}$$

The coordinate system xyz is related to the coordinate system XYZ which is given by the orbital axes. Since both at the center of mass of the spacecraft, the relationship is given by the rotations

$$\begin{aligned} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(\phi) & \sin(\phi) \\ 0 & -\sin(\phi) & \cos(\phi) \end{pmatrix} \begin{pmatrix} \cos(\theta) & 0 & -\sin(\theta) \\ 0 & 1 & 0 \\ \sin(\theta) & 0 & \cos(\theta) \end{pmatrix} * \\ \begin{pmatrix} \cos(\psi) & \sin(\psi) & 0 \\ -\sin(\psi) & \cos(\psi) & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \end{aligned} \tag{33}$$

Using this we may write $\mathbf{R}_0$ as

$$\mathbf{R}_0 = R_0 \left(-\sin(\theta)\mathbf{i} + \sin(\phi)\cos(\theta)\mathbf{j} + \cos(\phi)\cos(\theta)\mathbf{k} \right) \tag{34}$$

Substituting (34) into (32) we get

$$\mathbf{M}_G = \frac{3\mu_e}{R_0^3}\begin{pmatrix}(I_{zz}-I_{yy})\sin(\phi)\cos(\phi)\cos^2(\theta)\\ -(I_{xx}-I_{zz})\sin(\theta)\cos(\theta)\cos(\phi)\\ -(I_{yy}-I_{xx})\sin(\theta)\cos(\theta)\sin(\phi)\end{pmatrix} \tag{35}$$

From Kepler's laws, the orbital velocity (mean motion) ω_0 is given by

$$\omega_0^2 = \frac{\mu_e}{R_0^3}. \tag{36}$$

Substituting (36) into (35) and assuming again that the pitch and roll errors (θ and ϕ) are small, the gravity gradient moment is

$$\mathbf{M}_G \doteq 3\omega_0^2\begin{pmatrix}\phi\,(I_{zz}-I_{yy})\\ \theta\,(I_{zz}-I_{xx})\\ 0\end{pmatrix} \tag{37}$$

This will be used in our analysis of the torques on our spacecraft.

Solar Radiation Pressure Torque

A thing that might be surprising to most, the solar radiation pressure will provide the major long-term distance torque for our geosynchronous spacecraft. The solar radiation forces are due to momentum transfer from solar photons impinging on the spacecraft surfaces. A fraction, ρ_s, of the impinging photons will be specularly reflected, a fraction, ρ_d, will be diffusively reflected, and a fraction, ρ_a will be absorbed by the surface. While we are deciding on what materials and coatings will be on the surface, these numbers will be varying. Nevertheless we can derive their effect theoretically so that when the numbers are decided upon, we can "plug and chug". We can, however, derive the qualitative nature of the perturbations, and make quantitative SWAG's at the effects.

The surface area A, intercepts a beam of radiation with cross section $Acos(\psi)$ where ψ is the angle between the unit vector $\mathbf{n}$ normal to the surface and the unit vector $\mathbf{S}$ along the incoming photon. If all were absorbed, $\rho_a = 1$, the force on the area is $PA(\mathbf{n}\cdot\mathbf{S})\mathbf{S}$, where P is the solar radiation pressure. $\rho_a \neq 1$ in any real material, so

$$\mathbf{F}_a = \rho_a PA(\mathbf{n}\cdot\mathbf{S})\mathbf{S} \tag{38}$$

In a specular reflection, recall that "the angle of incidence equals the angle of reflection" so that we get

$$\mathbf{F}_s = 2\rho_s PA(\mathbf{n}\cdot\mathbf{S})\mathbf{n}. \tag{39}$$

The fraction diffusively reflected, ρ_d, can be considered to be absorbed and the re-emitted in uniformly distributed fashion into the hemisphere surrounding the point of "impact". Integrating the momentum transfer from this re-emittance over the hemisphere, we get that the tangential component is cancelled due to symmetry, of course leaving the normal term only. The total force is seen to be

$$\mathbf{F}_d = \rho_d PA(\mathbf{n}\cdot\mathbf{S})\mathbf{S} + \frac{2}{3}\rho_d PA(\mathbf{n}\cdot\mathbf{S})\mathbf{n} \tag{40}$$

Combining the forces above, the total solar radiation pressure on the surface is

$$\mathbf{F} = PA(\mathbf{n}\cdot\mathbf{S})\left[(\rho_a + \rho_d)\mathbf{S} + \left(2\rho_s + \frac{2}{3}\rho_d\right)\mathbf{n}\right] \tag{41}$$

Of course the fractions above add up to one. The solar radiation pressure moment $\mathbf{M}_s$ is given by

$$\mathbf{M}_s = PA(\mathbf{n}\cdot\mathbf{S})\mathbf{r}\times\left[(1-\rho_s)\mathbf{S} + 2\left(\rho_s + \frac{1}{3}\rho_d\right)\mathbf{n}\right] \tag{42}$$

where $\mathbf{r}$ is the vector from the center of mass of the spacecraft to the center of pressure of a given area, A. The solar radiation pressure, P, we will take as constant. We know that

$$\begin{aligned}\mathbf{S} &= \sin(\delta)\mathbf{J}_0 + \cos(\delta)\mathbf{K}_0 \\ &= \sin(\alpha)\sin(\delta)\mathbf{I} + \sin(\delta)\mathbf{J} + \cos(\alpha)\cos(\delta)\mathbf{K}\end{aligned} \tag{43}$$

where δ is the declination of the sun, α is the orbit angle measured from the space local noon, $\mathbf{I}_0$, $\mathbf{J}_0$, $\mathbf{K}_0$ are the vectors along the orbital axes at spacecraft local noon, and $\mathbf{I}$, $\mathbf{J}$, $\mathbf{K}$ are the unit vectors along orbital axes at α orbit angle. For a three axis stabilized spacecraft the solar radiation pressure along the pitch axis is very nearly periodic and thus for mean behavior, the net effect of this torque over an orbit period is nearly zero. The effect about the other axes has a secular component and will have to be accounted for. In most commercial systems, the solar arrays are kept rotating so as to point at the sun. This introduces the large secular terms about the roll and yaw axes. We will NOT have rotating solar arrays (wish we could afford them) but we will have antenna arrays that will introduce secular terms. In the application to our structure later, we will attempt to determine the mean secular terms from these arrays.

THREE-AXIS REACTION LOOP SYSTEMS

A three axis reaction loop system is three independent pitch, roll, and yaw control systems. Each axis will be controlled by changing the angular momentum of the loop system (wheels in commercial systems) in response to detected attitude error. We need attitude sensors for each axis and a loop for each axis. If we plug the equation (29) and (37) into (30), we get

$$\begin{aligned}M_{cx} + M_{sx} &= I_{xx}\ddot{\phi} + \left[4\omega^2(I_{yy} - I_{zz}) - \omega_0 h_y\right]\phi \\ &\quad + \left[-h_y - \omega_0(I_{xx} - I_{yy} + I_{zz})\right]\dot{\psi} + \dot{\theta}h_z - \omega_0 h_z + \dot{h}_x \\ M_{cy} + M_{sy} &= I_{yy}\ddot{\theta} + 3\omega^2\theta(I_x x - I_z z) + \omega h_x\phi \\ &\quad - h_z\dot{\phi} + \omega_0 h_z\psi + h_x\dot{\psi} + \dot{h}_y \\ M_{cz} + M_{sz} &= I_{zz}\ddot{\psi} + \left[\omega^2(I_{yy} - I_{xx}) - \omega_0 h_y\right]\psi \\ &\quad + \left[h_y + \omega_0(I_{xx} + I_{zz} - I_{yy})\right]\dot{\phi} - h_x\dot{\phi} + \omega_0 h_x + \dot{h}_z\end{aligned} \tag{44}$$

Once again, we will make "small" assumptions. We assume that even though these equations are obviously coupled, the small h_x, h_y, h_z, and ω_0 will allow us to ignore the coupling terms. If these coupling terms are eliminated then great simplification is afforded us in these equations and more importantly, the axes can be controlled independently. This will be the basis for the on board semi-autonomous control systems. During the early set up and despin phase, we will want to maintain constant ground control and can afford the complication of the coupling terms. These assumptions will in fact be adequate when we are on station and maintaining attitude. The equations will allow us to write simple equations for the control torques. The control torques are applied by letting the the rates of change of the angular momentum in our attitude control momentum storage devices be changed by applying power to them.

$$\begin{aligned} \dot{h}_x &= K_\phi(\tau_\phi\dot{\phi} + \phi) \\ \dot{h}_y &= K_\theta(\tau_\theta\dot{\theta} + \theta) \\ \dot{h}_z &= K_\phi(\tau_\psi\dot{\psi} + \psi) \end{aligned} \tag{45}$$

The control dynamics is very similar for each of these. We will concentrate on the pitch loop in a moment. The secular disturbing moments in the orbital coordinate system will lead to unacceptably high speed unless control jets or other devices are used to apply an external moment along the control axis to reduce the angularmomentum to well within the dynamic limits and as near to zero as possible. Therefore, the secular torques will require desaturation of the momentum storage devices. The cyclic disturbing torques will be "tuned out" by setting the gains, the K terms in (45), and should only affect the dynamic range allowable in the momentum storage devices.

Pitch Axis Control

For an initial look at the control of the pitch attitude, we will assume that the angular moment around the yaw and roll by the devices controlling those axes is zero. We will also assume that the slight asymmetry induced by the antennas in the moments of inertia about the yaw and roll axis is negligible. That is, $h_x = h_z = 0$ and $I_{xx} = I_{zz}$, respectively. In this case, our equation (44) for the pitch axis reduces to the much simpler

$$M_{cy} + M_{sy} = I_{yy}\ddot{\theta} + \dot{h}_y. \tag{46}$$

The solar pressure moment, M_{sy}, about the pitch axis is very nearly periodic because of the pitch axis angular rate of 1 revolution per sidereal day. For now, the control thrusters are not firing so $M_{cy} = 0$ and we are in the region of controllability for the fine adjustment devices. Thus our equation becomes

$$M_{sy} = I_{yy}\ddot{\theta} + K_\theta\tau_\theta\dot{\theta} + K_\theta\theta \tag{47}$$

by substituting (45) into (46). For $K_\theta, \tau_\theta > 0$, this equation may again be changed to a more convenient form, that of a second order damped system. The natural frequency, ω_θ, and the damping ratio, ζ_θ, are given by

$$\omega_\theta = \sqrt{\frac{K_\theta}{I_{yy}}} \quad \zeta_\theta = \frac{\tau_\theta}{2}\sqrt{\frac{K_\theta}{I_{yy}}} \tag{48}$$

The fine adjustment device is for applying a moment to the spacecraft to nullify the external moment. The transfer function of this well known and well studied control system is

$$G(s) = \frac{1}{I_{yy}s^2} \tag{49}$$

and

$$H(s) = K_\theta(\tau_\theta s + 1) \tag{50}$$

which gives us

$$G(s)H(s) = \frac{K_\theta(\tau_\theta s + 1)}{I_{yy}s^2} \tag{51}$$

The open loop transfer function, $G(s)H(s)$, has two poles at $s = 0$ and one zero at $s = -1/\tau_\theta$. Our design point will be to shoot for a critically damped system, $\zeta_\theta = 1$. For this system,

$$\tau_\theta = 2\sqrt{\frac{I_{yy}}{K_\theta}} \tag{52}$$

and the closed-loop transfer function is

$$\frac{\theta(s)}{M_{sy}(s)} = \frac{1}{I_{yy}(s + \sqrt{K_\theta/I_{yy}})^2} \tag{53}$$

We design the system with K_θ and τ_θ determined to maintain attitude errors within allowable limits that will themselves be determined by sun angle considerations and antenna pointing requirements.

The pitch error comes from several sources on our spacecraft, such as initial pitch error, impulse moments from the thruster burns for desaturation and station keeping, and the cyclic moment due to solar radiation pressure. Almost surely during thruster burn for station keeping the disturbance torques will be too large for the momentum storage devices to compensate for and thus jet firings will control attitude during these time intervals. In our design, a critically damped system, the response due to initial pitch error is

$$\theta(t) = \theta(0)\left(1 + \frac{t}{\tau}\right)e^{-t/\tau} \tag{54}$$

and

$$\tau = \frac{1}{\omega_0} = \sqrt{\frac{I_{yy}}{K_\theta}} \tag{55}$$

where $\theta(0)$ is the initial pitch error. If M_y is an impulse moment such that $M_y = m_0\delta(t)$, use of equation (53) gives us

$$\theta(t) = \frac{M_0}{I_{yy}}te^{-t/\tau} \tag{56}$$

The maximum pitch error occurs at $t = \tau$ and has value

$$\theta_{\max} = \frac{M_0\tau}{I_{yy}}\frac{1}{e} \tag{57}$$

For a sinusoidal disturbing moment, of the type

$$M_y = M_0 \cos(\omega_0 t) \tag{58}$$

such as the major components of solar radiation pressure moment, the steady state response is

$$\theta = \theta_{\max} \cos(\omega_0 t - \psi_0) \tag{59}$$

where the amplitude is given by

$$\theta_{\max} = \frac{M_0 \tau^2}{I_{yy}} \frac{1}{\left[(1-\tau^2\omega_0^2)^2 + (2\tau\omega_0)^2\right]^{1/2}} \tag{60}$$

and the phase angle by

$$\psi_0 = \tan^-1 \frac{2\tau\omega_0}{1-\tau^2\omega_0^2} \tag{61}$$

For $\tau\omega_0 << 1$, equation (59) is well approximated by

$$\theta = \frac{M_0 \tau^2}{I_{yy}} \cos \omega_0 t \tag{62}$$

The gain, K_θ, is selected on the basis of the steady state error and the time constant of the system.

The control torque is provided by the momentum storage device and using equation (45)

$$I_L \dot{\Omega} = -K_\theta(\tau_\theta \dot{\theta} + \theta) \tag{63}$$

The Laplace transformation of the equation for zero initial error is

$$\Omega(s) = -\frac{K_\theta}{I_L s}(\tau_\theta s + 1)\theta(s) + \frac{\Omega_n}{S} \tag{64}$$

where Ω_n denotes the initial angular velocity of the momentum storage device. For a critically damped with $\zeta_\theta = 1$, $\tau_\theta = 2\tau$, we get from (52) and (53) that

$$\Omega(s) = -\frac{2\tau s + 1}{I_L s(s\tau + 1)^2} M_{ys}(s) + \frac{\Omega_n}{s} \tag{65}$$

For impulsive disturbances of magnitude $M_y = M_0\delta(t)$, $M_{ys}(s) = M_0$, the loop angular speed response is

$$\Omega(t) = -\frac{M_0}{I_L}\left[1 + \left(\frac{t}{\tau} - 1\right)e^{-t/\tau}\right] + \Omega_n \tag{66}$$

The steady state response is

$$\Omega_{ss} = -\frac{M_0}{I_L} + \Omega_n \tag{67}$$

It follows from these equations that the long term effects of the impulsive disturbances is that the attitude does not change but the momentum storage speed changes as if the disturbance (jets firing etc.) acted directly on the momentum storage device. For a cyclic disturbing torque, the Laplace transform of the momentum storage response is

$$\Omega(s) = -\frac{(2\tau s + 1)sM_0}{I_L s(\tau s + 1)^2(s^2 + \omega_0^2)} + \frac{\Omega_n}{s} \tag{68}$$

For $\tau\omega_0 << 1$ the inverse Laplace tranform of the reduced formula in (68) is given by

$$\Omega_{ss} = -\frac{M_0}{I_L\omega_0}\sin\omega_0 t + \Omega_n \tag{69}$$

A secular disturbing torque will lead to an infinite angular momentum in the momentum storage devices unless an external moment along the pitch axis is applied and this is supplied by the jets and is called desaturation. The primary difficulty facing us is to determine error rates for pitch $\dot{\theta}$. The other axes are treated in a similar manner and will not be done here. This completes the theoretical derivation of the modeling equations for the attitude control system for Phase IV satellites as proposed by the current engineering committee design.

[1] **Design of Geosynchronous Spacecraft**, Brij N. Agrawal, Prentice-Hall, 1986.

[2] **Spacecraft Attitude Determination and Control**, Ed. James Wertz, Prentice-Hall, 1972.

Project SPARC at Northeast High - Two Decades of High School Space Science

Presented by Howard I. Ziserman, WA3GOV

Precollege students rarely get intensive field experience in space science, since most teachers at the high school and junior high school level have a difficult time even teaching basic physics and chemistry in the classroom. The pattern seen in the usual school is that science projects outside the classroom are limited and follow the basic curriculum. The amateur radio space program can augment classroom teaching of science by using the after school radio club as a window into low earth orbit and the basics of orbital mechanics, astronautics and electronics can be learned easily.

This presentation will describe a different type of school - a school where the after school club, although not a ham radio club at first, produced a change in the science curriculum of the school and brought about the founding of a "magnet" school concept specificly aimed at teaching space science with a hands on approach. Northeast High School in Philadelphia, PA has, for 24 years, had a space science program that teaches students the value of science education by being involved in the actual construction and operation of intricate spaceflight simulators. The aerospace magnet school draws students from all over the city of Philadelphia to special sciece courses. Many of these courses evolved into the classroom as a result of work on the various spacecraft simulators. Project SPARC (for SPAce Research Capsule) has now, in the mid 1980's, taken a new direction. With the flight of the first shuttle amateur radio experiment (SAREX) the extracurricular direction of space science education has now shifted from spaceflight simulations to the tracking of actual manned and unmanned spacecraft. The amateur radio club station at Northeast High, W3YC, has now become the central focus of project SPARC.

The use of the OSCAR satellites for communication and experimentation has begun. Future projects include the development of an experiment to fly as part of a NASA Get-Away-Special on the space shuttle and subsystem development and building of a transponder package for a future shuttle ejectable satellite.

AMSAT/National Space Society (NSS)

Space Education Network

by
K.O. Learner, II K9PVW P.O. Box 5014 Kokomo, IN 46904-5014
Office (EST in Indiana) 317+451-8767 Home 317+453-2947
AMSAT/NSS Space Education Net Manager
and
Greg Barr, Deputy Executive Director, National Space Society
Office: 922 Pennsylvania Ave, SE Washington D.C. 20003
202+543-1900 Home 202+544-4984

Abstract

The National Space Society (NSS) and the Radio Amateur Satellite Corporation (AMSAT) announce the Space Education Network (SEN). The goal of the Network is to provide information and conversations of interest to radio amateurs and others concerning a wide variety of space science and engineering topics. The Network will consist of amateur radio stations, both on the Earth and in space.

Bulletin and conversation topics and participants will be coordinated by the NSS. AMSAT will coordinate the amateur radio stations which will form the network via an amateur radio communication satellite.

Transmitting (uplink) capability will be optional for Earth stations in the Network, as some sessions will provide an opportunity for conversations between various Earth stations and the presenters.

Space Education Network communication services will be provided for interested educational groups by radio amateurs as a voluntary public service.

Some sessions will provide Slow Scan Television (SSTV) video. SSTV will provide approximately one high quality color picture per minute.

For direct reception and optional transmission via the satellite outdoor antennas are required. In some areas the SEN may be available on local amateur repeaters making reception possible with a handheld radio.

Background

As paraphrased in The FCC Rule Book(1), the Amateur Radio Service is defined as a voluntary, disciplined communications service guided by five traditional objectives:

1) to provide emergency or public service communications when normal communications are disrupted;
2) to advance the state of the art;
3) to improve individual skills in radio operation
4) to provide a reserve pool of qualified radio operators and technicians: and
5) to promote international goodwill.

The FCC rules consider the goals of the Amateur Space Service, in which we operate when working OSCARs, to be the same as the goals of the regular Amateur Radio Service. It seems natural to expand the range of knowledge implied by these goals from conventional radio techniques to a comprehensive group including many space related topics. Certainly the design, construction and operation of amateur radio communication satellites are making a large contribution toward meeting these goals. It is a logical step, therefore, to examine how the tools put in place by the satellite constructers may be used to further the goals of the Amateur Radio Service.

Need for Space Education

With the advent of space communications in amateur radio new communications skills have been required. The techniques of using OSCARs have already been spread to many hundreds of operators. However, the skills and knowledge required to design a mission for space operation remain concentrated in a few, dedicated individuals. Part of developing applied technology is to train many in the skills of an original few. To fulfill the goal of providing a trained knowledge pool, the amateur space community must institute a program of training in space operation techniques.

Also, it is natural that these new space communicators will desire to learn more concerning the functioning of various equipment and systems in space. Indeed, space engineering depends heavily on the sciences of physics and astronomy. With this strong dependence, there is a growing need for more educational material in these topics to be presented to the amateur radio community.

In addition to the radio amateurs interested in space activities, there are a growing number of members of 'grass-roots', space oriented organizations. There are a number of people who are already working in both areas, but the potential growth for both amateur radio and other amateur space interests is quite substantial. The possibility exists for a great synergism between amateur radio and other space interest groups.

Perhaps the most lasting enthusiasm will be generated among the young people touched by these ideas. Young people already interested in the various space related sciences will find in the amateur radio community a spirit of active experimentation in various space topics. Those entering amateur radio because of its communication aspects will be exposed to the world of space sciences. The result will be a meaningful knowledge experience for young people and a general trend of higher technical skills for the Amateur Radio Service of tomorrow.

In addition to the goals of involvement and enthusiasm, development of an educational space communications service will help to occupy and demonstrate efficient usage of amateur radio's valuable VHF, UHF and microwave spectrum allocations.

Introducing the Space Education Network

Given that one of the goals of the Amateur Space Service is to provide a pool of operators trained in the various topics of space communications, how can this be achieved?

One method of reaching this goal is through printed handbooks, manuals and articles in amateur radio and other periodicals. This method of education is quite successful if the person is aware of an interest in the topic. Quite a large body of excellent space education material exists in printed form at this time. As reference material it is indispensable. But, perhaps there is another forum that will catch the attention of people who are not aware of the space engineering work that has already been accomplished.

AMSAT and NSS leadership believe that the time has come to offer a technical and issue oriented communication session for radio amateurs via OSCAR. Realtime, interactive sessions including audio, video and data transmissions of bulletin material relating to space and communications sciences will be powerful 'lures' to newcomers. We expect this network to ignite sparks in both seasoned amateurs and newcomers, young and old. Because amateur radio will soon possess the communications tools necessary to link one third of planet Earth in such a real-time network, the opportunity has arrived to further space education.

AMSAT and the National Space Society (NSS) are pleased to announce that they have jointly established the AMSAT/NSS Space Education Network (SEN).

Goals

The goals of the SEN are:

1) to improve individual skills in the art of space communications
2) to encourage and facilitate a synergistic relationship between the amateur radio community and all people with an interest in space science and technology
3) to conduct a weekly network of amateur radio stations via an amateur radio communication satellite for the purpose of discussing material of interest to the amateur space community.

Bulletin Material

With its educational charter, the National Space Society is clearly in a position to assist and benefit from, its role as supplier of bulletin material for the Space Education Network. Mr. Barr, as administrator of the L5 Society, prior to the merger with the National Space Institute, began a correspondence with several volunteer members of the organization who had listed their resource skills as curriculum developers. Out of his survey of their interests came several suggestions for the development of a space development course.

In an effort to organize these individuals situated across the United States, project leadership was turned over to Thomas Becker, an educational consultant living in Missouri. After over a year of development work, Mr. Becker produced a report whose recommendations are of special interest in the development of this project.

The topic of "space education" is broad enough to encompass the history of rocketry, a history of events leading to the beginning of the Space Age thirty years ago this year, the achievements of the USSR, the United States and many other countries who currently possess or are working on a spacefaring capability, the impact of space technology on nearly every scientific discipline, and "the classroom instruction of scientific, sociological and artistic concepts of space technology and its daily application to human living on and off planet Earth."(2) In his recommendation to the Board of Directors of the L5 Society, Thomas Becker states "The space frontier is already an established frontier of human activity; in order to support this new and promising culture, the global community will have to become directly involved in the business of education."(2) It is our belief that the AMSAT/NSS Space Education

Network is a vital part of that involvement.

It is clear that a five to ten minute news and tutorial session on the subject of space development will not soon run out of information content. The challenge lies in organizing the material so that each session of the Space Education Network is selfcontained, yet, if combined together, becomes a cohesive, long-term educational presentation. In view of the broad spectrum of applicable material, we would like to suggest that we attempt to segment the contents of the SEN bulletins as follows:

News

Each week would open with five minutes devoted to current space development news from publications such as Space Daily, Space Business News, Aviation Week & Space Technology, Sky & Telescope and Science News.

Which Way is Up?

A look at the present state of space development with particular emphasis on the obstacles, both technical and non-technical, which appear to prevent the United States from pursuing an aggressive space program. This proposed ten minute segment would also provide a forum for emphasizing the positive achievements of existing space programs.

Once and Future Legacy

Space development aspires to open the possibility of a hopeful future like no other single program that planetary citizens have available. Why does it uniquely address the problems facing the world today? The synergy needed between many scientific disciplines in order to sustain human life in space provides a technology driver unlike that of any other program. How does the unique environment of space make it an ideal laboratory for research, development and manufacturing? These and related questions will be presented and discussed in this ten minute segment devoted to possible futures involving the development of space.

Retrospective

A brief look at any milestones in the history of the Space Age for the upcoming week.

Views

Mention of recent editorial viewpoints on aerospace issues.

Tutorial

The subject matter of these tutorials will range over a broad area of technical and scientific issues. Proposed topics include a description of how the amateur radio communications satellite being used for the SEN works, how it was placed into its orbit and why the particular operational characteristics it possesses were determined. This relatively concise topic can grow to encompass rocket motor design and operation, from the scale of launch vehicles to the motor contained in the spacecraft itself. From the beginning point of the spacecraft operating frequencies, a discussion of astronomy can ensue describing the relative noise contributions of the sky and the Earth as a function of frequency.

Beyond the currently operating spacecraft are several projects being proposed and designed by a variety of groups. Tutorials concerning these projects would serve to inform the amateur space community of both the techniques to be employed and how they might become involved.

Following Views, time will be allowed for interactive discussion. This discussion time will be most productive if those involved in the production of the material could be present to answer questions or stimulate discussion.

The total projected session time if all of these segments except Tutorial are included in a given bulletin would be on the order of one half-hour. When including a tutorial of more than one half-hour, the SEN will probably omit one or more segments. It seems likely that a SEN session of approximately one hour maximum is a good target. It is our feeling that material abounds in each area and there will rapidly come a time when choosing segments will become difficult.

The "segment "format also allows expansion and replacement of modules. For instance, a parallel project to involve the National Space Society Chapters in amateur radio satellite linkups would generate an interest in a Chapter News segment. Another advantage of the segmented format is that it easily allows bulletin material to be provided by a number of different groups.

Volunteers, both from NSS and AMSAT, will provide material to assist in the training of groups interested in producing bulletin segments for the SEN. Topical guidelines will be supplemented by writing guidelines for the bulletins. While the primary participants in the SEN will be radio amateurs with a relatively high level of education, the material should be written to be comprehensible to the average high school student. Since SSTV will be available for the SEN, special material will be produced to introduce the use of visual aids to accompany the voice bulletins. Material originated for the SEN should also meet certain standards so that it might be used for other educational applications such as development of reproducible audio/visual aids for public or classroom presentation.

It is the responsibility of NSS to coordinate segment topics among potential participants. It is the responsibility of AMSAT to coordinate the physical network resources. AMSAT and NSS will individually review each bulletin segment proposed for the SEN and the SEN will be conducted by volunteers who are members of AMSAT and/or NSS.

The Network

In the near term, AMSAT is expecting the launch of its second Phase-III spacecraft (Phase III-C) in the Winter of 1988. Given a successful launch, the spacecraft will become operational in early Spring, 1988. The Phase III series of amateur communication satellites are long lived, very sophisticated spacecraft. Placed in highly elliptical orbits, they spend many hours of each of two orbits per day continuously visible to the northern hemisphere. Further out in time is the AMSAT Phase IV program which is planned for geostationary (Clarke) orbit and an ideal vehicle for the SEN.

Phase III-C carries three transponders which may be used for the SEN. The first transponder to be activated will most likely be the mode J,L transponder. This device translates a band of frequencies from the 2m and 23 cm amateur bands (uplink) to the 70 cm amateur band (downlink). The mode J,L transponder is likely to be used for SEN most often.

The mode J,L transponder is a linear transponder that works most efficiently with CW or single-sideband (SSB) modes of transmission. The transponder can support several tens of SSB conversations at once. SSB may be used to transmit voice or any other modulation format that uses audio frequencies and results in a signal that is no wider than a voice signal. Within current amateur radio practice is a technique called slow-scan television (SSTV). SSTV can transmit a still picture, in color, with about the resolution of standard TV in about 36 seconds. Some sessions of the SEN will also include SSTV pictures to augment the voice bulletins and tutorials. Packet or digital (computer to computer) communications are also supported by this transponder. Software and other written data can be sent conveniently via packet radio at 1200 bauds.

Network Operations

The SEN will be conducted each Saturday. A period of time will be provided for members of the net to 'check-in' before the bulletin material is presented. At the conclusion of the bulletin, time will be provided for questions. As mentioned before, it is intended that the group responsible for production of each bulletin will have a representative present on the net for discussions. When SSTV pictures are available to accompany the bulletin, they will be transmitted before, during and after the bulletin material. This will allow a station with only one receiver to receive and record the SSTV for playback concurrent with the voice material or to have a second chance at reception.

The Phase III-C spacecraft will make approximately two orbits per day. This means that there will be two apogees per day. The SEN will be in session on each apogee. Apogee times are chosen because they are both the time of maximum radio coverage and minimum apparent motion of the spacecraft. This means that an antenna could be pointed at the predicted heading for that apogee and tracking could be avoided. Also, the doppler shift at apogee time is very small and changing very slowly which means that receiver tuning is practically eliminated.

The full potential of the SEN will be realized with interactive communication between the presenter of the bulletin material and the member stations of the SEN. Interactive communications with the coverage of a Phase III or IV spacecraft is a very powerful educational tool. As noted earlier, there are already a number of stations equiped for this type of interactive communications. As part of the public service aspect of amateur radio many of these stations will be available to share the enthusiasm of the SEN. The involvement of different modes of amateur communication such as OSCAR and SSTV will expose those who currently operate only one of these modes to another facet of amateur radio.

SEN and You

There are presently more than 1000 amateur stations equipped for OSCAR operation in the USA. This base provides many potential stations for the SEN. Each of these stations could provide an input to a local repeater to allow reception over a large area with a handheld radio.

AMSAT is a pioneer in the design and use of low cost satellite communications stations. This expertise has been well documented in the amateur radio literature and several handbooks. Interested short wave listeners (SWL) may wish to assemble a receiving station for OSCARs. Construction of such a station would make an excellent educational project at high school or college level.

Conclusions

The creation of an AMSAT/NSS Space Education Network using amateur communications satellite technology is overdue. The National Space Society, as a nexus of information on space development, is in a key position to fulfill its educational charter by coordinating the SEN bulletin material. By demonstrably applying space technology to space education, both AMSAT and NSS will create a greater general awareness of the potential of space development and further each organization's charter. This project will also reinforce the agreement in principle begun between AMSAT and the L5 Society in 1985 and demonstrate the potential of a further joint undertaking in the realization of the AMSAT Phase IV project.

References

(1) The FCC Rule Book, The American Radio Relay League, Sixth Edition 1986

(2) Assessment Report of the Director, Thomas Becker, Interim Space Curriculum Development Task Force, L5 Society

PACKET RADIO - THE USER INTERFACE

By Joe Kasser G3ZCZ

Introduction

The majority of the thinking and the software development in Packet Radio to-date has been in the area of the BBS and in message handling. Everyone assumes that messages exist yet ignore how those messages got into the packet radio network in the first place and how they get out of it later. This paper addresses that neglected aspect of the gendre; in other words, the User Interface or the Personal Packet Terminal Program (PPTP) and the environment in which it resides.

The Packet Radio Medium.

The Packet Radio Medium consists of what is happening in a given local area on a frequency channel time-shared by a number of amateur radio stations. It is a multiple access or distributed situation which has so far been treated almost the same as a single point-to-point situation such as the telephone line.

Unlike in a telephone based network, many of the stations in the network can, in real time, see information passing between other stations in that network. [1,2] Whereas the telephone based net may be considered as a centralized network in which everyone on it is connected to a single host, the amateur radio packet Local Area Network (LAN) is spread over a geographical area and should be considered as a distributed network. Packet Radio software to-date has been designed for a one-on-one connection ignoring the one-on-many capabilities available in a distributed LAN.

Consider the medium itself, Packet Radio is an ideal MESSAGE MEDIUM. While there is place for keyboard operation, Packet Radio really shines when passing messages. The Packet Radio operator is really interacting with the LAN. The TNC and PPTP can be considered as a single element between the human operator and the LAN, so that any discussion of the user or human interface must take into account activity on the LAN.

Packet Radio LAN Capability

VHF Packet radio systems can be considered as part of a LAN in which messages can be left by one station in a computer belonging to a second station. At HF the same is true, but the area of the LAN becomes greater.

The fundamental problem within the LAN is that people can only send and receive messages to or from any specific station when that station is on-line. To compensate for this, Packet LAN development parallelled that of the centralized telephone network. BBS stations were developed which allowed both messages and bulletins to be stored for later retrieval. As the requirement for bulletin messages is real in the Radio Amateur environment and the centralised LAN concept meets the requirements of both bulletin and point-to-point messages, the distributed LAN approach for point-to-point messages in the main seems to have been ignored.

Most Amateur Packet Radio Stations use computers to interface the TNC to the LAN. As there is all this computer power sitting in the shack, why not take advantage of it and include within the PPTP software which takes into consideration both the characteristics of the distributed LAN and how optimum use can be made of them for the user.

The User Interface.

This is defined as what the user types at the keyboard and sees on the screen of his computer when it is connected to a working TNC which by definition is part of the LAN. When somebody first gets a TNC, he gets a 'black box' which comes with a manual that seems bigger than than the box itself. The instructions on how to connect it to a transceiver may be easy enough to follow, but then the instructions on what to type and when, are a nightmare.

The TNC can operate in a Command Mode, in which you tell it to do something, or in a Converse Mode in which you are using it to pass text of some kind to other stations. Many newcomers confuse the two TNC modes. If you monitor the packet channels you will recognize command mode TNC instructions on the air, and when you use the TNC, well I'm sure that you still get, now and again, an 'Error' message when you type something thinking that you are in the Converse Mode but are really in the Command Mode.

The Personal Packet Terminal Program [PPTP].

Most of the commands that affect the parameters within the TNC are normally never touched. In fact once 'CONNECT', and 'DISCONNECT' have been figured out, and the difference between the Command and the Converse Modes (and how to get from the one to the other) are understood, the newcomer is able to use Packet Radio. From this time on he rarely uses any of the other TNC commands with the possible exception of 'MH'. Even the ones that should be adjusted when changing from VHF to HF operation most often never are.

From a human factors point of view, Packet Radio under these conditions is dissapointing. Tests have shown that the attention span of a person sitting at a terminal is about 2 seconds. In conventional RTTY, or AMTOR operation, the data communications rate is might be slow but at least something is happening all the time. In keyboard to keyboard Packet Radio contacts, often minutes seem to pass before the next packet shows up on the screen.

The PPTP's most commonly used at present on PC's are either YAPP [3] or conventional telephone modem driver programs. There is no smart PPTP. The need for "smart" PPTP's is however being perceived. The Mini BBS seen on the air is one example. Another example noticed in London and in Israel, is that stations equipped with IBM PC's or clones start off by using BBS programs as their PPTP. On one evening in London in August 1987 G3RWL taped about 10 BBS's, point to point direct connects, stations doing muti digipeat connects to other stations as well as to the BBS's all on the same channel and all using it simultaneously. It is a wonder that any traffic got through.

A PPTP program written in Turbo Pascal, named PK232COM, that is optimized for the radio amatuer LAN has been developed for the MS- DOS, IBM PC series of microcomputers. Although first written for the AEA PK232 Multi-Mode Data Controller, taking advantage of some of the specific commands built into the PK232. It has since been modified so that most of the PPTP Packet Radio functions will also work on a TNC2. The following list contains much of what this PPTP does both as the user interacts with it, and how it performs LAN related activities.

* Function Key Control

The commands to the TNC lie somewhat in between a mixture of operating, configuring and debugging. This PPTP relieves the user of figureing out how to tell the TNC to do what he wants it to do. It takes advantage of all the computing power at the user's fingertips (literaly) and uses software which may be locate either in the TNC or in the PPTP, but totally transparent to the user. The user in fact never has to tell the TNC to go into or out of the command or converse modes. The user tells the PPTP what he wants done by means of function keys, and the PPTP figures out what to tell the TNC to do the job.

* Terminal modes.

There are four single connect modes and two multiple connect modes of operation, as follows.

1 SOLO

In this mode, you will only see messages addressed to you. You will only get messages from people who connect to you. (This corresponds to 'MONITOR OFF').

2 TRAFFIC

In this mode you will see most of the traffic on channel. You can use this mode to check that the TNC is working. (This corresponds to the PK232 'MONITOR 4' [4] or 'MONITOR ON').

3 CQ/BEACON

In This mode, you will see CQ and BEACON packets on the channel. (This corresponds to the PK232 'MONITOR 1' and only works on the PK232.

4 READ THE MAIL

In this mode the terminal is set to display the contents of packets without the headers for selected stations. Apart from being able to copy both sides of a QSO, you can read the mail on a BBS or other stations and get BBS bulletins without connecting to that BBS your self. This cuts down on the number of messages sent on the LAN, since more than one station can copy the same Bulletin at the same time. This corresponds to 'MONITOR OFF' and 'MBX' <callsign> and only works on the PK232.

5 MULTIPLE CONNECT CAPABILITIES

Advantage is taken of the 10 I/O streams in the TNC for multiple access modes as follows;

5.1 The Individual Multi Connect Mode

This is the normal Multi Connect Mode as described in the TNC manual. Here you are connected to up to 10 stations and will send different traffic to each of them. Each time you wish to send something to a particular station, you must select the IO channel the station is connected on before typing the text or sending the file.

5.2 The Conference Multi Connect Mode.

In the Conference Mode on the other hand, everything that you type at the keyboard is transmitted to each station that you are connected with. Thus if you are linked to two stations each line will be packeted twice by the TNC. You don't have to worry about sending the wrong thing to the wrong person, as they will all get the stuff. This mode should be ideal for DX nets, 'contest spotting' and public event support.

* Automatic Answering Machine capability with display of message queue.

The PPTP incorporates a smart "answering machine" facility. You can leave messages on your system for different stations. When someone connects to you, if you left a message for him, he (or she or even it as the case may be) will receive it automatically. No one else should normally be able to download that message.

To ensure that people know that you have left a message for them, a 'MAIL for' list is loaded into your Packet Beacon and transmitted every 30 minutes. If no mail is pending then beacon transmissions are inhibited. This conforms to good operating practice on crowded channels (at least inhibiting the beacon does).

* Automatic Capture-to-Disk

All traffic received during connects is stored onto disk. Provision is also there for manual capture of any traffic monitored on the screen.

* Automatic logbook entries for Connects.

All connects are logged into a separate logbook file. The Logbook file is capable of being processed by a database Logbook Package.

* Printer on/off control.

The PPTP can print incoming information and will automatically shut off the printer on disconnect.

* Alert signal

The PPTP contains an Alert function to let you know when someone shows up on LAN. It is active when disconnected and the terminal set for 'TRAFFIC'. The PPTP scans the packet headers received from the TNC, and, when it sees a packet originated (or digipeated if the MRPT parameter in the TNC is set to 'ON'), by the station whose call has entered as the 'Alert' call, sounds an alarm at the console. The Alert function should (but can't be without getting at the TNC firmware) be independent of the terminal communications mode.

* Indicator that a specific station designated as the 'Target' call connected while you were away.

This function saves you dumping the capture-to-disk file to check if traffic has been received from a particular station who promised to send you some data that you need urgently.

* Split screen terminal display, at least three Windows displaying Incoming text, Outgoing text and Status Information.

The Status information includes the call of the Station you are connected with (if any), PPTP mode and status, number of connects, number of messages outstanding, PPTP configuration, Alert and Target calls.

When the PPTP sees a connect by the station whose call you have entered as the 'Target' call, it sets the flashing Connect Counter display to show a 'happy face'.

* Simplified keystrokes for connect paths and loopbacks.

Connect path information may be stored in an ASCII text file (PK232COM.DIR which is compatable to YAPP.DIR [3]) in the following format.

```
Alon 4Z4ZB V 4X6AA
Milt 4X6AA
LR   4X6LR
hf-il 4x4hf v 4z4zb 4x4il
hf-rj 4x4hf v 4z4zb 4z4rj
```

You create this file with your wordprocessor in its non document mode. You must leave AT LEAST one space character between the key word and the connect path. When you attempt a connect, the PPTP scans this file to see if what you typed matches one of the key words (first word) on any line of the file. It also ignores the case of what you typed in. If it does not find the key word, it will try to connect with whatever you typed in.

A LOOPBACK is when you connect to yourself through someone else. You should use this to test a connect path when the station you want to connect with is connected to a third station. Instead of causing QRM to him by trying to connect to him and getting a 'busy' signal if the path is good, loopback using him as a digipeater to test the path. The loopback should be performed with a minimum of keystrokes. Thus to loopback through K8PNW you just have to use the regular PPTP function key that does the connect operation (Function key 7), but type '/K8PNW' (slash [callsign] instead of [yourowncall] via [callsign]).

* Path determination to Dx station.

On VHF, if you want to establish a digipeat path to a station somewhat out of your direct range, you need to know which of the stations that you can connect with can hear that desired DX station. If you could get a call monitored (MH list) from the stations that you connect with, you would be able to see if the station you are connected with has heard your desired DX station. Thus as the TNC can't do it, the PPTP is capable of being triggered to send its 'MH' list to the connecting station.

By judicious use of this capability you can determine paths to other stations. Note however, that just because one station can hear another station, it does not mean that it can work it. For example, the station you are connected with may be using a power level of 1 watt or so, while the station 200 miles away that it heard was using 100 watts. Test the path yourself, or/and leave a message asking about the reliability of the connect path between those two other stations. The DX station also may not be on-line all the time.

* Remote File Downloading

There comes a time when you want to leave a file on your system for someone to download later. For example, you have the latest AMSAT or ARRL DX bulletin, and you want to pass it on. You could pass it to selected people by copying the file to individual messages which wastes a lot of disk space.

On the other hand you

could tell people that the file was available for downloading. You could do this either in the CTEXT connect message line which everyone gets when connecting to you, or in individual messages if you don't want everyone to know about it. The PPTP is not designed as a BBS, however it does have the capability for remote downloading of files.

* Automatic Count of, and indication of Packet connects.

  The counter shows the number of connects made to the PPTP since you last reset the counter. Its a usefull indicator of how much trafic has come in since you last looked at the screen. The counter is resetable by means of a function key.

* Digipeat monitoring and capture.

  Although the TNC can digipeat on its own, there may be times when you want to know when you are being used as a digipeater and to capture-to-disk the contents of any packets digipeated through your station. (A typical example of this situation is when stations on your 'forbidden country list' digipeat through you and you may have a need to show what data was "exchanged".) This capability is in the PPTP.

* Capable of automatic connect attempts to snatch a QTC.

  In the disconnected state, the PPTP monitors 'QTC' lists and when it sees its own call in one, automatically attempts a connect to snatch the message. In this manner there is no need to manually repeat connect requests to stations to whom messages are addressed in the hope that they have joined the LAN. When any station signs on to the LAN (ie the time when the equipment is powered up), it will, within 30 minutes, monitor a QTC list from every other station on the LAN and download its own traffic. In fact in an ideal situation, all one would have to do to "send" a message would be to leave it in one's own PPTP which would then set the QTC list in the Packet Beacon. The QTC_Snatch in the destination PPTP function would take care of the message transfer.

  In the PACSAT environment, the QTC_Snatch function would be used to automate reception of messages at remote ground station sites. When the spacecraft is within the communications window of a ground station for which it has traffic for and transmits a beacon 'QTC mail-for' list, the ground station will automatically download its traffic.

  As the QTC_Snatch may not be legal in certain countries, this capability is only configurable at the time of loading the program and is not re-configurable on-line.

* Automatic Beacon Mode CQ caller.

The PPTP has the capability to call CQ repetetively and either signal you when a reply is received or work the connect and call CQ again after the disconnect.

This ROBOT feature is designed for DX-Peditions, special event stations, meteor scatter, moonbounce, propagation research beacons, areas of low activity and to enable "off-channel" or random frequency HF Packet operation.

In case of abuse: if someone running the PPTP has their beacon timer set too often, the PPTP can be shut down remotely by someone connecting with it and telling it to 'QRT'. This takes them off the air for a while at least.

* Local Area Network (LAN) store and forward.

The PPTP is capable of storing messages to be delivered in the manner of a 'selective' answering machine. When someone connects, any message pending is delivered without the need for any further action. In case of some error a 'repeat request' function is available.

All stations in the LAN should in the ideal case be able to store messages for any other station in the LAN.

* Bulk dump (forwarding) of messages around the LAN.

There are many instances when the owners wish to take their systems off-line yet still wish that their messages be posted in the LAN. The PPTP thus contains a facility for bulk 'dumping' of messages between different computers in the LAN.

<u>LAN Protocol</u>

The LAN has to be usable by all stations connected within it no matter how smart or dumb a PPTP they are running. The commands thus should be manual as well as function key driven. The language used should be reasonably familiar to Radio Amateurs and be capable of being used by those with little or no knowledge of English.

In the LAN environment, path determination and other functions as well as messages transferrence may be performed using elements of the Q code adapted into a High Level Network Communications Language (NC/L) [1,2].

To receive a message, do nothing, you receive them automatically when connecting/linking to another station. In case of a problem you may request a repeat. You should also normally not be able to read messages adressed to another person. Bulletins are not considered as messages, they are considerd to be files.

NC/L uses elements of the Q code in CAPITAL letters with a ':' character prefix and suffix (eg. :QSL:). The PPTP doesn't respond to Lower case 'Q' NC/L commands in order to allow 'help' information to be transmited over the air without also triggering a response.

Elements in use to-date in PK232COM Version 1.43 are (in alphabetical order) as follows.

:EOF: End of message, (^Z is used in Packet, :EOF: is used in AMTOR).

:QBM: To download a file.
:QJG: No more messages pending.
:QMH: To request a 'MH' list.
:QNO: Error or function not present/active.
:QRV: Ready for message.
:QRT: To shut down a packet mode beacon station.
:QRU: To upload messages.
:QSL: Confirm receipt.
:QSM: To request a repeat of a message.
:QSP: To leave a message.
:QTC: Messsage list.

Proposed extensions are as follows.

:QYU: YAPP format file upload.
:QYD: YAPP format file download.

NC/L In Use.

All command words in NC/L if requiring an extension, are followed by one space character. The following words are transmitted to a remote PPTP.

:QBM: To download a file, send :QBM: filename.type.

The filename.type is the file you want. For example

:QBM: ARRLDX.Ø15

Note the single space character between :QBM: and the file name. The PPTP is not designed as a BBS, however if you leave a file or bulletin for someone to download, you may tell them about it by leaving them a message (which they will get automatically when they connect) and no one else connecting will know that it is there.

:QMH: To request a call monitored list ('MH') from the station that you are connected with, send :QMH:.

:QSM: To request a repeat of a message, send :QSM:.

You use this if the link was marginal and the connect request got through but the data didn't.

:QSP: To leave a message for someone, send :QSP: callsign.

The protocol is as follows. When connected to someone who has their computer configured as a host, if you want to store a message you send the following instruction to the other station :QSP: <callsign> where <callsign> is the call of the station that the message is for, not the callsign of the host station in whose computer you are storing the message. Do not use SSID's. [Note use only one space character after the :QSP:].

For example if you want to store a message for G3ZCZ, or G3ZCZ-1 or even G3ZCZ/4X in 4X6AA's computer which is configured to Store and Forward messages, you would first connect to 4X6AA and then send the request to store the message as
:QSP: G3ZCZ .

The other computer will respond either with a statement saying that it is ready for you to go ahead, or send a message saying that it can't comply. If it is ready you get a positive reply in the the form of :QRV: <callsign> which if you know the Q code, means " I am ready to accept a message for <callsign>".

At this time you may go ahead and send the message. Use either a control Z (^Z) character or the character sequence :EOF: followed by a carriage return (the ENTER key) to terminate the message.

Once you have completed the message, the other (host) computer will either reply that the message has been successfully stored or give you an error message.

If the message is stored and ready to be sent next time the addressee connects to that computer, you will see the response :QSL: on your screen. If something went wrong, you will get back a negative response taking the form :QNO: followed by a number. The number tells you why the operation failed.

:QRT: To shut down a packet mode robot or beacon station which is causing QRM, connect with that station and tell it to 'QRT' by sending :QRT:.

:QRU: To upload or download messages from one PPTP to another, send :QRU:.

When the QRU function is invoked locally or remotely, either by you or for example, by 4Z4ZB connecting to you and sending you the command :QRU:, any messages addressed to any stations for which you have designated him as a 'Store and Forward' node (MBX) will be transferred from you to 4Z4ZB just as if you QSP'd the messages manually.

You may only use the QRU function with stations which you have predesignated as Store and Forward nodes (MBX). Everybody designates their own Store and Forward nodes based on the 'MH list' of the station being designated. The is little point in designating someone as a 'Store and Forward' node for stations that they cannot connect with, unless they happen to be in a digipeat path for inter LAN message passing.

While QRU gives you the capability to bulk upload messages to another station in your local area, when you take your machine off line, it may also be used to transfer messages between two LANs (such as the Baltimore and Washington DC Areas) via well sighted gateway digipeaters. It can also be used for long distance transfers but in a very inefficient manner.

:QNO: 'NO' or error.

The following error numbers are associated with message store and forward operations.

- ? Non valid NC/L word.
- 1 Computer not configured as Store and Forward system.
- 2 Requested ASCII file/ message (:QBM:) does not exist.
- 3 You made an error in the name of the callsign for whom the message is intended (It must be at least 3 characters long).
- 4 File creation error in host system.
- 5 Error occurred during reception and storage of message. Could be that the computer ran out of space on the disk, or something else went wrong in storing the message.
- 6 :QRU: You are not authorised as a store and forward mailbox.
- 7 :QRU: Error in opening MBX file.
- 8 :QRU: Error in closing MBX file.
- 9 :QRU: Sequence Error in callsign of message to go. The bad callsign will be shown after the error number.
- 90 NC/L defined function not implemented in this release.
- 99 PK232COM compatable program, but requested function has not been implemeted.

:QJG: The QRU sequence is complete. There are no more messages pending.

:QRV: <callsign>

The computer is ready for you to send the message. End the message with a control Z (^Z) character, or the sequence :EOF: .

:QSL: <callsign).

Confirms receipt of message to that callsign.

:QTC: Messsage list.

This precedes a list of callsigns for whom messages are stored up on a computer. It is used in Packet Beacon transmissions.

PROPOSED EXTENSIONS

:QYU: and :QYD: YAPP format file upload and download.

LAN Message Format

When you QSP a message, it is stored just as if you had left it in your system (except that a header is added identifying the time of reception and the call of the sending station). Should a message for that station already be in the system, yours should be appended to it. In the event the your upload is aborted, the amount of text received before the abort occurred should be stored as the message. There should also be a stored note within the message stating that the upload was aborted.

When you disconnect from the host station, its beacon will be updated.

Once the message is loaded in the host, it can only be deleted by the operator of the host station.

PK232COM Version 1.42.

All this and more is available for the IBM PC and clones in the shape of PK232COM Version 1.42. As the program was first written for the AEA PK232 TNC, and the data throughput at HF seems better using AMTOR, it also contains AMTOR related robot functions.

In this version of the program most of the packet features described herein can be used by those owners of TNC2's or compatables.

The major development, debugging and testing of PK232COM (Versions 1.00 to 1.41) took place in Jerusalem in the summer of 1987. There the ROBOT station G3ZCZ/4X using just an FT-101 and a dipole antenna operated on an intermittent shedule mostly overnight and on weekends mainly on 20 Meters AMTOR and Packet until the power supply transformer in the FT-101 smoked.

Amongst its achievements were;

* WAC in both Packet and AMTOR modes.

* It worked nearly 50 countries each on both AMTOR and Packet. The computer said that it made 663 Packet connects with 371 different stations, and 526 AMTOR links with 330 different stations. It even worked countries that I still I haven't, usually because propagation was only present late at night or very early in the morning, local time.

* A 10 day long AMTOR QSO between G3ZCZ/4X and VU2IJ in which VU2IJ would link up, receive his message and leave a reply which would be answered the following day.

* The first intra-Jerusalem (perhaps even intra-4X) AMTOR QSO which took place between G3ZCZ/4X and 4X6AA. The unusual part of the QSO was that both G3ZCZ and 4X6AA were operating 4X6AA, while the Robot was operating at G3ZCZ/4X.

* Pioneer Robot Propagation Beacon Experiment.

The Robot put out a CQ

every 2 to 4 minutes when active. This must have been the world's first HF Beacon station that could receive propagation reports from listeners in real time. This was not a mailbox. Whereas I (the beacon keeper) could leave messages for anyone and did, others could only leave them for me. Several stations contacted commented that they used the robot as an indicator of propagation, and I could tell by the log when propagation was present to DX areas.

If such Robot beacons were to replace the existing IARU HF beacons, and were to be located in remote DX countries, I feel sure that the QSL hunters would be more than glad to work them and provide propagation reports in real time.

Acknowledgements.

I would like to acknowledge and thank the many radio amateurs around the world for their help, suggestions and patience in the design, testing and debugging of the many features of the program.

References

1 From RTTY to Packets, Joe Kasser, G3ZCZ, First ARRL Amateur Radio Computer Networking Conference, 1981.

2 Software for Amateur Radio, Joe Kasser, G3ZCZ, published by TAB Books, Blue Ridge Summit, Pa. 17214 USA (Book number 1560).

3 YAPP, Yet Another Packet Program Version 2.0, Jeff Jacobsen, WA7MBL.

4 PAKRATT Model PK-232 Multi-Mode Data Controller Operating Manual, Advanced Electronic Applications, Inc.

A SATELLITE DATA DISPLAY STATION FOR NATIONAL SCIENCE AND TECHNOLOGY WEEK

by
Robert J. Diersing
Associate Professor of Computer Science
Corpus Christi State University
6300 Ocean Drive
Corpus Christi, TX 78412
(512)-991-6810-X476

INTRODUCTION

Since the launch of UoSAT-1 in 1981, various types of data collection systems have been in operation almost continuously at Corpus Christi State University. For the past two years a completely automated data collection system has been in use. The details of the current system have been described in [1].

The data collection system is not in a location that is accessable to the general student population and the data that is displayed is still in its raw form. Because of this, consideration had been given to the construction of a data display station on several occasions. The event that finally caused the construction of the data display station to begin was the university's decision to participate in the 1987 National Science and Technology Week.

BACKGROUND

National Science and Technology Week is sponsored by the National Science Foundation and took place April 5-11, 1987. The program was started in 1985 for the purpose of increasing public awareness of science, engineering and mathematics and to encourage young people to seek careers in those areas. Each year, there are a variety of programs on the national agenda but most of the Week's events and activities are local. The next National Science and Technology Week observance will be April 24-30, 1988.

The College of Science and Technology at Corpus Christi State University includes biology, chemistry, computer science, geology, nursing, mathematics, and medical technology. Undergraduate degrees are offered in all of these fields and graduate degrees are given in biology, nursing, and computer science. Each department made some contribution to the Week's activities which included preparing exhibits, appearing on local television, and organizing daily seminars and film festivals. The public was invited to all activities and the result was a week-long open house for the College of Science and Technology. The week closed with a presentation by Astronaut Tony England from NASA Johnson Space Center on Friday night. He spoke on his space shuttle mission and plans to build the space station.

The remainder of this paper will focus on two different aspects of the satellite data display station that was built for National Science and Technology Week. First, attention will be given to the visitor's viewpoint. In other words, what did the visitor see and what was the reaction. Second, the technical details of the system will be summarized.

THE VISITOR'S VIEWPOINT

The satellite data display station allowed visitors to see decoded telemetry data from the UoSAT-1 and UoSAT-2 spacecraft. The system consisted of two separate computer systems. One computer was used to run the tracking program written by Roy Welsh, W0SL, which was used to display the positions of the satellites in real-time. In addition to the ground track display, there were four other CRT displays in operation. These showed: (1) a raw (but validated) telemetry frame from UoSAT-1 and UoSAT-2; (2) a decoded UoSAT-1 telemetry frame; (3) a decoded UoSAT-2 telemetry frame; and (4) a decoded system status line from a UoSAT-2 telemetry frame. When a satellite was visible at the ground station, the display normally used to show the raw telemetry frames was used to show the data being captured in real-time. The appropriate display was updated after the satellite was no longer visible.

Types of Visitors and Reactions

It seemed that there were three distinct audiences. The first consisted of regular full-time students who attend classes during the daytime. These are primarily under-graduate students. The second group were the night students who are mostly graduate students. The third group consisted of persons who came to the university to view the exhibits as a result of newspaper advertising. This group included students of elementary and junior high school age. The following comments are solely personal opinion based on having observed most of the activity from close at hand. There are undoubtedly exceptions to the generalizations about to be made.

By far, the most interested group were the students who were younger than college age. In some cases, the students were brought by their parents to view the exhibits while the parent attended class. This was particularly true during Tuesday through Thursday nights. You will note that I did not mention the presence of high school age students. There were a few but they were outnumbered by the younger students.

Second in line of interest seemed to be the evening students. As was mentioned before, these tend to be graduate students. A significant number are students who have been in the work force for a while and are returning to complete their advanced degrees.

Both these first two groups understood the purpose and significance of the display. It was quite interesting to observe one person explaining to another how to read the data on the ground track display and determine how long it might be before the satellite was visible again. It was also interesting to note that that these same groups were represented in the same proportions at the closing session. Again, parents and pre high school age students clearly outnumbered high school and college age students.

TECHNICAL DETAILS

The automated tracking system already in use is built from surplus S-100 bus microcomputers. Dedicated applications are ideal uses for obsolete equipment and a similar philosophy was in developing the UoSAT data display station. An AT&T 6300 computer was used for the real time ground track display but an S-100 bus computer was used to perform the data editing and display functions. The data editing and display computer communicates with the data capture computer of the system documented in [1].

The AT&T 6300 computer is used to run the tracking program developed by Roy Welsh, W0SL. The Cromemco CDOS operating system is used in the data editing and display control computer. A single application program written in PL/I-80 along with a few Z-80 assembly language subroutines perform the data editing and display.

Hardware Details

The multiple CRT display system was constructed from readily available 15 inch Ball CRT monitors. These are frequently advertised in surplus computer parts magazines in both amber and green phosphor versions. The 15 inch monitors require a 24 V 1.5 A power source which was provided by two separate supplies, one for each pair of displays.

The monitors are driven by ZRT-80 terminal controller boards sold by Digital Research Computers of Texas. The ZRT-80 controller boards are connected to serial ports provided by multiple SSM I/O-4 boards in the S-100 bus computer. One serial port is used to communicate with the data capture computer system.

Software Details

Writing the data editing and display control program was a straightforward task. The only issue requiring some thought was the method for a single application program to control multiple displays. The method used was an adaptation of the CP/M-80 IOBYTE which has a three bit field that can be used to specify the system console number.

Support for the multiple display screens was accomplished by first modifying the CDOS operating system device drivers to support the multiple console field of the IOBYTE. The implementation is such that the input may be taken from a different device than the device where output is directed. Once the selection of a console I/O device is made, all standard input/ouput statements in the application function as usual. When a console device change is required, the PL/I-80 application calls a Z-80 assembler subroutine which in turn calls the appropriate entry point in the device driver code to switch to the new default input and display devices.

Anyone who may want additional details of the software and hardware implementations can contact the author at the address given at the beginning of the article.

CONCLUSION

This paper has presented two different aspects of what might be called "marketing" the amateur radio space program--one being the opportunity to do the marketing and the other being the technical details on how it was accomplished. If marketing sounds too businesslike then substitute something like "making others aware of." Since a significant portion of this 1987 AMSAT Space Symposium is devoted to educational issues, it is appropriate to give attention to this particular aspect of our avocation.

I would like to encourage all AMSAT members to place a high priority on taking action when there is an opportunity to present our endeavors to any group. In the future we should make a sustained and organized effort to develop the use of amateur radio satellites in education at all levels. At the same time we should document our activities in spacecraft design, construction, and operation for distribution to professional organizations and the general public as well as our fellow amateur radio operators. An observance such as National Science and Technology Week is one opportunity to work toward both of these goals.

ACKNOWLEDGEMENTS

I would like to thank Martin Sweeting, G3YJO, Jeff Ward, G0/K8KA, and the UoSAT operations staff for including the messages shown below in the UoSAT-2 bulletins during National Science and Technology Week. For those who made it a point to watch the live data capture, seeing the personalized messages added an extra dimension to the activities.

- -

**** UoSAT-OSCAR-11 BULLETIN - 080 02 April 1987 ****

UoSAT MISSION CONTROL CENTRE,
University of Surrey, Guildford, Surrey, England

** MESSAGES **

TO: CORPUS CHRISTI STATE UNIVERSITY FROM: UoSAT

We would like to say "hello" to those attending the demonstration of a UoSAT Receiving station at Corpus Christi State University, in Texas. The station is coordinated by Bob Diersing, N5AHD, a long time UoSAT listener and author of several articles on automatic UoSAT data capture. Recently, those at CCSU have helped experimenters at The University of Surrey by providing much-needed archival data concerning the Digital Communications Experiment on UO-11. We hope that your National Science and Technology Week exhibition goes well! - de G0/K8KA

**** UoSAT-OSCAR-11 BULLETIN - 081a 10 April 1987 ***

UoSAT MISSION CONTROL CENTRE,
University of Surrey, Guildford, Surrey, England

** CORPUS CHRISTI STATE UNIVERSITY **

Greetings to Corpus Christi State University. Good luck with your demonstration of a UoSAT ground station.

- -

BIBLIOGRAPHY

1. Diersing, R.J., "Microcomputer Systems for UoSAT Tracking and Data Acquisition", Proceedings of the Fourth AMSAT Space Symposium, November, 1986, Page 39.

CLASSROOM APPLICATIONS OF SATELLITES IN THE U.K.

Craig I. Underwood BSc, PGCE, FBIS.

UoSAT Spacecraft Engineering Research Unit,
Department of Electronic & Electrical Engineering,

UNIVERSITY OF SURREY
Guildford,
Surrey GU2 5XH,
England.

SUMMARY

Traditionally, the role of satellites within education has been seen as that of a common-carrier for the dissemination of educational materials - particularly into areas poorly served by conventional communications networks.

Whilst satellites such as UoSAT-2 can play this role admirably using its Digital Communication Experiment payload and Bulleitn Service, both the UoSAT spacecraft have gone further; providing the first dedicated school's experiments stimulating a growing interest in space technology, both in the U.K. and abroad, via direct and active participation by school groups. This has encouraged schools to become interested in other satellite systems including the meteorological and TV broadcast satellites.

The UoSAT Programme offers schools, colleges and universities a unique opportunity to take a direct part in space research, with the minimum of cost and complexity. The data provided by the two UoSAT satellites are of such a quality and quantity that they are having a significant impact on science teaching in the UK - fitting in very well with the new criteria laid down for the GCSE examinations. Further, a postgraduate Masters Degree (MSc) Course in Satellite Communications Engineering has been established at Surrey to help prepare student engineers for the space industry. The reception of meteorological satellite imagary and direct access to TV broadcasts from Europe and elsewhere, are stimulating other areas of the curriculum.

The provision of educational satellites, and the establishment of a support network based around the National Resource Centre for Satellites in Education - within the UoSAT Unit, has provided the UK with a valuable resource for the improvement of technical education nationally; whilst also stimulating young people to consider engineering (particularly space engineering) as a career.

1. INTRODUCTION

Earth-satellites are now part of everyday life; providing global telephone communications, television broadcasts and weather pictures direct to our homes. It is important to aquaint young people with the rapidly advancing technologies of telecommunications and data handling which are in the process of transforming our lives, and the direct reception and use of satellite data provides a natural vehicle for this kind of technical education.

Classroom Applications of Satellites in the U.K.

Currently there is much concern over the declining number of students who wish to enter an engineering or technical career, so it would seem that initiatives that raise the profile of engineering within schools should be welcome. There is much work to be done; many students perceive engineering as a low-status activity without really having any experience f what engineers actually do. The problem is compounded by the increasing shortage of suitably qualified teaching staff.

The UK 'Satellites in Education' Programme, catalysed by the UoSAT Spacecraft Programme, addresses these concerns in two ways. Firstly it involves spacecraft engineers working with teachers to present students with examples of modern technology in a context that is both interesting to the student and educationally valuable; not just as a 'gimmick'. Secondly, there is a training element attached so that teachers can acquire knowledge and skills in the appropriate technologies.

Space is an emotionally exciting topic; stirring the imagination of school-children and students in a way that is difficult to emulate in other disciplines; however, their involvement in space has been, of necessity, largely a second-hand experience due to the expense hitherto incurred. We believe that if space education is to have a significant impact, then young people must have direct access to space technologies to be able to experience, for themselves, the advantages and limitations they offer.

Traditionally, the role of satellites in education has been that of a communications common-carrier for educational material; often into remote areas where other forms of communication are impractical. Whilst UoSAT-2 can fulfill this role using its Digital Communications Experiment payload and the Bulletin Service, it, together with UoSAT-1, provides a unique space-bourne experiment platform that is directly accessible to schools. The two UoSAT satellites, whilst primarily engaged on satellite engineering research, have provided the first dedicated schools' experiments and have stimulated a growing interest in space technology through direct access and participation. Advances in semiconductor electronics have made powerful yet inexpensive microcomputers and low-cost ground-station equipment readily available and the use of the UoSAT's, as well as other satellites, has grown rapidly.

The UoSAT spacecraft have directly stimulated the formation of a national Satellites In Education Programme, and a 'National Resource Centre for Satellites in Education (NRCSE)' has been established at Surrey to serve as the national focus and technical back-up to this programme; serving the needs of the educational community throughout the UK. The Resource Centre offers a telephone/ electronic mail consultancy service available nationally, and maintains a library of books, audio-visual resources, and satellite reception equipment for use in teacher-training activities. Its unique location, within the UoSAT Unit, provides for a very strong liason between the educational and spacecraft technical communities; to their mutual benefit.

The availability of its own educational/ scientific satellites, and the formation of a national programme of satellite education have, together, given the U.K. a world lead in this form of technical education.

2. SPACE EDUCATION WITH SATELLITES

Various satellites are used in a variety of educational contexts ranging from Surrey's own post-graduate and undergraduate teaching programmes, right through to use at primary school level.

2.1 University Teaching Using UoSAT

The research into spacecraft engineering carried out within the UoSAT Unit is incorporated into formal teaching programmes at Surrey in two ways:

1) **Undergraduate Projects** - where final year BSc. students are able to undertake year-long projects directly associated with the UoSAT team, working on spacecraft data analysis, groundstation equipment or, indeed, development of future satellite systems or experiments. Typical of recent project titles are:

    - Design of a Digital Sun Sensor for UoSAT-C
    - Design of a Doppler-Tracking Receiver for UoSAT-1 & 2
    - Design of an Earth Horizon Sensor for UoSAT-C
    - Satellite Tracking and Mission Analysis Software
    - UoSAT-1 CCD Camera Image Data Display and Processing
    - Investigation into On-Board Data Handling Networks

2) **Postgraduate MSc in Satellite Communications Engineering** - a one year (full-time) course comprising lectures, seminars, laboratory work, assignments and a three-month project. The course includes a module on Spacecraft Engineering which uses the UoSAT spacecraft as a basis for teaching - both in systems analysis in lectures and in direct 'live' demonstrations of spacecraft functions. Typical of recent project titles on this course are:

    - Design of a telecommand subsystem for UoSAT-C
    - Analysis of orbital transfer mechanisms from STS-GAS launch
    - Design of a tailored-pattern UoSAT-C groundstation antenna
    - Design of a microprocessor-based telemetry system for UoSAT-C
    - UoSAT-2 DSR data retrieval and error-code validation
    - Design of uplink receivers for UoSAT-C

Thus, through direct teaching and extended projects, students at Surrey are exposed first-hand to spacecraft operations, space technology and satellite communications. Surrey is unique in being able to offer this close relationship between teaching and its own satellites in orbit.

2.2 Tracking Satellites in Schools

The major emphasis of this paper will be on the use of UoSAT and other satellites in the secondary school sector (11-18 years) - partly as this represents one of the biggest growth areas for satellite education, and partly as this represents the area that has to be influenced if there is to be a change in the uptake of engineering careers and courses at 18+ years.

Classroom Applications of Satellites in the U.K.

The idea of tracking satellites in schools is not altogether new; in the mid 1960's Geoffrey Perry (physics teacher) and Derek Slater (chemistry teacher and radio-amateur) of Kettering Grammar School became famous for their work in tracking Soviet satellites and the discovery of the Soviet 'Plesetsk' launch site. For many years, radio-amateurs have been monitoring the behaviour of the OSCAR (Orbital Satellite Carrying Amateur Radio) satellites through the telemetry data transmitted back to Earth, and some have been able to receive the 'Automatic Picture Transmission' (APT) images transmitted from the polar-orbiting meteorological spacecraft. In some cases, these radio-amateurs have also been school-teachers, and have used these data as a basis for some classroom activities [1,2].

The formation of groups such as the UK Coordinating Committee on Satellites in Education has, over the last two years, encouraged and supported a tremendous growth in the use of satellites in schools. In-Service Teacher Training (INSET) Courses, run under the National "Satellites in Education" Programme, have introduced many teachers to the idea of using satellites, and satellite-data in their lessons.

The satellite systems used directly by UK schools include:

Meteorological (Imaging):

o	NOAA (TIROS-N) Series	US. Polar-Orbiting	(VHF)
o	METEOR Series	USSR. Polar-Orbiting	(VHF)
o	METEOSAT	ESA. Geostationary	(SHF)

TV Broadcasting (TVRO):

o	INTELSAT-V (27.5 W)	INTELSAT. Geostationary	(Ku Band)
o	EUTELSAT ECS-1	EUTELSAT. Geostationary	(Ku Band)
o	GORIZONT	USSR. Geostationary	(C-Band)

Radio-Amateur (Scientific-Engineering/ Educational):

o	UoSAT-OSCAR-9 (UoSAT-1)	UK. Polar-Orbiting	(VHF/UHF)
o	UoSAT-OSCAR-11 (UoSAT-2)	UK. Polar-Orbiting	(VHF/UHF)

Radio-Amateur (Communications):

o	AMSAT-OSCAR-10 (Phase III)	AMSAT-DL/AMSAT-US. Molniya	(VHF/UHF)
o	FUJI-OSCAR-12 (JAS-1)	JAMSAT. 50 Deg. Incl.	(VHF/UHF)
o	RS- Series	USSR. Polar-Orbiting	(HF/VHF)

However, even accepting this general increase in awareness, it must be realised that for most teachers, including science teachers, the idea of using real data beamed directly from space into the classroom conjures up the image of expensive and technically-complex equipment - requiring a detailed knowledge of such complex subjects as orbits, radio-frequency electronics and digital communications technology.

In reality this is not the case. Although some knowledge in these areas can be very useful, it is by no means essential. The advent of relatively inexpensive, 'off-the-shelf' satellite receiving systems available from educational equipment manufacturers, have made this kind of work a practical proposition; even for those teachers who lack a technical background.

3. Satellites and Education

The advent of sophisticated satellites using radio-amateur frequencies such as UoSAT-OSCAR-9 (UoSAT-1), and more recently UoSAT-OSCAR-11 (UoSAT-2), together with the increased availability of computing technology in the form of the personal/ home microcomputers and inexpensive software, has revolutionised the value of satellite data as a teaching resource.

UoSAT-1, launched on 6th October 1981, was the UK's first low-cost satellite focussing on cost-effective spacecraft engineering and space education. One of its mission objectives is "..to stimulate and promote a greater awareness of, and interest in space engineering and science in schools, colleges and universities by direct, active participation in the satellite experimental programme...". The satellite engineering and experiment data are transmitted in such a manner that they are readily received by simple, low-cost amateur ground-terminals.

UoSAT-2, launched on 1st March 1984, has continued with these mission objectives.

A typical UoSAT system for use in schools consists of a crossed-yagi antenna, pre-amplifier, receiver tuned to 145.825 MHz (within the VHF amateur band), demodulator and microcomputer. All the 1200 baud ASCII encoded data can be displayed and processed by the computer; including telemetry, whole-orbit data, Bulletin, on-board computer status-messages, Digital Communication Experiment titles and Newsflashes [3]. A typical cost of such a system purchased from established educational equipment manufacturers is around £250.00 (not including the microcomputer) - although it is possible to receive simple data for only £30-40 as a start.

3.1 The Use of UoSAT Data in the Classroom

The use of 'live' data from the UoSAT-1 and -2 satellites has a number of attractive features. To begin with, the work associated with the setting-up of an inexpensive satellite receiving station within a school, and the procedures involved in obtaining data from the spacecraft on a regular basis, have a tremendous educational potential. There is great scope for pupil-project work, involving scientific, mathematical, design and organisational skills, which have a wide impact on the school curriculum.

This kind of project work, involving the basic 'technology' of satellite reception, is of particular relevance to the new General Certificate of Secondary Education (GCSE) with its emphasis on practical work as the solution to 'real' problems [4]. Having constructed a ground-station, the data obtained from the satellite then becomes a valuable educational resource.

The UoSAT Programme is of particular importance to science education because of the quality and quantity of its data:

(i) Practical work based on UoSAT data provides an ideal basis for problem-solving activities, and the devising and testing of hypotheses; again reflecting the approach indicated in the GCSE National Criteria.

(ii) The use of UoSAT data provides a closer match to 'real' scientific experimentation, such as that carried out in industry and higher-education, than that associated with more traditional school science.

For example, in a typical school-science experiment, a small number of paired data points would be plotted on a graph to indicate the (usually linear) relationships and trends within the data. By contrast, a single UoSAT pass may produce many thousands of data items. This means that the selection of data, the identification of 'good' and 'bad' data (and the criteria for making this distinction) and the handling of this data using numerical and graphical techniques become real issues (as indeed they are in a real research context), in a way that is not possible when using small quantities of somewhat 'stage-managed' data.

Thus, UoSAT data provides a vehicle for the development of the skills of judgement and discrimination that are vital to those pursuing an interest in a scientific or technological discipline. In particular, the sheer quantity of data available for analysis provides an excellent opportunity to use a school microcomputer performing a task which mirrors closely the use of its 'real-world' counterpart; that of an information handling tool, enabling the user to concentrate on the higher-order problems of analysis and interpretation.

3.2 Interpreting UoSAT-2 Telemetry Data

Every 4.84 seconds, the UoSAT-2 telemetry sub-system [5] compiles a telemetry 'frame' which is transmitted to the ground, having been modulated onto the 145.825 MHz radio-frequency carrier. This signal is detected by the antenna and radio-receiver at the ground-station, and the data is demodulated for input into a microcomputer.

It has become a common procedure in schools to record the data on audio-tape (referred to as 'raw-data') with the computer switched off in order to minimise radio-frequency interference. After the satellite-pass, the computer is switched on and the audio-tape is played back into the computer, usually via a hardware demodulator.

The computer is then used to decode and process the raw-data, using software described in the following section that has been developed at the Scarborough Sixth Form College and the University of Surrey for the BBC microcomputer (Model B or Master). The UoSAT Ground Control Centre at Surrey uses 13 BBC microcomputers to control the spacecraft in orbit and retrieve and display telemetry and experiment data. BBC microcomputers were chosen for these task for two reasons:

i) they have good I/O interfaces and graphics at reasonable price;

ii) virtually every school in the UK has been equipped with a BBC microcomputer.

The software, available through educational equipment manufacturers, provides a menu-driven data-handling package that allows data to be stored, processed and analysed in a variety of ways.

The raw telemetry-data, once stored in audio form on cassette tape, can be played through a demodulator into the computer and displayed on the screen. The screen display (Figure 1) allows the user to check that the data has been successfully recorded. Clearly, however, it is still far from being intelligible and further processing is required.

These data may also be recorded on disc, for later recall. This feature is particularly useful in a teaching situation as it is unlikely that the satellite pass will occur at just the time required for the lesson.

The main program takes the raw-data, previously stored on disc, and processes and validates it. As mentioned previously, each channel's data has associated with it a transmission error-check digit. This can detect simple bit-errors in transmission, but it cannot correct such errors. Individual digits, whole channels or indeed major parts of frames may become corrupted in the transmission-receiving stage and one of the functions of the program is to discriminate between corrupted and acceptable data. The procedures used are not appropriate for detailed description in this paper, however, they provide useful exercises in devising algorithms for pattern-seeking and discrimination. This process - the extraction of a signal from the associated noise - is very common in scientific work, and it is well worthwhile introducing such concepts at secondary-school level.

There are also display programs which allow the processed data to be examined both in terms of a validated 'raw' format, and in terms of the actual 'engineering' results, calculated from the telemetry calibration equations provided by the University of Surrey (Figure 2).

So far, the stage has been reached where data from any of the sensors around the spacecraft can be examined, and their 'engineering' values noted. The data are still very 'numerical' in form, and they do not lend themselves easily to analysis for trends. Further software in the package is capable of graphing the output of any of these sensors against time.

The processed-data files generated by first part of the package are used by the second part to generate 'graphics' files. This involves the examination of frame headers, and the extraction of date and time data. Again allowance is made for data corrupted in transmission, and the times are verified by pattern-seeking techniques similar to those used on the telemetry data.

Once created, the experimenter can 'roam at will' over a menu of all the sensors, and graph or tabulate their outputs against time. The graphs are auto-scaling, and are intended to give a 'quick-look' guide to the short-term time dependent behaviour of the satellite. The tabular data can be fed into more complex graphing packages to examine trends more closely.

Analysis of these graphs can give a detailed picture of the behaviour of the satellite under a variety of operating conditions.

3.3 Student Participation

One model for the use of these data in schools is to present students with a some information as a 'seed' for discussion. Students can then be asked to put forward suggestions as to the meaning of the data, and in the process, their understanding of scientific principles can be drawn out and (hopefully) enhanced.

For example, Figure 3 shows the graph of data taken from the "Z-Axis Magnetometer" during an early orbit of UoSAT-2. Having covered the action and purpose of the sensor, the students may be asked to form hypotheses as to the form of the graph. There are obviously some strange discontinuities in the field-strength measurements. Are these real variations in the Earth's magnetic field? Could it be a sensor failure or possibly a quantisation effect?

Students should appreciate that magnetic fields are generated by electric currents, and in discussion, they might well suggest that these anomalous events could be due to an electrical system switching on and off; thus generating an intermittant magnetic field which could be superimposed on the background field due to the Earth. If this is true, whch system could it be?

This is perhaps where the real science begins. Is the graph meaningful? Can hypotheses be formed which explain these results?

UoSAT's attitude is controlled passively by the gravity-gradient boom. The forces involved in this system are very small, and insufficient to maintain stability for any length of time. For this reason, and to achieve initial gravity-lock, an active attitude control system is implemented, using magnetorquers - electro-magnet coils wrapped around the edges of the solar-panels. When currents are passed through these, a magnetic field is generated, which interacts with the Earth's own field to create a small torque on the satellite.

This is an obvious candidate for the cause of the discontinuities, as confirmed by examination of the appropriate status-point graph and the +14V line current (Figure 4).

A graph plotted from a more recent orbit (Figure 5) shows the time-variation in the current generated by the four solar-arrays on UoSAT-2. It will be noted that there is a periodic variation in all of these graphs, and comparison of opposite faces (+X,-X and +Y,-Y) show an interesting phase relationship; when one panel is generating current, its opposite number is not.

Again, students might be asked to form hypotheses that could explain the form of these graphs.

The process of science demands that any such hypotheses be tested. The large number of sensors provide ample opportunity to conduct these tests.

Could it be that the satellite is spinning? If, so, this would surely show itself in the graphs of the magnetic field sensors; a sinusoidal oscillation, equal in period to such a rotation might be expected.

Examination of the magnetic field sensors (Figure 6) does indeed show exactly this response in both the 'X-axis' and "Y-axis' magnetometers, but not the 'Z-axis" one.

This leads to the conclusion that there is a spin, and the period of the spin is consistant with variations in the solar-array currents. Also, the non-periodic respose of the Z-axis instrument further indicates that the satellite is spinning around this particular axis.

However, closer examination reveals a small 'ripple' (the satellite is wobbling) and the magnitude of the field-strength is slowly decreasing. Why? What might be the effect of the satellites motion along its orbit during this time? The answers to these questions can be found by examining data taken over one or more orbit.

Over the period of a single pass (typically 10 minutes), slow variations are difficult to discern; however, the satellite also transmits 'Whole-Orbit Data', which can reveal the longer-term behaviour of the spacecraft sub-systems.

The UoSAT Spacecraft Engineering Research Unit has, through the NRCSE and Surrey Satellite Technology Ltd., made available much of its ground-station data-display software and schools may obtain whole-orbit data dumps directly from the spacecraft. Examination of a whole-orbit dump of the Z-axis magnetometer (Figure 7) shows that there is a periodic pseudo-sinusoidal variation with the same period as the orbit of the satellite. By correlating the data with the position of the satellite (as given by a tracking program), it can be shown that the Z-axis readings are related to the geo-magnetic field; the readings are a maximum when the satellite is over the south polar region; a minimum over the north polar region, and close to zero over equatorial lattitudes.

This periodic variation corresponds to the satellite operating in a 'gravity-lock' mode, where the gravity-gradient boom sticks out into space - directly away from the Earth's centre. As this boom represents the 'Z-axis' of the satellite, it might be expected that when the satellite is over high northern lattitudes, most of the Earth's magnetic field should be aligned with this axis - giving a large sensor reading (in fact in the northern hemisphere this is large and negative, as by convention, the field-lines converge on the north magnetic pole - anti-parallel to the spacecraft's Z-axis).

As the satellite moves towards the magnetic equator, less and less component of the field will be aligned along the 'Z-axis', leading to a near-zero value in equatorial lattitudes. It is this effect that is also showing up in the telemetry data; however that data only represents about ten percent of the orbit.

Checking the time that these data were received reveals that they came from a morning pass. Those famillier with UoSAT-2's orbit will realise that the satellite was on a North-to-South trajectory as observed from the UK, meaning that the satellite had come out of Earth-eclipse, and passed over the northern polar region into the morning sunshine. What effect would this have on the satellite?

It might be expected that during the eclipse period (which occurs every orbit), the satellite would have cooled down, and should now be being heated by the sun's rays. Checking the facet temperatures (Figure 8) confirms this, showing both a general rise in temperature as the satellite passes further into sunlight, and a periodic effect related to the spin.

It also shows that the facets begin to cool down again as the satellite moves further south - i.e. closer to the sun position in the sky. Initially, this might seem counter-intuitive; however, the reason becomes clear upon consideration of the geometry of a gravity-locked satellite. As the satellite moves closer to the apparent position of the sun in the sky, so the solar-illumination of the side-facets decreases; the sun now illuminating the 'top' (+Z) facet. Thus, the side facets will cool slightly as the satellite approaches the apparent position of the sun in the sky (Figure 9 shows these effects over several orbits).

3.4 Summary of Use of UoSAT in the Classroom

The examples outlined above begin to indicate the tremendous potential of UoSAT data in education. The satellites can be considered to be orbiting experiment packages which are directly accessible to schools, colleges and universities; allowing investigations into the phenomena associated both with the behaviour of spacecraft, and with the nature of the near-Earth environment (e.g the Giger-Muller tubes on UoSAT-1 can be used to investigate the radiation environment). Much of these data are of direct relevance to the core science curriculum e.g. radioactivity, dynamics, behaviour of charged particles, magnetic fields, etc.

3.5 Other Satellites

The use of UoSAT satellites by schools has stimulated the further use of other satellites. Currently, the NRCSE is supporting work with satellites in three major areas:

i) Remote Sensing/ Meteorology;
ii) Space Science;
iii) Communications/ Television Receive-Only.

3.5.1 Meteorological Satellites

By far the most popular spacecraft for use in schools are the meteorological satellites. This is probably due to the immediacy of the data they produce; i.e. readily identifiable images of the Earth and its weather systems; and also the fact that these satellites are well known from their output, which can be seen on television news and weather reports every day. The UK is serviced by a number of these spacecraft: METEOSAT, th- TIROS-N (NOAA) series and the Soviet METEOR series, and all these can be readily accessed by schools.

METEOSAT - operated by the European Space Agency (ESA) - is a spin stabilised satellite in geostationary orbit, approximately 36,000 km above the Earth's surface, positioned at zero degrees West along the Equator. From this position, its radiometers can scan approximately one third of the Earth's surface. Schools can receive the WEFAX image data direct from the satellite by monitoring the 1694.5 MHz and 1691.0 MHz (S-band) downlinks. The systems used in schools typically consist of a satellite dish antenna (1m diameter, non-steerable), a feedhorn/ pre-amplifier/ downconverter to convert the S-band signal down to VHF (typically 135.5 MHz), and a VHF weather-satellite band receiver/ decoder linked to a microcomputer or frame-store. This allows the infra-red and visible images (broadcast according to a fixed ESA schedule) to be stored and processed to a limited extent. Such systems cost in the region of £700.00 (not including the computer or frame-store).

TIROS-N - operated by the US National Oceanographic and Atmospheric Administration (NOAA) - are 3-axis stabilised satellites in low-Earth (850 km), sun-synchronous, near-polar orbit. The current satellites are NOAA-9 and NOAA-10. They each carry scanning radiometers which scan lines orthogonal to the motion of the satellite. As the satellite passes-by, a swath is scanned underneath the satellite, both in the visible and infra-red parts of the spectrum. Schools can receive the resultant, real-time image data from the Automatic Picture Transmission (APT) system, by monitoring the VHF downlink on 137.5 MHz (NOAA-10) or 137.62 MHz (NOAA-9). The satellites have a period of approximately 102 minutes, and pass within range of the UK about 6 times per day, with a typical pass lasting between 10 and 15 minutes.

A typical school-based reception system consists of an 'omni-directional' crossed-dipole with reflector antenna (fixed-mounting), a VHF satellite band (136-138 MHz) receiver, a decoder and microcomputer or frame-store. The allows the reception and display of images covering a swath from northern Scandenavia to North Africa. Such systems cost in the region of £250.00 (not including the computer or frame-store).

METEOR - operated by the USSR - is the Soviet equivalent to TIROS-N and may be received on the same equipment.

Images from these spacecraft have an obvious place in the geographical subjects, providing a new and dynamic way of teaching the concepts of meteorology, environmental science and physical geography. Their use goes further; into the science curriculum on the nature of electromagnetic radiation and the design of remote sensing systems; and into the more general area of information technology - looking at the communications, coding and processing involved.

3.5.2 Television Receive-Only Satellites

Modern language departments are showing increasing interest in the use of foreign video material derived from satellite-TV. True direct-broadcasting satellites (DBS) covering Europe have yet to be launched; however, it is possible to receive TV broadcasts from conventional communications satellites. The relatively low power of these transmissions require the use of relatively large receiving dishes on the ground (typically 2m diameter) and, compared to the sytems so far described, relatively sophisticated technology.

INTELSAT-Va (F-11) - operated by the International Telecommunications Satellite Organisation - is a 3-axis stabilised satellite, in geostationary orbit positioned 36,000 km above the Equator at 27.5 degrees West.

EUTELSAT-1 (ECS-1) - operated by the European Communications Satellite Organisation - is a similar communications satellite, in geostationary orbit at 13 degrees East.

Both carry a number of TV channels from the UK, France, Germany and Italy, which are broadcast in the Ku-band (10.95 - 12.5 GHz). A typical school sytem for the reception of these signals comprises of a polar-mounted dish antenna (2m diameter), a feed-horn / low-noise block downconverter (LNB), receiver and television or monitor. The costs depend upon the system, but are typically around £1500.

Access to foreign language broadcasts is particularly valuable in Europe, where there are a relatively large number of different languages spoken within a reasonably small geographical area. Teachers hope that as well as providing an interesting and stimulating resource for the learning of languages, the TV image also conveys some of the rich cultural diversity of the European nations.

Those teachers who are also radio-amateurs can use the radio-amateur satellite service to carry communications between geographically separated schools. The OSCAR and RS series of satellites have carried voice communications between schools, and now UoSAT-2, with its DCE Store-and-Forward Comunications payload offers the chance for schools to become linked together worldwide via gateway stations - exchanging text, software, pictures, indeed anything that can be carried in digital form.

4. THE SATELLITES IN EDUCATION PROGRAMME

The availability of the UoSAT spacecraft stimulated a number of school-based projects [6,7,8] and these were to have a significant impact on the Satellites in Education Programme. However, it is fair to say that, in general, the response of schools to satellites has developed more slowly than initially expected; obviously the provision of educational satellites, alone, is not enough and other kinds of support are also needed - such as texts, work-sheets, easily-assembled receiving equipment, software, advice and teacher training.

This additional and very necessary support is provided by the UK Satellites in Education Programme, which resulted from a convergence of a number of pre-existing projects and technical innovations; co-ordinated through the UK Co-ordinating Committee for Satellites in Education (UKCCSE).

4.1 The U.K. Co-ordinating Committee for Satellites in Education

In March 1985, the MEP (Microelectronics in Education Project) Software Unit and the University of Surrey jointly called a meeting of many of those involved in the use of satellites in education; including industrialists, academics, teachers and equipment manufacturers. The primary conclusion of the meeting was that in order to realise the full potential of satellites in education, there was a need to co-ordinate and promote activities in this area. Thus, a co-ordinating body:- the UKCCSE, was formed in order to fulfill this role. The Committee identified a number of educational aims that are associated with the use of satellites in activites spread across the curriculum; ranging from the physical sciences to the humanities [9].

4.2 INSET Provision - The Role of the National Resource Centre

By July 1986, negotiations with the Manpower Services Commission (MSC) had been successful in establishing a programme of in-service training (INSET) and research on satellites in education under the TVEI-Related In-Service Training (TRIST) scheme [TVEI is the Technical and Vocational Educational Initiative - an attempt to make children's learning more relavent to the needs of industry]. Through this programme, the National Resource Centre for Satellites in Education (NRCSE) was established within the UoSAT Unit at the University of Surrey, and a number of pilot schemes were set up in eight Local Educational Authorities (LEAs) throughout England and Wales. Eventually, it is hoped that some or all of these projects will act as the nucleii for the development of regional centres, offering help and advice on the practice of using satellites in schools on a local basis.

The whole programme was managed from the University of Surrey, with two INSET tutors carrying out the day-to-day management, training and evaluation tasks. One tutor was based in Dyfed, and was responsible for the co-ordination of activities in most of the LEAs involved; whilst the other (based at the NRCSE) was responsible for the South-East LEAs, and was additionally responsible for the running of the Resource Centre at Surrey.

The NRCSE acts as the central technical support for this programme, as well as acting as a national focus for enquiries into the use of satellites in education.

Information is available through conventional mail and telephone services, as well as through electronic mail services such as The Times Network for Schools (TTNS). A library of resources is held for use in INSET activities, including audio-visual materials, books, computer software and demonstration ground-station equipment for UoSAT and also NOAA, METEOSAT and EUTELSAT. These resources are used by schools on an occasional basis, and are also used to prepare lectures and demonstrations that are given both at Surrey and elsewhere in the UK. The Centre also generates a number of papers and practical exercises on the use of satellites in education.

The NRCSE at Surrey is a focus for a number of other satellite projects, including a programme run in conjunction with the British National Space Centre (BNSC), through the Royal Signals and Radar Establishment (RSRE) and Plymouth Polytechnic, which has placed Television-Receive Only (TVRO) terminals in ten schools spread throughout the UK for educational evaluation.

The TRIST programme ended in March 1987, and now the INSET activities carried out at the NRCSE must be, to a greater or lesser extent, self-financing. LEAs are now expected to pay for INSET on a more 'commercial' basis out of the funds assigned to them under the Grant-Related In-Service Training (GRIST) regulations.

6. CONCLUSIONS

The UoSAT spacecraft have played a pioneering role in space education - both in the U.K. and abroad - at all levels ranging from university graduate teaching programmes right down to primary schools. The easily available satellite data provided offers a unique opportunity to participate directly in space research in a way that is educationally effective, and also stimulates interest engineering and technology as a career.

The establishment of a National Resource Centre for Satellites in Education within the UoSAT Spacecraft Engineering Unit ensures a strong liason between the educational and space engineering communities - co-ordinated on a national level. The support offered by the NRCSE has proved to be instrumental in the encouragement of schools to make use the UoSATs and other satellites in an educational context. It is clear that an on-going programme of in-service training is required to train teachers to make effective use of these resources, to become familiar with the technologies involved, and to further develop curriculum materials on these themes.

The continued commitment of the UoSAT Unit to space education, via its satellite engineering programme and its support of the NRCSE, provides the UK with a valuable resource and a world lead in this form of technical education.

7. ACKNOWLEDGEMENTS

Special thanks are due to Eric Twose (Scarborough Sixth-Form College) and Dr. Robin Millar (University of York) for their major contributions to the above work, the Manpower Services Commission for their financial support of the Satellites In Education Programme and the NRCSE at Surrey, the Council for Educational Technolgy, and the University of Surrey for providing accomodation for the NRCSE.

7. REFERENCES

1. Duff, D.A. (1981) "The Use of Satellites by Schools and Colleges" IN Physics Education, Vol.16, pp.352-356, 1981 (Part 1) and Vol.17, pp.19-24, 1982 (Part 2).

2. Educators at Talcott Mountain Science Center (1975) "Space Science Involvement", American Radio Relay League Inc., Newington, Connecticut 06111.

3. Sweeting, M.N., et. al. (1987) "UoSAT Data Booklet", UoSAT Spacecraft Engineering Research Unit, University of Surrey, Guildford.

4. DES (1986) "GCSE: The National Criteria", Department of Education and Science, HMSO, London.

5. Mansi, L. (1987) "The UoSAT-2 Telemetry System", IERE Journal Special Edition on the UoSAT-2 Spacecraft (t.b.p.).

6. Temple, A. (t.b.p.) "The Welsh Satellite Project", Microelectronics in Education Support Unit (MESU), Dyffed, Wales.

7. Spencer, S.J. (1985) "The Sheffield Project: Satellites", AMSAT-UK, London.

8. Underwood, C.I. (1986) "Satellites in the Curriculum: A Project Report for C.S.C.S", Centre for the Study of Comprehensive Schools, University of York, ISBN 0-947574-09-3.

9. Gilbert, J.K. (1985) "Satellites in Education: A Strategy Paper", The U.K. Co-ordinating Committee for Satellites in Education, University of Surrey.

```
********************************************************************************
* Sat-Pack:  UoSAT-2 RAW TELEMETRY FILE DISPLAY    [ Press <ESCAPE> to exit. ]  *
* Reading from file: R.TEST-2                      [ <SPACE> to toggle pause.]  *
********************************************************************************
Y70104128
00506301468B02673003348C04052305039F06025107052008047B09037D
10293911332212000313063714135215440416181F175164184915195397
20470121184E22660023000124000625000726097A27556328511F295248
30513431040632286D33579B34000735264636317037430338476E39504B
40765041120642642643061044166145000146000247494A48506F494779
505563511027526753533308D54649A55000056000357499658494459506F
60826A615BE7621F4E6333056444026517056647ED67700668000E69000F
¦UOSAT-2              8510270104133
00505001478A02673003349D04052305039F06025107052008047B09037D
10295F11332212000313063714129F15440416181F175157184863195397
20443121184E22660023000124000625000726097A27556328512C295248
30513431040632286D33579B34000735265736317037430338476E39504B
40766341120642642643063244166145000146000247494A48506F494779
50563551102752676053682A54653155000056000357499658494459507E
60826A615BE7621F4E6333056444026517056647ED67700668000E69000F
¦UOSAT-2              8510270104138
00504101482F02672103349D04052305039F06025107052008047B09037D
10298211332212000313063714125315441516181F175146184827195397
20421521183922660023000124000625000726097A27557228513D295248
30513431040632286D33578A34000735266436318F37430338476E39504B
40766341120642642643063244167045000146000247494A48506F494779
50569F51102752677153684C54653155000056000357499658494459507E
60826A615BE7621F4E63330564440265170566482E67700668000E69000F
¦UOSAT-2              8510270104142
00503601492E02672103351404052305039F06025107052008047B09037D
10302011332212000313064014128E15440416181F17513118477D195397
20399121185F22660023000124000625000726097A27557228514A295248
30512531040632286D33579B34000735267536319E37430338476E39504B
40766341120642642643065444167045000146000247494A48506F494779
50574351102752678E53685D54658A55000056000357499658494459507E
60826A615BE7621F4E63330564440265170566468A6770066
```

FIGURE 1: RAW UoSAT-2 DATA DISPLAY

UoSAT-2 SATELLITE TELEMETRY

Source file: 'P.TEST-1'

FRAME No. : 8510270104128 (1)
Mission time : 27/10/85 10:41:28
AOS date/time : 27/10/85 10:39 hrs.

Analogue Data Channels: 00-59

00	<506>	Solar array current -Y	19.0000	mA.
01	<468>	Nav mag X axis	1.4980	uT.
02	<673>	Nav mag Z axis	33.1979	uT.
03	<348>	Nav mag Y axis	-16.5564	uT.
04	<052>	Sun sensor no.1	< >	
05	<039>	Sun sensor no.2	< >	
06	<025>	Sun sensor no.3	< >	
07	<052>	Sun sensor no.4	< >	
08	<047>	Sun sensor no.5	< >	
09	<037>	Sun sensor no.6	< >	
10	<293>	Solar array current +Y	423.7000	mA.
11	<332>	Nav mag (wing) temp	-0.5797	C.
12	<000>	Horizon sensor	< >	
13	<063>	Spare (tbd)	< >	
14	<135>	DCE RAMUNIT current	9.6418	mA.
15	<440>	DCE CPU current	126.4500	mA.
16	<181>	DCE GMEM current	28.4286	mA.
17	<516>	Facet temp +X	-7.2000	C.
18	<491>	Facet temp +Y	-2.2000	C.
19	<539>	Facet temp +Z	-11.8000	C.
20	<470>	Solar array current -X	87.4000	mA.
21	<184>	+10V line current	178.4800	mA.
22	<660>	PCM voltage +10V	9.9000	V.
23	<000>	P/W logic current (+5V)	0.0000	mA.
24	<000>	P/W Geiger current (+14V)	0.0000	mA.
25	<000>	P/W Elec sp.curr (+10V)	0.0000	mA.
26	<097>	P/W Elec sp.curr (-10V)	9.0210	mA.
27	<556>	Facet temp -X	-15.2000	C.
28	<511>	Facet temp -Y	-6.2000	C.
29	<524>	Facet temp -Z	-8.8000	C.
30	<513>	Solar array current +X	5.7000	mA.
31	<040>	-10V line current	19.2000	mA.
32	<286>	PCM voltage -10V	10.2960	V.
33	<579>	1802 comp curr (+10V)	121.5900	mA.
34	<000>	Digitalker current (+5V)	0.0000	mA.
35	<264>	145MHz beacon power O/P	385.0000	mW.
36	<317>	145MHz beacon current	69.7400	mA.
37	<430>	145MHz beacon temp	10.0000	C.
38	<476>	Command decoder temp (+Y)	0.8000	C.
39	<504>	Telemetry temp (+X)	-4.8000	C.
40	<765>	Solar array voltage (+30V)	24.9000	V.

FIGURE 2: PROCESSED UoSAT-2 DATA DISPLAY

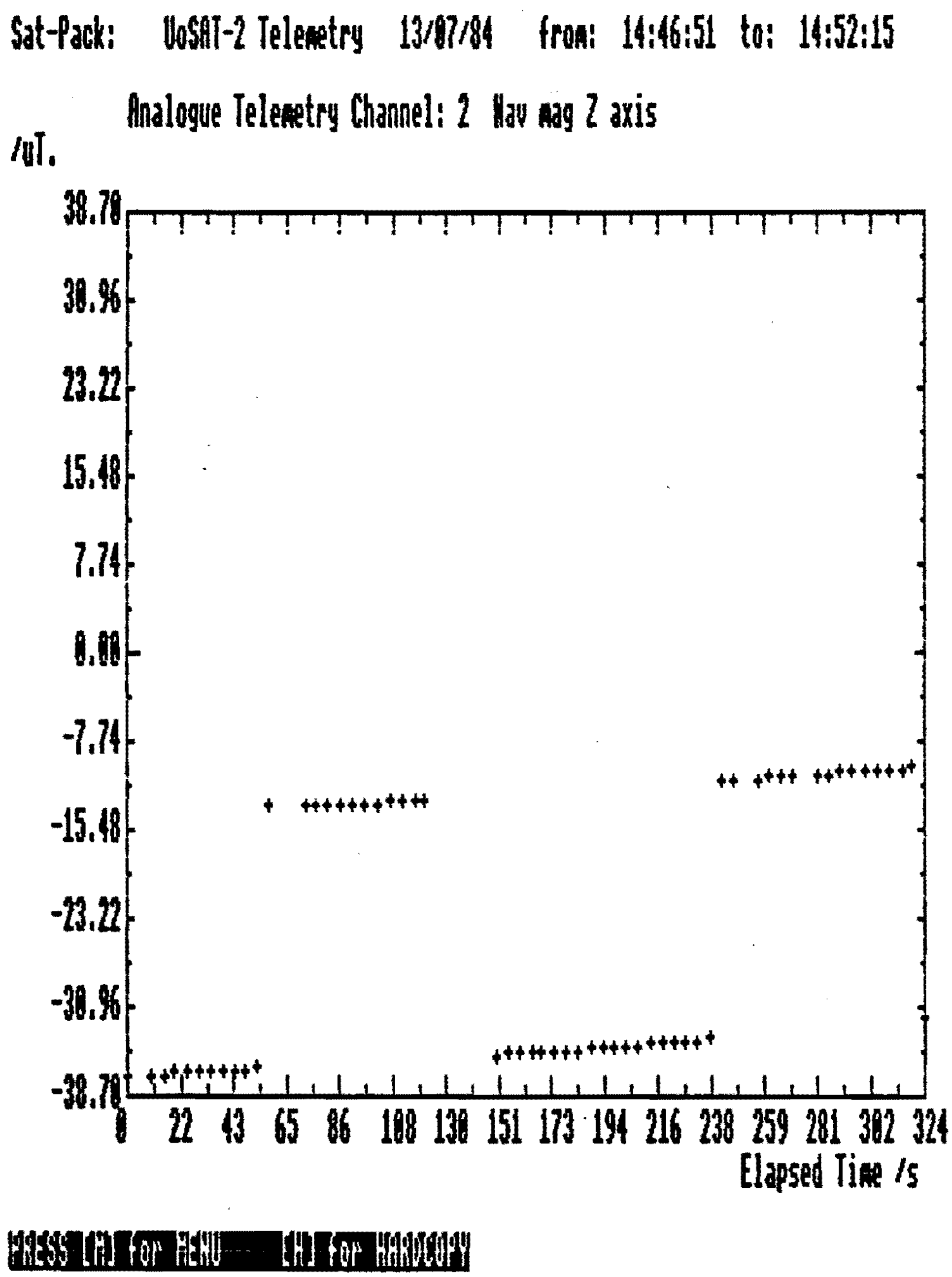


FIGURE 3: Z-AXIS MAGNETOMETER

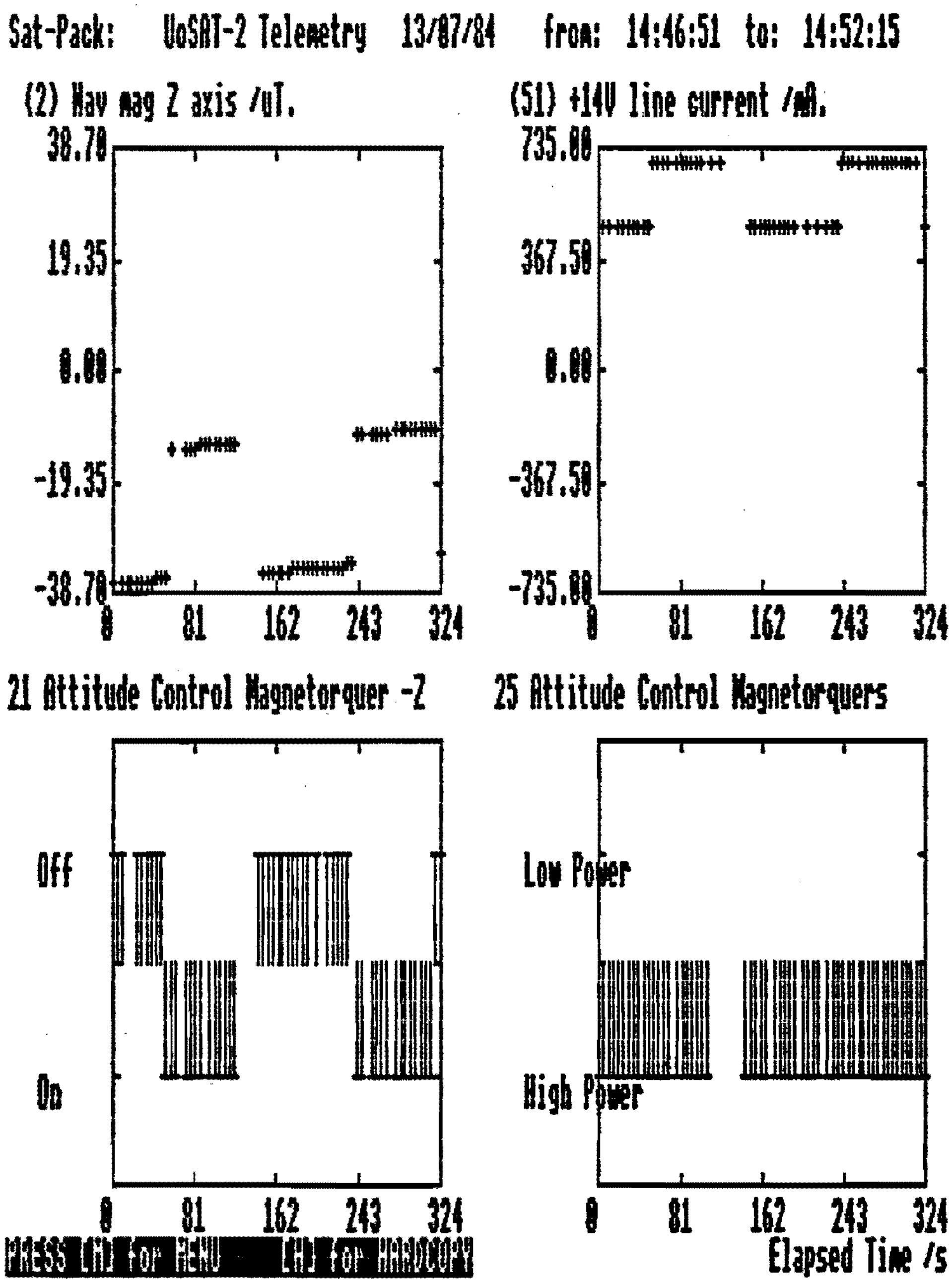


FIGURE 4: MAGNETORQUER FIRINGS

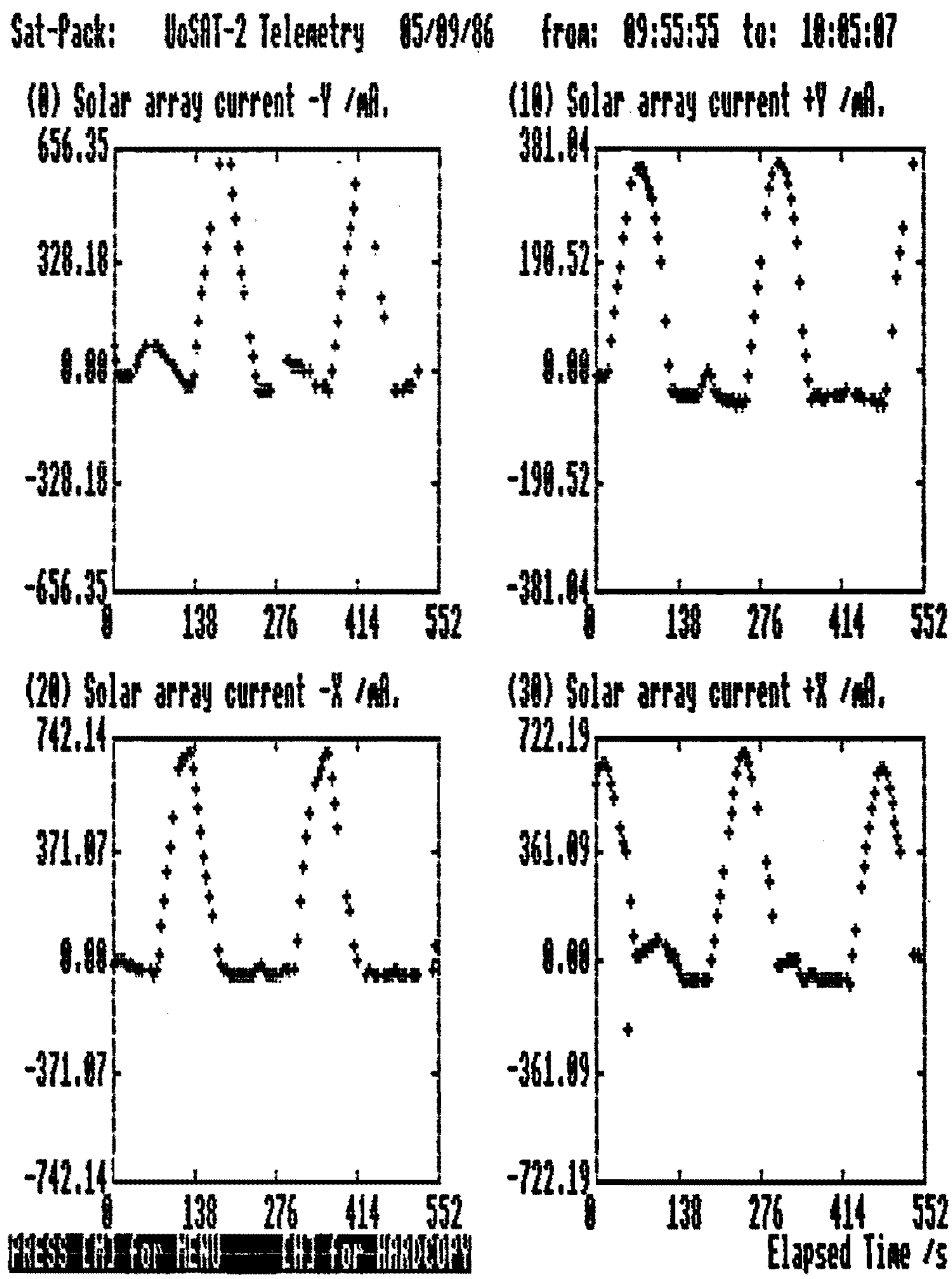


FIGURE 5: SOLAR-ARRAY CURRENTS

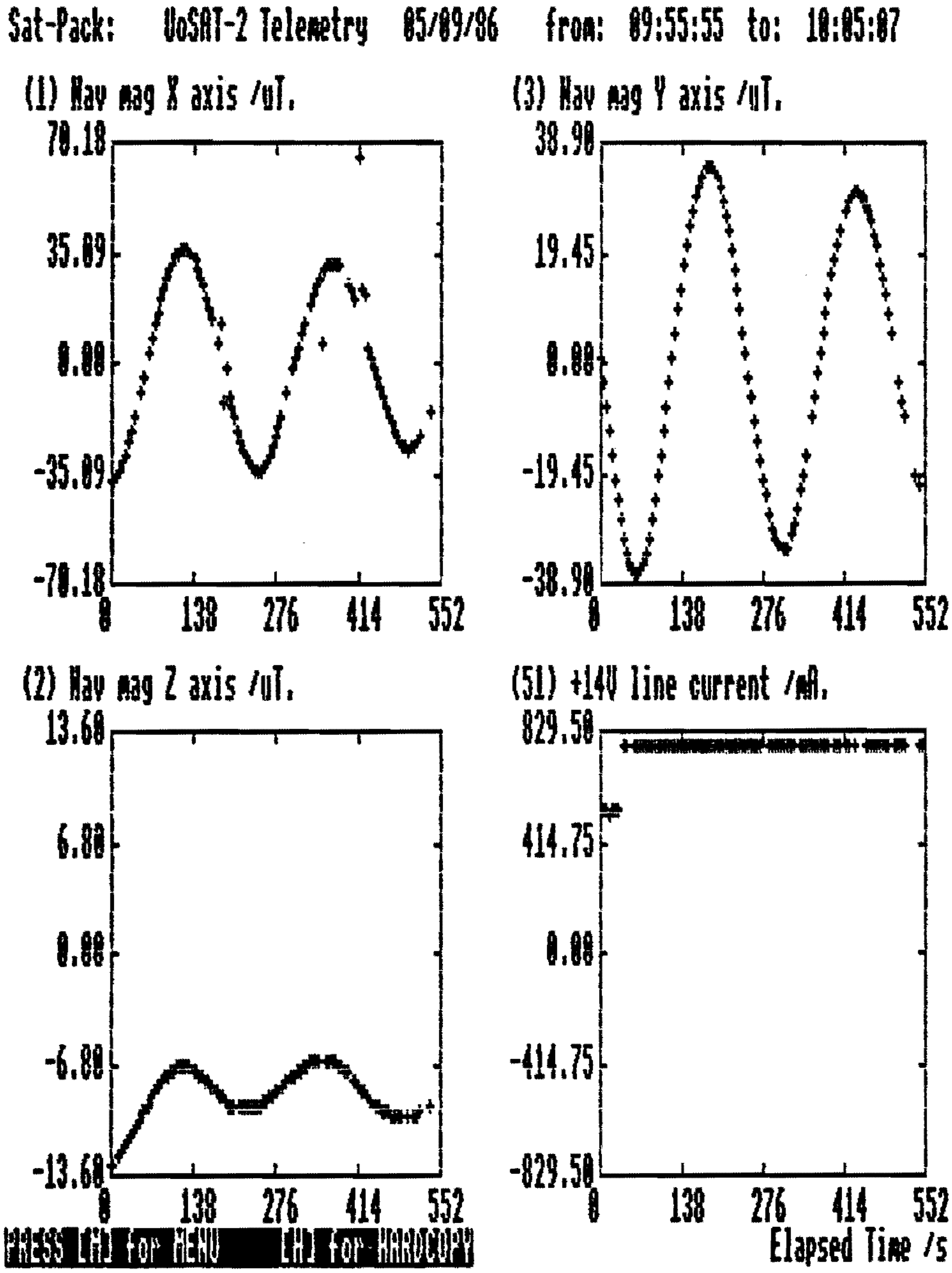


FIGURE 6: NAVIGATION MAGNETOMETERS

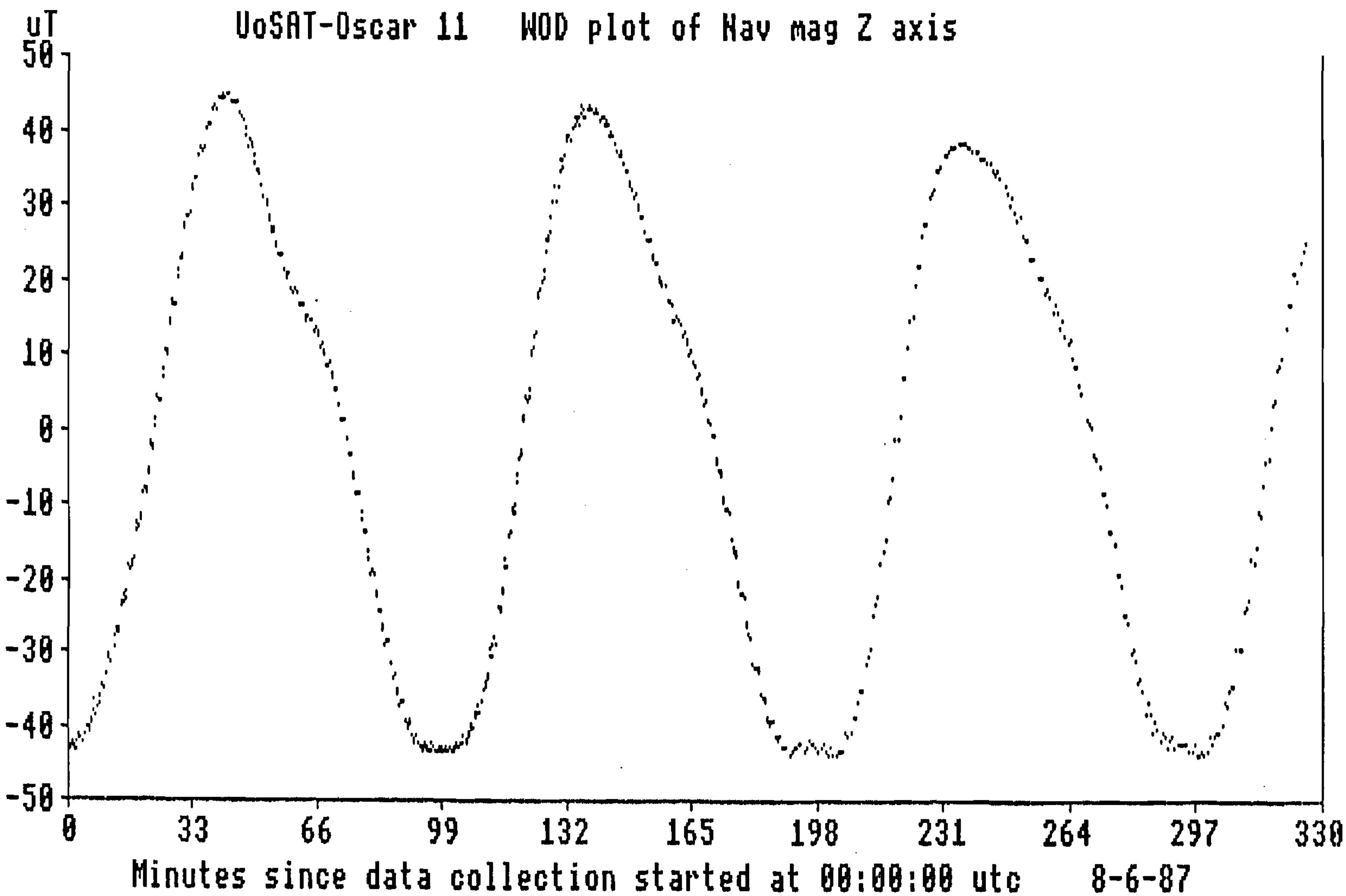


FIGURE 7: WOD-DUMP OF Z-AXIS NAVIGATION MAGNETOMETER

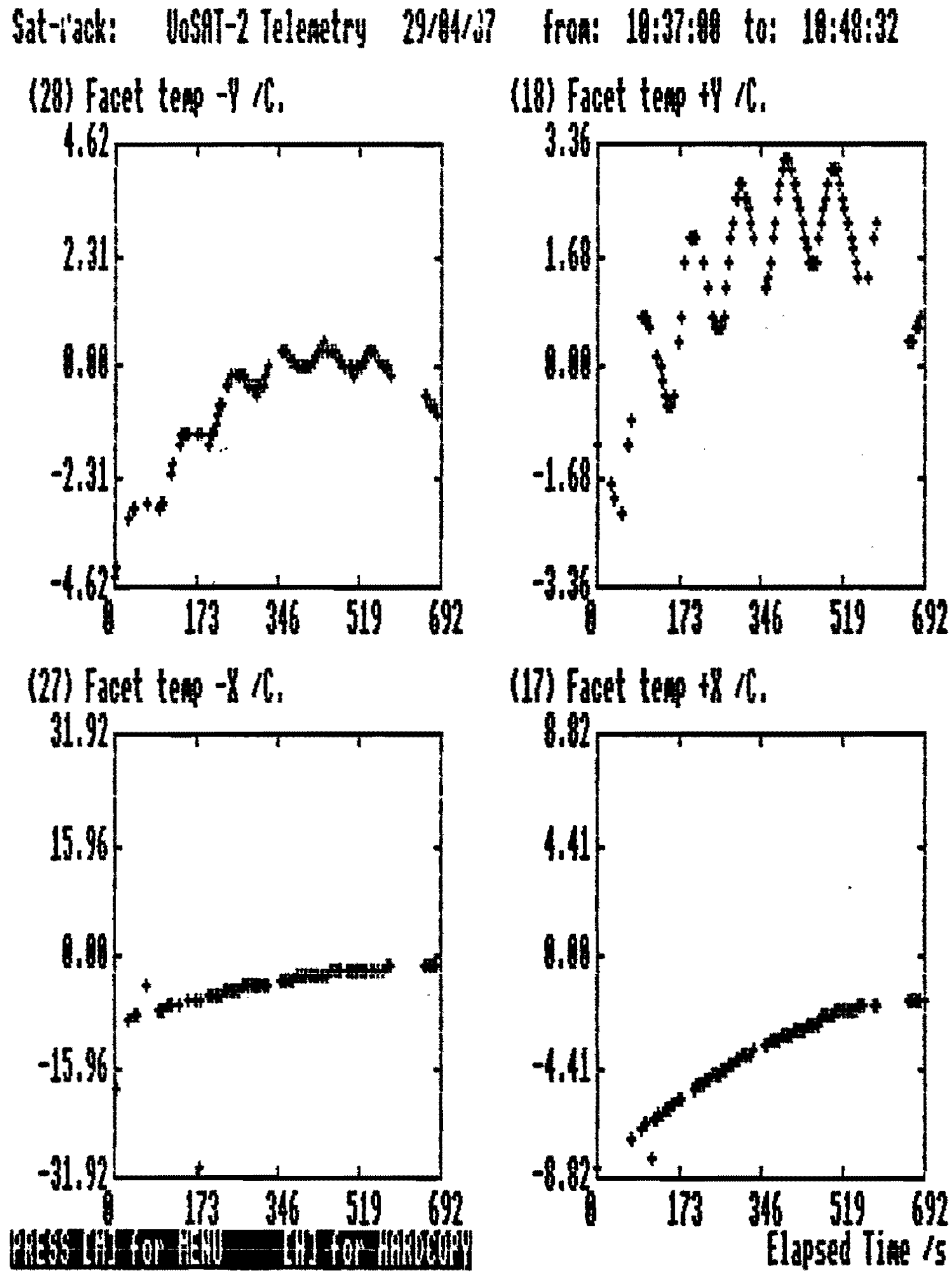


FIGURE 8: SPACECRAFT FACET TEMPERATURES

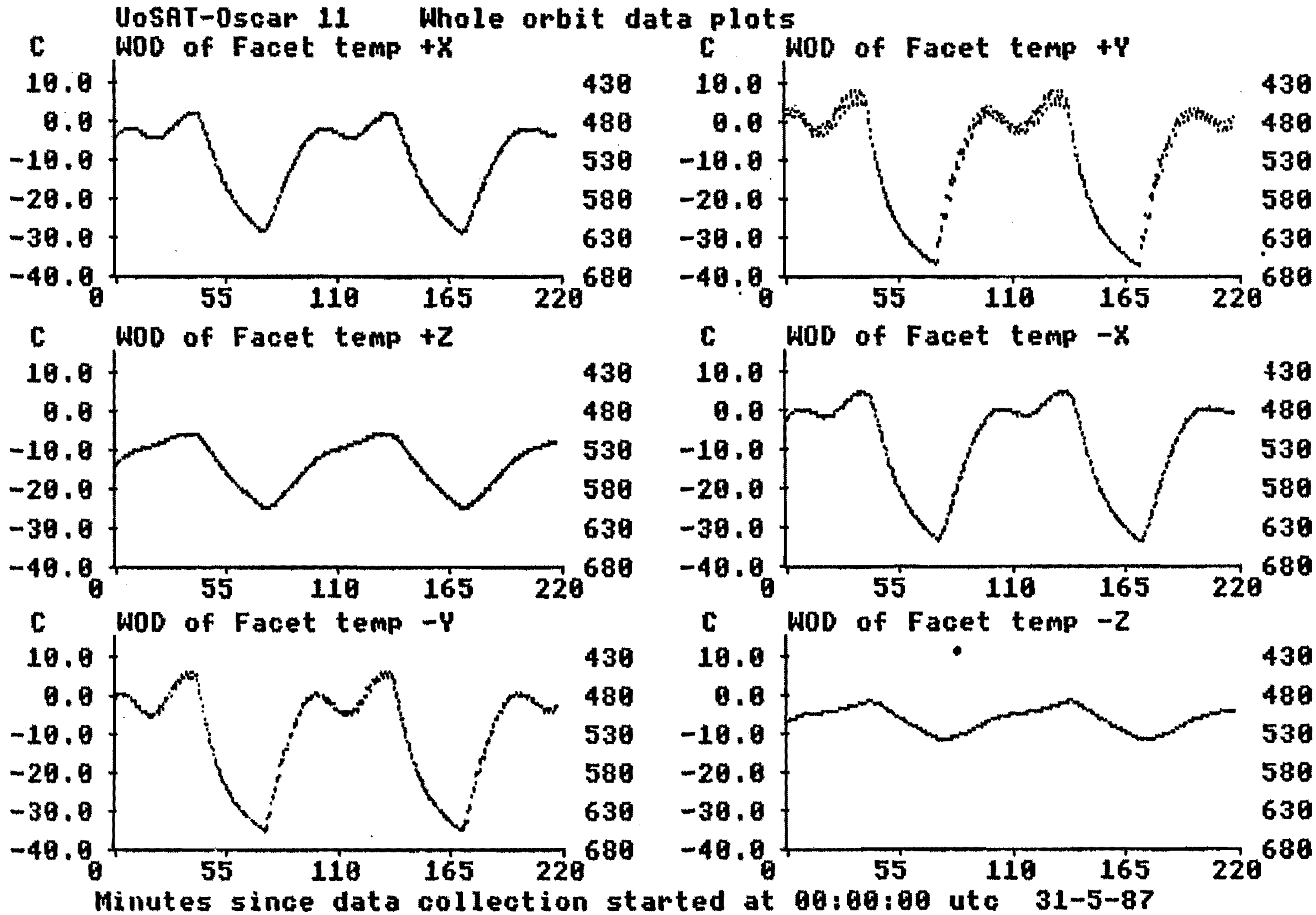


FIGURE 9: WOD-DUMP OF SPACECRAFT FACET TEMPERATURES