NTIA REPORT 90-261

# Technical Considerations Concerning Use of a Geostationary Operational Environmental Satellite (GOES) to Support the PEACESAT Network on an Interim Basis

R. D Jennings
R. D. Cass

U.S. DEPARTMENT OF COMMERCE
Robert A. Mosbacher, Secretary

Janice Obuchowski, Assistant Secretary
for Communications and Information

April 1990

## PREFACE

The Institute for Telecommunication Sciences (ITS) has performed a number of technical tasks as part of the responsibilities of the National Telecommunications and Information Administration (NTIA) for re-establishing the Pan-Pacific Educational and Cultural Experiments by Satellite (PEACESAT) network and services provided by the network. This report contains the results and conclusions of studies and testing completed by ITS to examine the technical feasibility of using a Geostationary Operational Environmental Satellite, on an interim basis, to re-establish the network and services that had been provided using the Applications Technology Satellite-1. Some discussion of considerations that are relevant to the conclusions also are included.

The views, opinions, and/or conclusions presented in this report are those of the authors. They do not represent an official position of the National Telecommunications and Information Administration or of the U.S. Department of Commerce.

Certain private companies and commercial systems and equipment are identified in the report to adequately describe the studies and testing that were conducted. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the companies or systems and equipment are necessarily the best available for the purpose.

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## LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AMSAT | Radio Amateur Satellite Corporation |
| APT | automatic picture transmission |
| ATS | Applications Technology Satellite |
| AUSSAT | Australian Satellite System |
| CCIR | International Radio Consultative Committee |
| CDA | control and data acquisition |
| $C/N_0$ | carrier-to-noise power density ratio |
| CTP | command telemetry processor |
| DCPI | data collection platform interrogation |
| DCPR | data collection platform reports |
| EC | earth center |
| EE | earth edge |
| EIRP | equivalent isotropically radiated power |
| F.S.M. | Federated States of Micronesia |
| FM | frequency modulation |
| GOES | Geostationary Operational Environmental Satellite |
| G/T | (receiver) gain-to-system noise temperature ratio |
| HIG | Hawaii Institute of Geophysics |
| HPA | high power amplifier |
| IAG | (PEACESAT) Impact Assessment Group |
| IF | intermediate frequency |
| INTELSAT | International Telecommunications Satellite Organization |
| INMARSAT | International Maritime Satellite Organization |
| ITS | Institute for Telecommunication Sciences |
| IPUG | International PEACESAT Users' Group |
| IRIG | Inter-Range Instrumentation Group |
| LEASAT | Satellite system leased to the U.S. Navy Space Command (owned and operated by Hughes Communication Services, Inc.) |
| LNA | low-noise amplifier |
| MARISAT | Maritime Satellite System |
| MFR | multi-function repeater |
| NASA | National Aeronautics and Space Administration |
| NBFM | narrow-band frequency modulation |

| | |
|---|---|
| NESDIS | National Environmental Satellite, Data, and Information Service (formerly known as NESS) |
| NESS | National Environmental Satellite Service (now known as NESDIS) |
| NOAA | National Oceanic and ATmospheric Administration |
| NTIA | National Telecommunications and Information Administration |
| PEACESAT | Pan-Pacific Educational and Cultural Experiments by Satellite |
| PCM | pulse-code modulation |
| PTT | post, telegraph, telephone |
| RF | radio frequency |
| SCPC-FM | single-channel-per-carrier frequency modulation |
| SMS | synchronous meteorological satellite |
| SNR | signal-to-noise power ratio |
| SNRD | signal-to-noise power ratio density |
| SOCC | Spacecraft Operations Control Center (at NESDIS) |
| SVISSR | stretched VISSR |
| TOP | (PEACESAT) Technical Options Panel |
| T&C | telemetry and command |
| TT&C | tracking, telemetry, and command |
| UH | University of Hawaii |
| VISSR | visible/infrared spin scan radiometer |
| VSAT | very small aperture terminal |
| WEFAX | weather facsimile |

# TECHNICAL CONSIDERATIONS CONCERNING USE OF GOES TO SUPPORT THE PEACESAT NETWORK ON AN INTERIM BASIS

R. D. Jennings and R. D. Cass*

The Institute for Telecommunication Sciences (ITS) has performed a number of technical tasks as part of the responsibilities of the National Telecommunications and Information Administration (NTIA) for re-establishing the Pan-Pacific Educational and Cultural Experiments by Satellite (PEACESAT) network and services provided by the network. This report contains a brief discussion of the PEACESAT network and services using the Applications Technology Satellite-1 (ATS-1) as background to the current work and the technical material developed at ITS in performing this work. The tasks supported by NTIA on which this report contains information include: (1) participation in the Technical Options Panel (TOP) to define PEACESAT operational and users' requirements and the identification of possible satellite resources to replace the ATS-1 satellite, (2) a brief discussion of the history of the Geostationary Operational Environmental Satellites (GOES) as a candidate satellite to replace ATS-1 with particular attention given to description of the GOES communication subsystem, (3) analysis of the suitability of the GOES S-Band transponder to support the PEACESAT network (as an interim solution), and (4) analysis of the technical considerations pertaining to command and control of a GOES satellite being used for PEACESAT during an interim period.

Key Words: ATS-1; GOES; International PEACESAT Users' Group (IPUG); low-cost earth stations; PEACESAT; PEACESAT Impact Assessment Group (IAG); PEACESAT Technical Options Panel (TOP); satellite command and control

## 1. INTRODUCTION

The Institute for Telecommunication Sciences (ITS) has performed a number of technical tasks as part of the responsibilities of the National Telecommunications and Information Administration (NTIA) for re-establishing the Pan-Pacific Educational and Cultural Experiments by Satellite (PEACESAT) network and services provided by the network. This report contains results of the technical work completed by ITS and some discussion of considerations that are relevant to the results achieved.

Section 2 presents a brief history of PEACESAT as operated using the Applications Technology Satellite-1 (ATS-1). This history provides a basis for

*The authors are with the Institute for Telecommunication Sciences, National Telecommunications and Information Administration, U.S. Department of Commerce, Boulder, CO 80303-3328.

defining network and service operational requirements. It also summarizes the work conducted by the PEACESAT Technical Options Panel (TOP) to identify and recommend other satellites that should be considered for replacing the failing ATS-1. Technical staff from ITS assisted with the work of the TOP.

Section 3 presents the results of work done by ITS in evaluating the suitability of a Geostationary Operational Environmental Satellite (GOES) System satellite (either GOES-2 or GOES-3) as an interim replacement for the ATS-1. A brief, general description of the GOES System is given to establish context for discussing in more detail the GOES communication subsystem and the work done by ITS. The work included analysis of the technical suitability of the GOES multifunction repeater (MFR) for PEACESAT network service, as well as field measurements to determine the operational health of the GOES-2 and GOES-3 satellites. The requirements for command and control of the satellite while supporting PEACESAT also are examined.

Section 4 presents the conclusions and recommendations that are drawn from the work done by ITS.

# 2. PEACESAT

## 2.1 History and Operation with ATS-1

In 1966, the National Aeronautics and Space Administration (NASA) launched the first of six experimental satellites, Applications Technology Satellite-1. The satellite had an expected three-year life span and was used primarily to demonstrate the feasibility of optical imaging systems aboard geosynchronous satellites. These imaging systems were the forerunner of those on the current GOES. The satellite also had a class C transponder that could support low capacity voice transmissions.

In 1971, NASA completed its experiments with ATS-1 and requested proposals for additional experiments using the satellite. In response, the University of Hawaii (UH) proposed and was authorized to conduct the PEACESAT project; an educational, medical, and scientific communication experiment for non-commercial social and cultural exchanges between the countries of the Pacific Basin region. NASA supported the PEACESAT project by annually renewing the authorization and operating the satellite at no cost to the users. The University of Hawaii contributed funds to support a central PEACESAT facility in Honolulu that was managed by the University of Hawaii Social Science Research Institute.

ATS-1 was particularly well suited for the users in the Pacific Basin region. Because of its narrowband VHF transponder design, very small and inexpensive ($2,000 to $5,000 each) earth stations for voice and facsimile transmissions were possible. More elaborate stations could support data and slow-scan video transmissions as well. Figure 1 shows a block diagram of a typical PEACESAT earth station. The earth station consisted of a slightly modified amateur VHF mobile radio (the frequency spread between the transmit and receive section was increased and the transmit/receive switch bypassed to allow operation using two antennas), a 150-W VHF linear power amplifier, and two cross-beam Yagi or helical antennas, one for the 149 MHz uplink frequency and the other for the 135 MHz downlink frequency. In many instances the antennas were home-built and the primary station power was provided by batteries charged from photovoltaic cells. Also, some of the stations in Micronesia were delivered by canoe.

In 1982, ATS-1 was moved from its initial position at 149° W longitude to the more stable orbital position of 162° E longitude in order to conserve station keeping fuel. This new position facilitated the establishment of at least six major inter-cultural communication networks in the Pacific Basin region. Three such networks are shown in Figure 2. The satellite provided links between numerous points, including the West Coast of the United States, Hawaii, over twenty Pacific island nations, and the American trust territories. (See Table 1.) The satellite was used typically as a point-to-multi-point communication system, with the majority of transmissions originating from Suva, Fiji, and the University of Hawaii. The networks served to improve the exchange of social, environmental, health, and educational information and contributed to a general easing of traditional colonial separations.

In April 1984, under NASA's direction, the Hawaii Institute of Geophysics (HIG) assumed the responsibility of tracking and controlling ATS-1. This allowed NASA to discontinue the support of VHF controlled spacecraft but keep ATS-1 usable. In August 1985, the remaining ATS-1 station-keeping fuel was exhausted and the satellite drifted out of the Pacific region. With the Pacific islands no longer within the ATS-1 footprint, the satellite was turned off to avoid interference with other satellite systems.

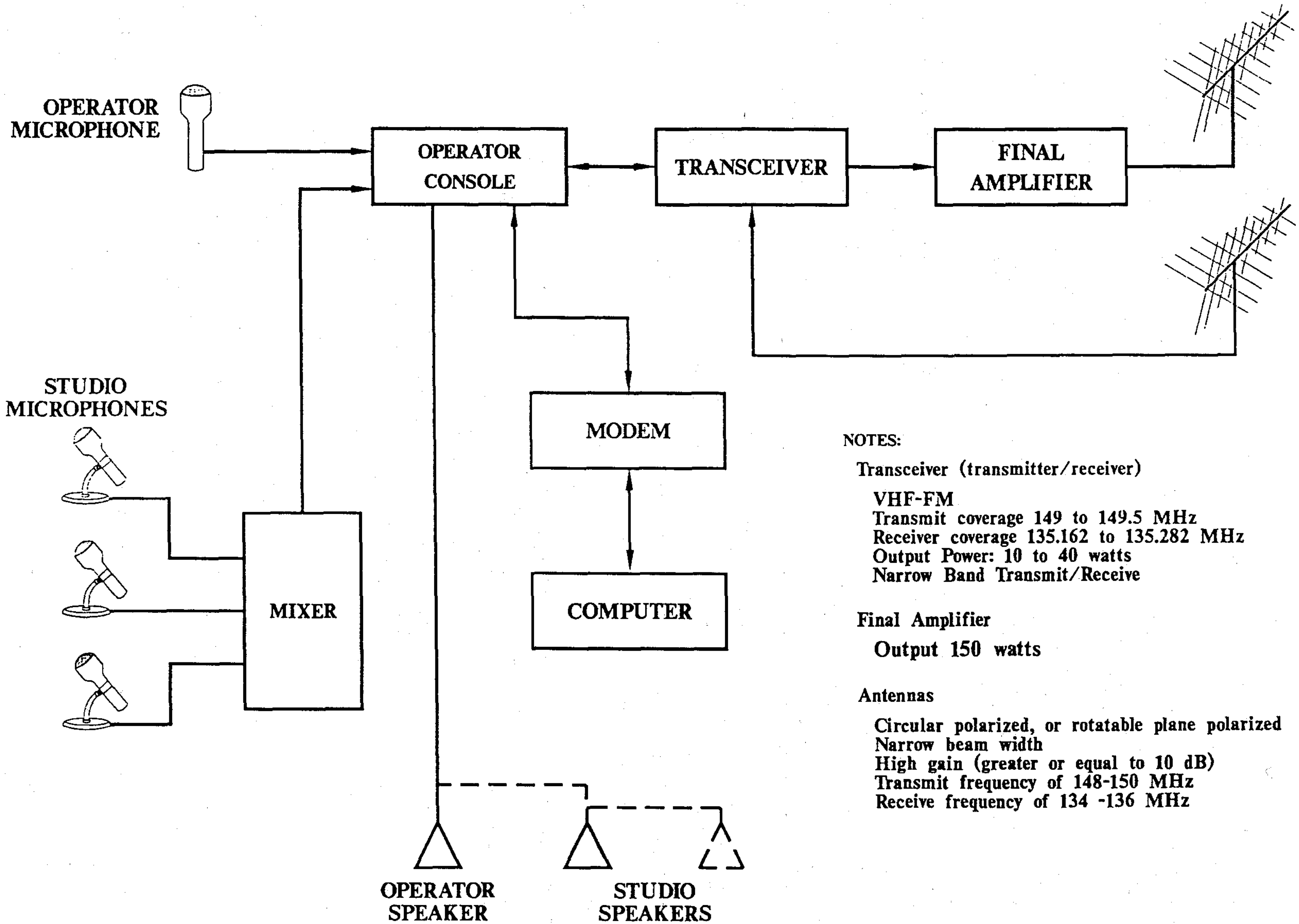


Figure 1. Typical PEACESAT earth station using ATS-1.

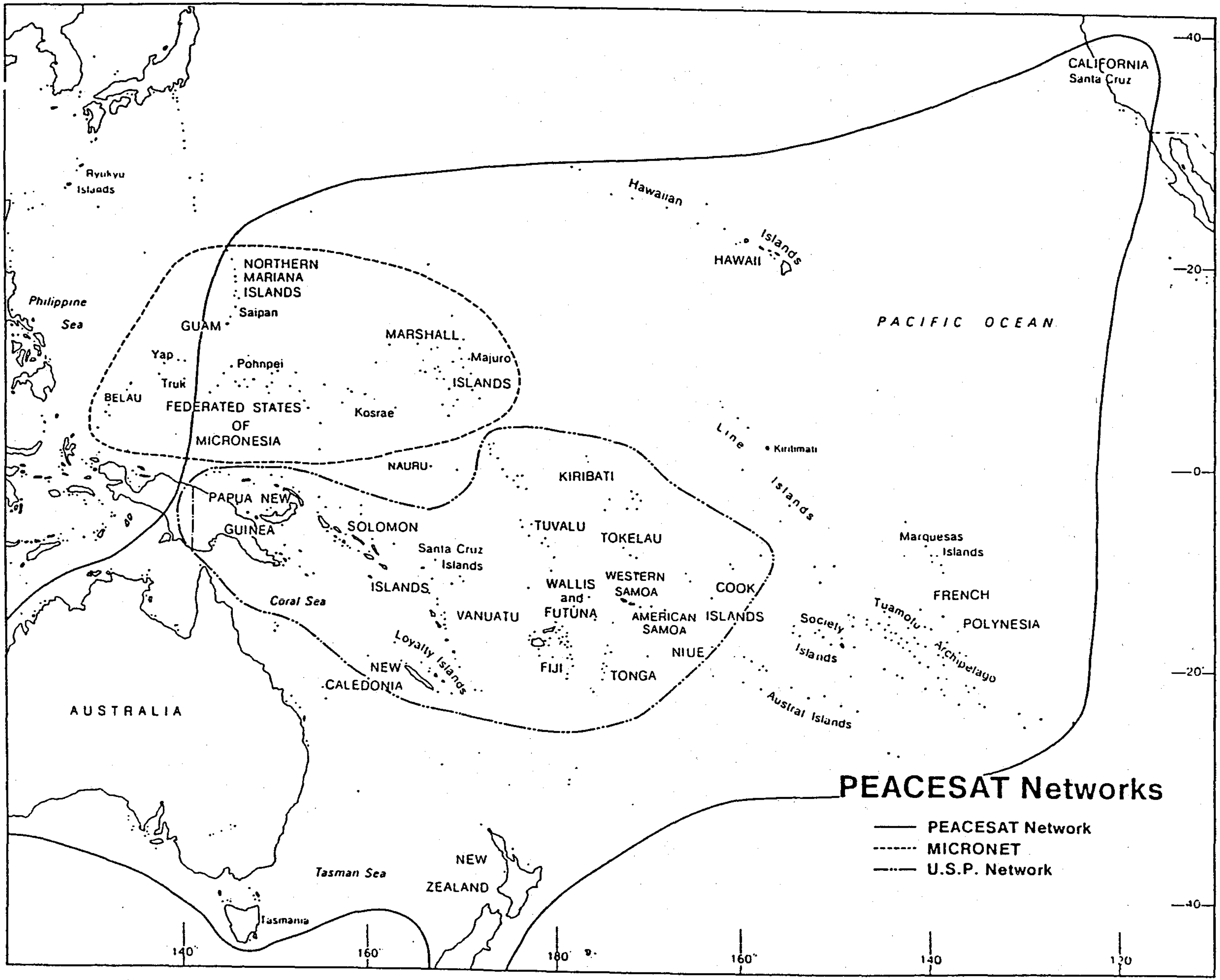


Figure 2. The major inter-cultural networks in the Pacific Basin supported by PEACESAT using ATS-1 (PEACESAT, 1988a).

Table 1. PEACESAT User-Terminal Locations

1. Adelaide, South Australia
2. Apai, Western Samoa
3. Bentley, Australia
4. Canberra, New South Wales, Australia
5. Darwin, Northern Territory, Australia
6. Footscray, Australia
7. Funafuti, Tuvalu
8. Guam
9. Honiara, Solomon Islands
10. Honolulu, Hawaii
11. Kelvin Grove, Australia
12. Kosrae, Federated States of Micronesia (F.S.M.)
13. Lae, Papua-New Guinea
14. La Trobe, Australia
15. Magill, Australia
16. Majuro, Marshall Islands
17. Niue
18. Noumea, New Caledonia
19. Pago Pago, American Soma
20. Palau (Belau)
21. Perth, Western Australia
22. Pohnpei, F.S.M.
23. Rarotonga, Cook Islands
24. Suva, Fiji
25. Saipan, Northern Mariana Islands
26. Nuku 'Alofa, Tonga
27. Tarawa, Kiribati
28. Toowoomba, Queensland, Australia
29. Truk, F.S.M.
30. Vila, Vanuata
31. Wellington, New Zealand
32. Yap, F.S.M.

In December 1987, Congress appropriated funds and directed that NTIA help the University of Hawaii re-establish the PEACESAT service. Coincidentally, after the Congressional authorization was made, ATS-1 completed an orbit of the Earth and re-appeared over the Pacific in early 1988. NASA is again operating the satellite for Pacific-wide telecommunications and the short-term re-establishment of the PEACESAT service. However, ATS-1 continues to drift and will be out of range of the Pacific in late 1989. Thus, a permanent replacement space segment is required if the PEACESAT network and services are to continue.

### 2.2 Operational and User Requirements

The Pacific Basin region is very large, covering over seven time zones and containing the international date line. Providing coverage for this vast area puts two major requirements on a satellite-based communication system like PEACESAT. The spacecraft antennas must provide horizon-to-horizon earth coverage such as is shown in Figure 3. And, the system must be available 24 hours a day, seven days a week to support a schedule similar to the ATS-1 Schedule of Networks shown in Table 2.

The PEACESAT users' basic service requirements were developed as part of the PEACESAT Satellite Selection Study (PEACESAT, 1988b). These basic service requirements, as modified slightly for the Request for Information (NTIA, 1989), are shown in Table 3. The service area ranges from Hawaii on the east to Palau on the west. A satellite positioned at 160° E longitude would provide an ideal coverage area for PEACESAT (see Figure 3). However, a satellite positioned anywhere between 150° W longitude (Figure 4) and 140° E longitude (Figure 5) would provide adequate coverage. The azimuth and elevation angles for the PEACESAT terminals listed in Table 1 are given in Appendix A for satellites at 150° W, 160° E, and 140° E longitude.

The minimum signal transmission requirement for PEACESAT is a single half-duplex voice circuit. The next step in capability would be to include a half-duplex, 1200-baud data circuit. A desirable configuration would support simultaneously two full-duplex voice circuits and two full-duplex, 64-kb/s data circuits. The ultimate configuration would be a system with sufficient bandwidth to also include slow-scan or compressed video. A 20-dB baseband voice signal-to-noise ratio and 6-dB link margin are desirable.

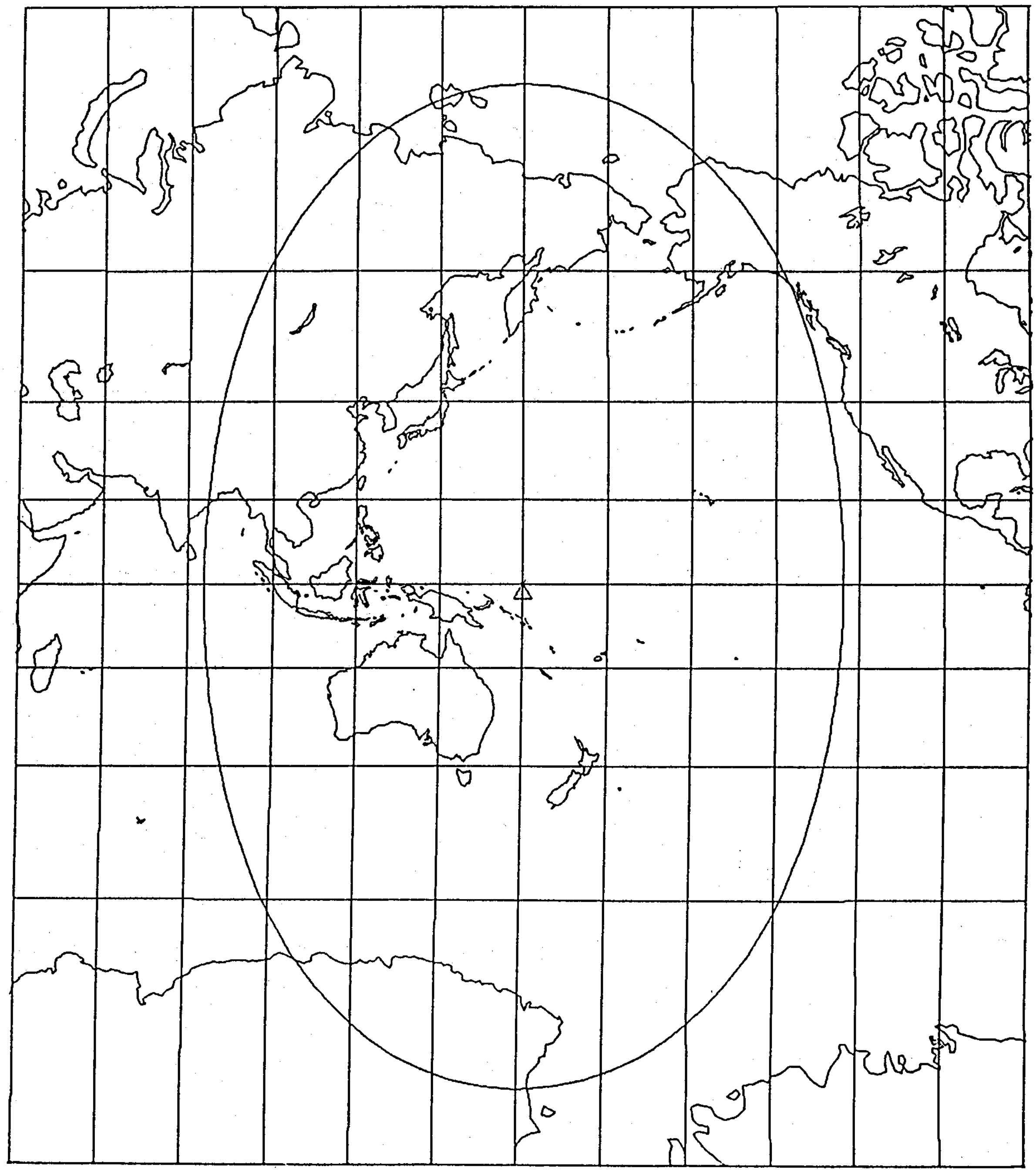

Figure 3. Footprint for "earth coverage" from a satellite located at 160° E longitude.

Table 2. The ATS-1 Schedule of PEACESAT Networks (PEACESAT, 1988a)

# ATS-1 SCHEDULE OF NETWORKS

| HST | GMT | SUNDAY<br>MONDAY | MONDAY<br>TUESDAY | TUESDAY<br>WEDNESDAY | WEDNESDAY<br>THURSDAY | THURSDAY<br>FRIDAY | FRIDAY<br>SATURDAY | SATURDAY<br>SUNDAY |
|---|---|---|---|---|---|---|---|---|
| 2 pm | 0000 | MICRONET | MICRONET | COMPUTER | MICRONET | MICRONET | MICRONET | |
| 3 pm | 0100 | KANGAROO | KANGAROO | KANGAROO | KANGAROO | COMPUTER | | |
| 4 pm | 0200 | ALL ATS1 | USP | USP | USP | USP | USP | PEACESAT |
| 5 pm | 0300 | PEACESAT | PEACESAT | PEACESAT | PEACESAT | PEACESAT | PEACESAT | PEACESAT |
| 6 pm | 0400 | PEACESAT | PEACESAT | PEACESAT | PEACESAT | PEACESAT | PEACESAT | PEACESAT |
| 7 pm | 0500 | PEACESAT | KANGAROO | KANGAROO | KANGAROO | KANGAROO | | |
| 8 pm | 0600 | USP | USP | USP | USP | USP | USP | |
| 9 pm | 0700 | USP | USP | USP | USP | USP | USP | |
| 10 pm | 0800 | MICRONET | MICRONET | MICRONET | MICRONET | MICRONET | | |
| 11 pm | 0900 | MICRONET | MICRONET | MICRONET | MICRONET | MICRONET | | |
| | 0930 | KANGAROO | KANGAROO | KANGAROO | KANGAROO | KANGAROO | | |

| HST | GMT | MONDAY<br>MONDAY | TUESDAY<br>TUESDAY | WEDNESDAY<br>WEDNESDAY | THURSDAY<br>THURSDAY | FRIDAY<br>FRIDAY | SATURDAY<br>SATURDAY | SUNDAY<br>SUNDAY |
|---|---|---|---|---|---|---|---|---|
| 12 am | 1000 | KANGAROO | KANGAROO | KANGAROO | KANGAROO | KANGAROO | | |
| 1 am | 1100 | KANGAROO | KANGAROO | KANGAROO | KANGAROO | KANGAROO | | |
| 2 am | 1200 | ASIANNET | ASIANNET | ASIANNET | ASIANNET | ASIANNET | | |
| 3 am | 1300 | ASIANNET | ASIANNET | ASIANNET | ASIANNET | ASIANNET | | |
| 4 am | 1400 | COMPUTER | COMPUTER | COMPUTER | COMPUTER | COMPUTER | COMPUTER | COMPUTER |
| 5 am | 1500 | COMPUTER | COMPUTER | COMPUTER | COMPUTER | COMPUTER | COMPUTER | COMPUTER |
| 6 am | 1600 | COMPUTER | COMPUTER | COMPUTER | COMPUTER | COMPUTER | COMPUTER | COMPUTER |
| 7 am | 1700 | COMPUTER | COMPUTER | COMPUTER | COMPUTER | COMPUTER | COMPUTER | COMPUTER |
| 8 am | 1800 | OCEAN | OCEAN | OCEAN | OCEAN | OCEAN | OCEAN | OCEAN |
| 9 am | 1900 | PEACESAT | PEACESAT | PEACESAT | PEACESAT | PEACESAT | PEACESAT | PEACESAT |
| 10 am | 2000 | USP | PEACESAT | PEACESAT | PEACESAT | USP | PEACESAT | PEACESAT |
| 11 am | 2100 | USP | USP | USP | USP | USP | OCEAN | USP |
| 12 pm | 2200 | OCEAN | OCEAN | OCEAN | OCEAN | OCEAN | OCEAN | USP |
| 1 pm | 2300 | MICRONET | MICRONET | MICRONET | MICRONET | MICRONET | OCEAN | MICRONET |

Table 3. PEACESAT User Service Requirements (NTIA, 1989)

# PEACESAT USER SERVICE REQUIREMENTS

**The following PEACESAT user service requirements have tentatively been identified**

## Service Area

**Ideal Satellite Position, 160 degrees East with full disk coverage**
**Inclination Tolerance no more than +/- 7 degrees**
**Satellite position requirement extremes: 150 degrees West to 140 degrees East**

## Signal Transmission

**Minimum requirements:**

**Voice: Half-duplex; 1 circuit (1 carrier)**
**Data: Half-duplex; 1 circuit (1 carrier) 1200 baud (packet-switched network)**

**Desirable requirements:**

**Voice: Full-duplex; 2 circuits (4 carriers)**
**Data: Full-duplex for rates up to 64 kbps; 2 circuits (4 carriers)**

## Channel Assignments

**Support either analog or digital services to meet user requirements at any instant for voice, data, and slow scan (and/or compressed) video needs.**

**Desired Signal-to-Noise Ratio:** Greater than 20 dB

**Fade Margin:** 6 dB

**Network Connectivity:** Interactive Mesh, full earth disk coverage

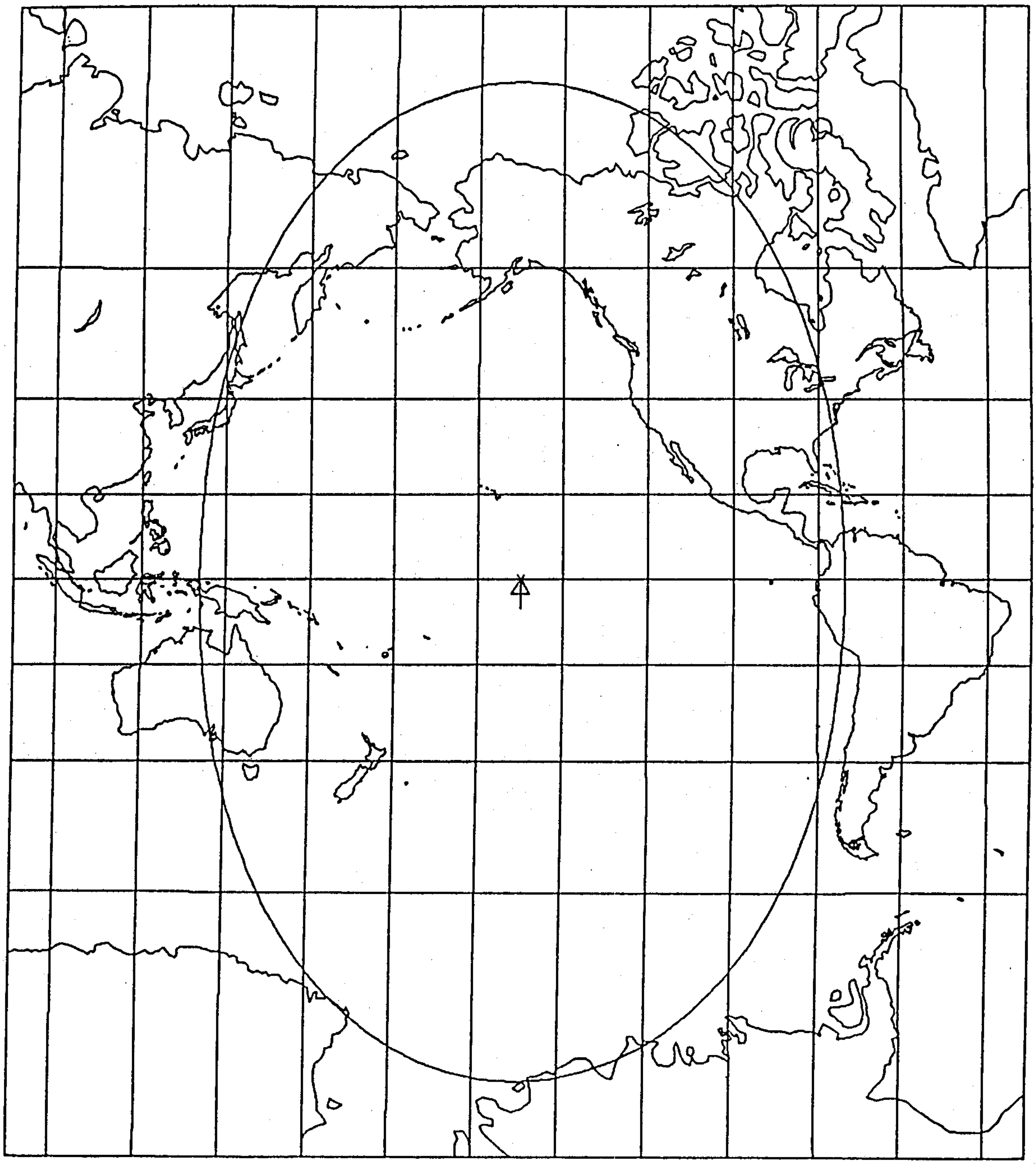

Figure 4. Footprint for "earth coverage" from a satellite located at 150° W longitude.

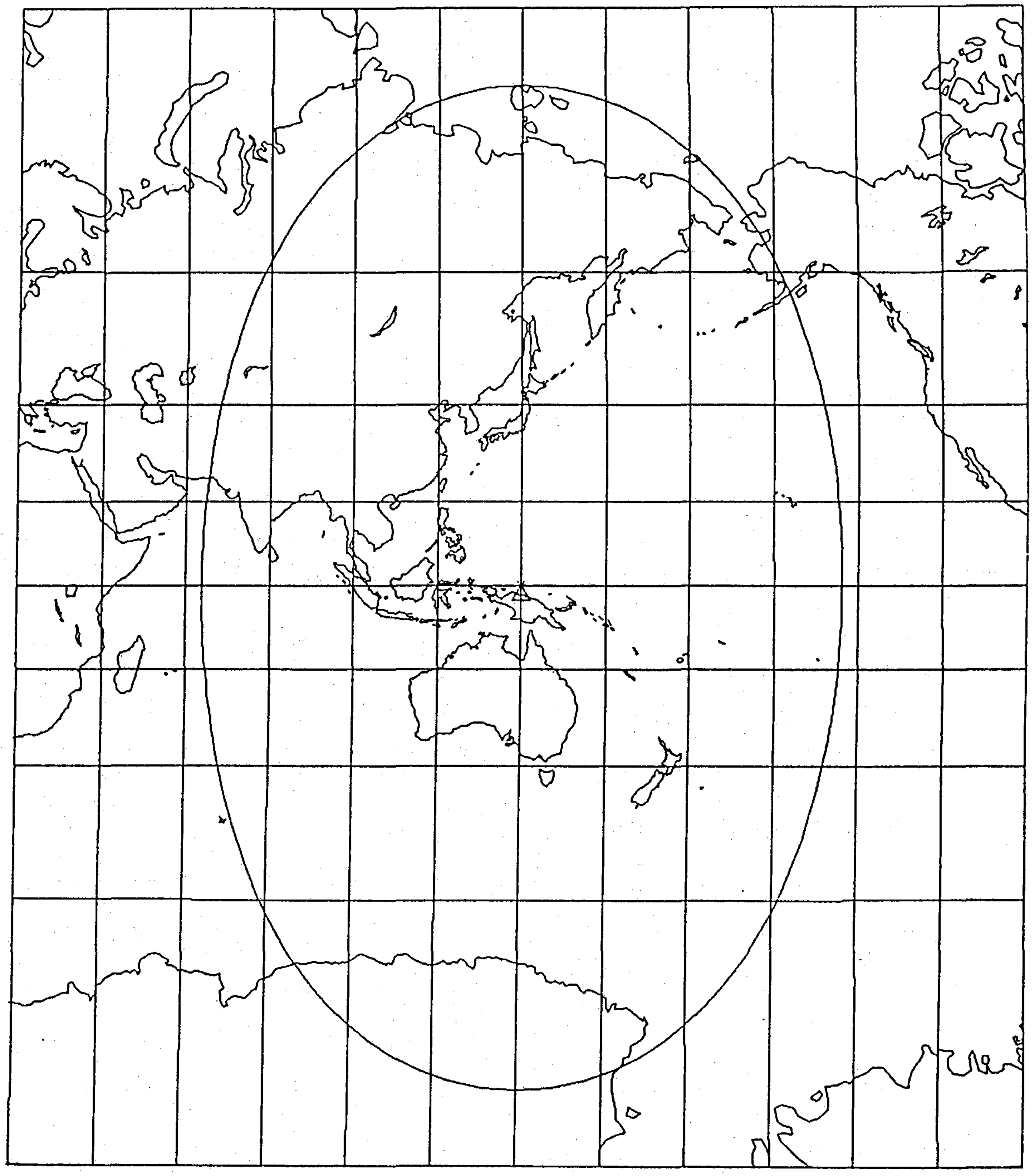

Figure 5. Footprint for "earth coverage" from a satellite located at 140° E longitude.

PEACESAT will operate in many different modes, point-to-multipoint for distance education, multipoint-to-multipoint teleconferencing for round table discussions and cultural interchange, and point-to-point for medical emergency and disaster relief. Thus, the system is very symmetric and would operate as an interactive mesh network in which all earth stations must be able to communicate with all other earth stations, preferably with a single satellite hop. It is not a typical very-small-aperture-terminal (VSAT) network with a large central hub station.

The success of PEACESAT can be attributed largely to the small, simple, inexpensive user earth stations. Many of the stations were assembled by the PEACESAT users with locally available components. The simple amateur radio technology of the stations allowed maintenance by technicians with not much more than a high school education. And, the $2,000 to $5,000 cost per station allowed the smaller island nations that could not afford commercial telecommunication service to participate in the PEACESAT exchanges. Thus, a prime requirement from the users' perspective is that the system be very easy to use and maintain and have low initial and recurring costs.

### 2.3 Summary of Studies: Space Segment to Replace ATS-1

As the first step in re-establishing the PEACESAT service, the PEACESAT Satellite Selection Study was initiated. The objective was to identify appropriate space segment replacement alternatives for ATS-1. The study began on June 1, 1988, under the direction of the UH PEACESAT Program and NTIA, and was a collaborative effort among past PEACESAT users, UH, and NTIA representatives.

Three subgroups were formed: the Technical Options Panel, the Impact Assessment Group (IAG), and the International PEACESAT Users Group (IPUG). The TOP investigated the technical feasibility of each option. The IAG investigated the cultural, political, and user impact of the technology, coverage area, and cost associated with each option. The IPUG, working with the IAG, provided a user's assessment of each option. A Cost Analyst also was retained to investigate the financial impact of each option.

Table 4. Initial ATS-1 Replacement Satellite Systems Investigated by the TOP

1. Radio Amateur Satellite Corporation's Phase IV satellite with a VHF or UHF transponder (AMSAT VHF/UHF)
2. AMSAT S-Band
3. Australian Satellite System (AUSSAT)
4. GOES UHF
5. GOES S-Band
6. INTELSAT Single Channel per Carrier
7. INTELSAT Frequency Division Multiplex
8. LEASAT - 8 (LES)
9. MARISAT UHF
10. MARISAT L-Band
11. INMARSAT

Based on orbital position, coverage, and availability, the satellite systems listed is Table 4 were selected for further study by the TOP. These systems were investigated in greater detail, with emphasis on the technical, financial, and political aspects of each. Technical information on orbital position, network connectivity, earth station technology, operating frequency, and implementation lead time was gathered. Rough cost estimates for the user earth stations, necessary tracking, telemetry and command (TT&C) or hub stations, space segment lease costs, and recurring maintenance costs were generated for each system. Political implications such as spectrum coordination as well as the ease of user access to the service, and local post, telegraph, telephone (PTT) coordination also were assessed.

It became obvious early in the study period that it was necessary to identify separate interim and long-term space segment replacement options. The interim option was defined to be a system that would be in place and operational by the time ATS-1 drifted out of range in late 1989 and that would meet the minimum PEACESAT service requirements. The long-term option was defined as a system that would be in place some time later, have a minimum 10-year life, and be able to support the desired PEACESAT service requirements.

On October 24, 1988, the study was concluded and a final report issued (PEACESAT, 1988b). Table 5 lists the final ranking of the interim and long-term options recommended for further consideration.

Table 5. Final PEACESAT Satellite Selection Study Ranking (PEACESAT, 1988b)

| | Interim Option | Long-Term Option |
|---|---|---|
| 1. | MARISAT UHF | AMSAT VHF/UHF |
| 2. | GOES S-Band | AMSAT S-Band |
| 3. | MARISAT UHF | AMSAT S-Band |

It has been determined subsequently that the MARISAT UHF system is not available for PEACESAT use. It also is currently needed by the U.S. Military. Thus, option 2, GOES S-Band for the interim and AMSAT S-Band for the long-term is being pursued as the PEACESAT space segment replacement system for ATS-1.

## 3. GOES--POSSIBLE INTERIM SATELLITE FOR PEACESAT

### 3.1 Brief History of GOES

The United States Congress passed a law in September 1961 that established a meteorological satellite system. The Geostationary Operational Environmental Satellites, operated by the National Oceanic and Atmospheric Administration (NOAA) are a major component of that system. To date, nine geostationary, meteorological satellites have been launched. These are:

| Satellite | Launch Date |
|---|---|
| SMS-1 | May 1974 |
| SMS-2 | February 1975 |
| GOES-1 | October 1975 |
| GOES-2 | June 1977 |
| GOES-3 | June 1978 |
| GOES-4 | September 1980 |
| GOES-5 | May 1981 |
| GOES-6 | April 1983 |
| GOES-7 | February 1987 |

The first five of these spacecraft were built by Aeronutronics Ford; the remaining spacecraft were built by Hughes Aircraft Company.

The Synchronous Meteorological Satellites (SMS) and GOES satellites built by Aeronutronics Ford are spin-stabilized (nominally 100 rev/min), solar-array-covered cylinders that are 75 in (1.905 m) in diameter and 51.25 in (1.302 m) in length. Subsystems carried by each satellite include the following:

1. a Visible/Infrared Spin Scan Radiometer (VISSR)
2. a VISSR Digital Multiplexer
3. a Communications subsystem (see Section 3.2)
4. a Space Environment Monitor
5. a Telemetry & Command (T&C) subsystem
6. the Power subsystem
7. an Attitude Determination and Antenna Control subsystem
8. an Auxiliary Propulsion System
9. an Apogee Boost Motor

Characteristics of the communications subsystem determine the ability of a GOES satellite to provide the transponder bandwidth needed to support the PEACESAT network. That subsystem is described in the following sub-section, and it becomes the focus of much of the remainder of this report.

NOAA's meteorological satellite system normally includes two operational, geostationary satellites--GOES-East (GOES-7) located at about 75° W and GOES-West (GOES-6) located at about 135° W longitude. However, GOES-6 suffered a premature failure in January 1989, and the system now has only one operational satellite, GOES-7, relocated to 82° W longitude. A similar failure of optical components in the VISSR for GOES-2 and GOES-3 has also rendered these satellites essentially useless as meteorological satellites. However, the communications subsystem on each satellite is still operational.

This report examines the technical feasibility of using the S-Band transponder (part of the communications subsystem) on either the GOES-2 or GOES-3 satellite to provide transponder bandwidth for the PEACESAT network for an interim period until efforts are completed to secure other transponder bandwidth for long-term use. GOES-2 is located at 112.8° W and GOES-3 is at 129.8° W longitude, so either satellite would need to be relocated if it were to be used for the PEACESAT network. (As noted earlier, these satellites were built by Ford.)

### 3.2 GOES Communication Subsystem Description

The GOES communications subsystem has receivers, transmitters, and antennas designed to provide the following functions:

1. **Command Reception.** Receive an amplitude-modulated/frequency-shift keyed/phase modulated S-Band command signal via a 60-kHz bandwidth IF channel, and provide an FSK/AM baseband signal to the command detector of the telemetry and command (T&C) subsystem. The command uplink is at 2034.2 MHz.

2. **Telemetry Data Transmission.** Accept a telemetry baseband signal consisting of 188 b/s pulse-code modulation (PCM) and Inter-Range Instrumentation Group (IRIG) subcarrier B or IRIG subcarrier E signals, and phase-modulate a carrier signal. The signal is then upconverted, amplified, and transmitted via the S-Band antenna. The carrier signal is at 1694.0 MHz.

3. **Stretched VISSR/WEFAX/Ranging.** Receive a stretched VISSR (SVISSR) signal or Weather Facsimile (WEFAX), or ranging signals at S-Band, route the signal through an 8.2 MHz bandwidth limiting intermediate frequency (IF) amplifier, and transmit the signal via the S-Band despun antenna. The band is centered at 1687.1 MHz on the downlink.

4. **VISSR Data Transmission.** Accept two 14-Mb/s inputs from the VISSR multiplexer and quadriphase-modulate an 81.6-MHz carrier signal with these data. The carrier signal is upconverted, amplified, and transmitted via the S-Band antenna. The signal spectrum is centered at 1681.6 MHz.

5. **Data Collection Platform Interrogation (DCPI).** Receive a DCPI signal at S-Band (2034.925 MHz), amplify, and frequency-convert this signal for subsequent retransmission at 468.850 MHz via the UHF transmitter and despun antenna.

6. **Data Collection Platform Reports (DCPR).** Receive DCPR data within the 400-kHz bandwidth at a nominal center frequency of 401.9 MHz. These data are frequency converted, amplified, and retransmitted at S-Band at 1694.5 MHz via the S-Band antenna.

The ranging, SVISSR, and WEFAX signals are all relayed by the hard-limiting, multi-function repeater that has intermediate frequency (IF) bandwidth of 8.2 MHz. The frequency plan for performing all of these functions is illustrated in Figure 6.

Two redundant S-Band transponders are provided on each satellite. Each transponder consists of an S-Band receiver, an S-Band transmitter, and an S-Band power amplifier. The proposed, interim use of GOES-2 or GOES-3 for PEACESAT would require only a portion of the bandwidth provided by each transponder. Bandwidths of about 100 kHz centered on the middle trilateration ranging frequencies at 2030.2 MHz uplink and 1688.2 MHz downlink have been suggested.

The S-Band receiver front end is a conventional balanced mixer followed by a low noise, IF preamplifier. The nominal IF for the receiver is 87.1 MHz. Noise figure for the downconverter assembly is less than 7.5 dB. The wideband IF section includes four linear amplifier stages, two limiter modules, a

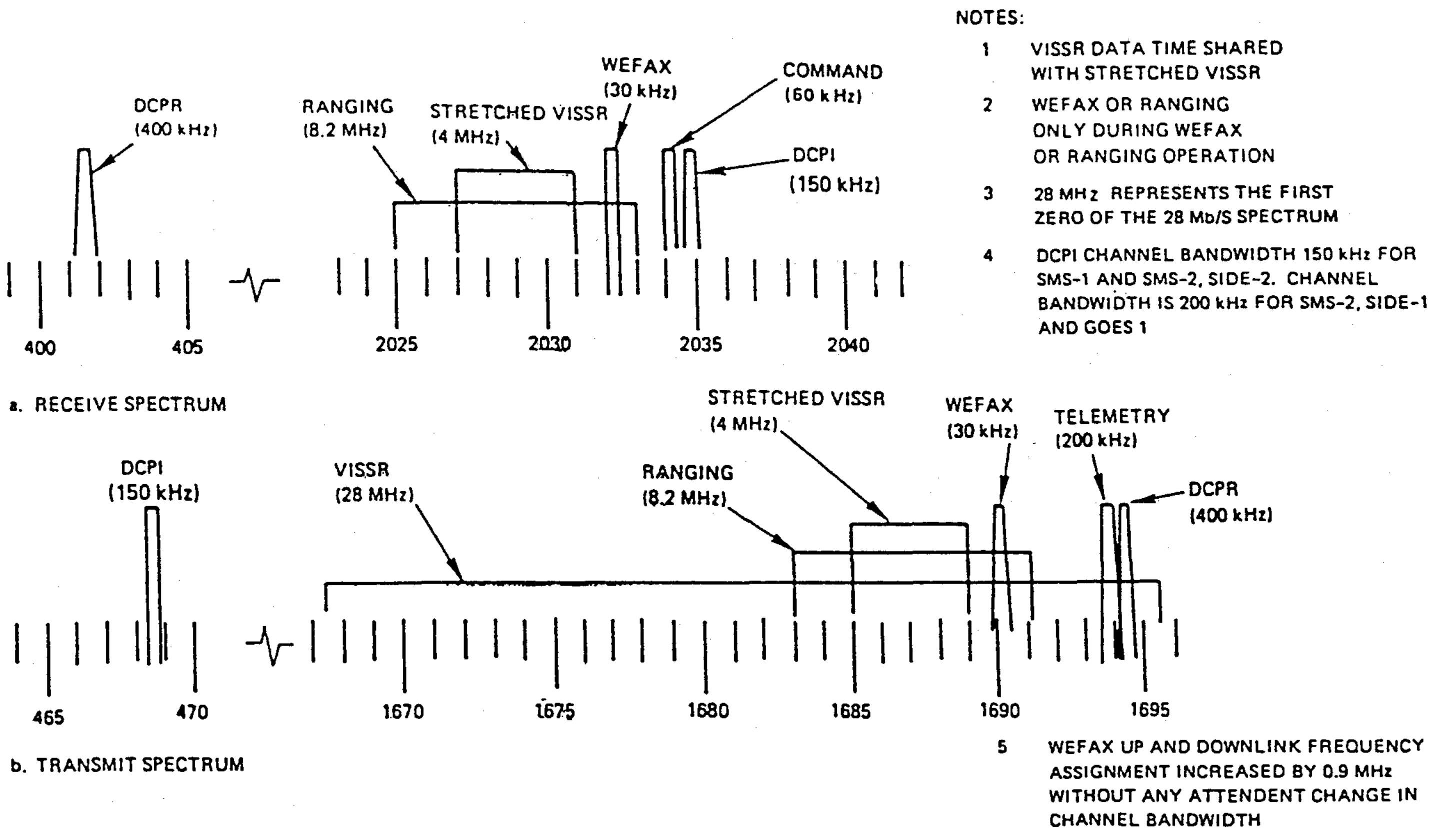


Figure 6. The frequency plan for normal GOES functions (Ford, 1977).

seven-pole band-pass filter designed for 8.2 MHz bandwidth with Butterworth response, and an output amplifier stage. The receiver provides hard limiting with constant output to the transmitter power combiner at a nominal level of -7 dBm over a dynamic range from -70 dBm to thermal noise (about -97 dBm in the 8.2 MHz bandwidth), referenced to the receiver input.

Following upconversion of the signal to be transmitted, and operating in the "normal" (power) mode, a four-stage driver amplifier provides a nominal constant power (signal plus noise) of 0.5 W (27 dBm) to the MFR power amplifiers. The S-Band, solid-state power amplifiers deliver 5 W at 1700 MHz with 50% to 55% efficiency. Power amplifier output powers are added to achieve nominal total output power of 20 W (43 dBm) delivered to the antenna.

The S-Band communications antenna assembly consists of an electronically switched, despun, linearly polarized antenna with about 15.5 dB gain within 9.1° of beam center. A wideband PIN diode switch with low insertion loss is used to despin the antenna array. The antenna array consists of 32 rows of wideband S-Band radiating elements mounted around the circumference of the satellite. Each of the 32 rows contains four Yagi radiating elements. The beam is formed by energizing only five adjacent rows to form a 20-element amplitude-steered array. Four variable power dividers are used to gradually transfer power from one radiating row of the S-Band elements to another so as to minimize pattern ripple.

A summary of communication subsystem typical characteristics for the S-Band transponder, taken from Ford (1977), is given in Table 6.

### 3.3 Analysis of GOES S-Band Transponder for PEACESAT

Detailed link calculations for the VISSR, processed (or stretched) VISSR (SVISSR), and WEFAX links are given in reports prepared by Ford (1977). A consolidated copy of these calculations for a satellite at 135° W is presented as Table 7. The column labeled **CDA to Satellite** contains information for the uplink from the Control and Data Acquisition (CDA) Station at Wallops Station, VA (37.8° N, 75.2° W). The last three columns contain downlink information. The column labeled **Satellite to NESS** is information for the link to the National Environmental Satellite Service (NESS), now known as the National Environmental Satellite, Data, and Information Service (NESDIS), Station in Suitland, MD (38.8° N, 76.9° W). The columns labeled **Satellite to APT** are information to

Table 6. Typical Characteristics for the S-Band Transponder (Ford, 1977)

| Parameter | S-Band Characteristic | Comments |
|---|---|---|
| G/T (Figure of Merit) | $\geq$ -25.7 dB/K | See equivalent isotropically radiated power (EIRP) comment. |
| EIRP, "Normal" Mode | $\geq$ +54.5 dBm | Applies anywhere within 9.1° of antenna beam center. |
| Antenna Pattern | Earth coverage | |
| Polarization | Linear | |
| Antenna Operation | Electrically despun | |
| Image Rejection | $\geq$ 60 dB | |
| Frequency: | | |
| Receive Center Frequency | 2029.1 MHz | See Figure 1 for additional frequency utilization information. |
| Transmit Center Frequency | 1687.1 MHz | |
| Receiver Noise Figure | $\leq$ 7.5 dB | |
| Bandwidth | 8.2 MHz | Multi-function repeater (MFR) only |
| Dynamic Range: | | Determined by predicted levels of received signals referenced to the receiver input. |
| Wideband IF (MFR) | Thermal noise to -70 dBm | |
| Amplitude Response | ±1 dB | Applies for a specific frequency within 3-dB bandwidth and within dynamic range. |
| Time Delay Variation | 10 ns | |
| Receiver Selectivity: | | Selectivity defined as 30-dB bandwidth. |
| Wideband IF (MFR) | 15 MHz | |
| RF Power: | | Minimum RF power levels provided to antenna switching matrix. |
| Normal Mode | 22 W | |
| Receiver Squelch: | By command | From digital multiplexer. |

Table 7. Consolidated Link Calculations for a GOES Satellite Located at 135° W to Provide VISSR, SVISSR, and WEFAX Communications (Ford, 1977)

| FUNCTION | CDA to Satellite | Satellite to NESS | Satellite to APT (EC) | Satellite to APT (EE) |
|---|---|---|---|---|
| 1. XMTR Power., dBm | 57.0 | 43.5 | 43.5 | 43.5 |
| 2. Cross-Products & Pwr. Sharing Loss, dB | ----- | 0.6 | 0.6 | 0.6 |
| 3. XMT Line Loss, dB | 1.6 | 4.3 | 4.3 | 4.3 |
| 4. XMT Antenna Gain, dB | 46.8 | 15.4 | 17.6 | 15.2 |
| (Offbeam Loss, dB) | (0) | (2.2) | (0) | (2.4) |
| (Angle, degrees) | (0) | (8.4) | (0) | (8.7) |
| (Antenna Size, ft.) | (60) | ----- | ----- | ----- |
| 5. EIRP (Signal), dBm | 102.2 | 54.0 | 56.2 | 53.8 |
| (Total) | | (54.6) | (56.8) | (54.4) |
| 6. Free Space Loss, dB | 190.6 | 188.9 | 188.0 | 189.4 |
| (Range x $10^3$, km) | (39.82) | (39.82) | (35.65) | (42.24) |
| (Frequency, MHz) | (2030) | (1687) | (1687) | (1687) |
| 7. Polarization Loss, dB | 0.2 | 0.2 | 0.2 | 0.2 |
| 8. RCV Antenna Gain, dB | 13.8 | 40.0 | 31.6 | 31.6 |
| (Antenna Size, ft.) | ----- | (24) | (10) | (10) |
| (Offbeam Ctr. Loss, dB) | (2.5) | (0) | (0.5) | (0.5) |
| (Angle, degrees) | (8.4) | (0) | (0.8) | (0.8) |
| 9. RCV Line Loss, dB | 6.8 | (0) | 2.0 | 2.0 |
| 10. RCVR Input Power Level, dBm | -81.6 | -95.1 | -102.4 | 06.2 |
| 11. Sys. Noise Temp., dB-K | 32.1 | 24.8 | 30.4 | 30.4 |
| ($T_S$-K) | (1630) | (300) | (1093) | (1093) |
| 12. Boltzmann's Constant, dBm/Hz-K | -198.6 | -198.6 | -198.6 | -198.6 |
| 13. RCVR Input $N_o$, dBm/Hz | -166.5 | -173.8 | -168.2 | -168.2 |
| 14. RCVR Input $C/N_o$, dB-Hz | 84.9 | 78.7 | 65.8 | 62.0 |
| 15. XMTR Output $C/N_o$, dB-Hz | ----- | 84.9 | 84.9 | 84.9 |
| 16. Overall $C/N_o$, dB-Hz | 84.9 | 77.7 | 65.8 | 62.0 |
| 17. Required $C/N_o$, dB-Hz | ----- | 74.2 | 57.0 | 57.0 |
| 18. Margin, dB | ----- | 3.5 | 8.8 | 5.0 |
| 19. S/C Input C/N, dB | 15.8 | ----- | ----- | ----- |
| 20. G/T, dB/K | -25.1 | 15.2 | -0.8 | -0.8 |

Automatic Picture Transmission (APT) terminals; **EC** denotes earth center (or sub-satellite point) and **EE** denotes earth edge.

The information provided in Table 7 is the source of GOES performance characteristics used for analysis of GOES to support the PEACESAT network. In particular, the values given for uplink and downlink polarization losses, satellite receiving and transmitting antenna gains, off beam-center reductions in satellite antenna gains, satellite receiving system line loss, satellite receiving system noise temperature, satellite transmitter power, and satellite transmitter line loss are used in computing link budgets for a number of different options in using a GOES to provide PEACESAT network services.

Three radio frequency (RF) power conditions for the transponder are considered, recalling that the MFR is a hard-limiting repeater. These conditions are

1. the input signal to the satellite receiver is relatively high power compared to the receiving system noise power. A ratio of input signal power ten times the noise power is assumed. Under this condition, virtually all repeater output power for the downlink transmission is devoted to the signal. (Signal power gain through the high power amplifier for this condition is nonlinear.)

2. the input signal to the satellite receiver is equal in power to the receiving system noise power. Under this condition, the repeater output power is assumed to be shared equally between the signal and the noise. (Signal power gain through the high power amplifier for this condition may be quasi-linear for relatively small variations in the input power.)

3. the input signal to the satellite receiver is very low power compared to the receiving system noise power. A ratio of input signal power equal to one-tenth the receiving system noise power is assumed. Under this condition, less than one-tenth of the repeater output power is devoted to the signal (and more than nine-tenths of the output power is devoted to the noise). (Signal power gain through the high power amplifier for this condition is approximately linear for "operational" variations in the input power.)

Three levels of network capability for PEACESAT also are assumed. These network capabilities are

1. a single access to the repeater; this would compare to a single circuit with half duplex operation.

2. two accesses to the repeater; this would compare to a single circuit with full duplex operation.

3. four accesses to the repeater; this would compare to two circuits, each with full duplex operation.

We assume that narrowband frequency modulation (NBFM) would be used and that the circuits that would be provided would be normal, 3-kHz baseband bandwidth voice and/or voice-bandwidth data circuits. The audio signal-to-noise ratio (SNR) criterion for these circuits is based on voice quality defined by the International Radio Consultative Committee (CCIR) as marginally commercial quality. It is recommended in CCIR Recommendation 339-6 (CCIR, 1986) that audio SNR of at least 15 dB coupled with an RF signal-to-noise power density ratio (SNRD) of at least 56 dB are required for a single-sideband system.

Akima (1976) has used these recommended values to determine the required input signal-to-noise ratio for a frequency modulated (FM) system. The input signal-to-noise ratio for the system can be converted easily to a carrier-to-noise power density ratio[1], $C/N_0$, that is convenient to determine in link-budget calculations such as those provided in Appendix B (of this report). Akima first assumes that the 3-kHz baseband noise power would be psophometrically weighted (using a psophometric weighting function such as is used for commercial telephone service). He concludes that the psophometrically weighted audio SNR that would be required lies in the range of 20 to 25 dB. Additional assumptions that he makes to determine the required input signal-to-noise ratio include:

- an ideal FM demodulator.
- the modulated (FM) signal is received in the presence of additive white Gaussian noise.
- a small modulation index, e.g., 2 or 3 (therefore, no significant improvement can be expected with the use of threshold-extension techniques).

He notes that input SNR (to the demodulator), denoted as $R_{in}$, is the ratio of the modulated signal power to the noise power in the IF bandwidth, $B_{if}$. But, he further notes, it is more convenient to consider the ratio of the modulated signal power to the noise power in the bandwidth that is characteristic to the modulating signal. He, therefore, defines intrinsic SNR ($R_i$) as the ratio of the

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[1]In this report, $C/N_0$ is used to denote carrier-to-noise power density expressed in decibels, whereas $c/n_0$ is used to denote the ratio expressed in numeric values.

modulated signal power to the noise power contained in the baseband bandwidth, $B_{bb}$. Intrinsic SNR, $R_i$, is related to $R_{in}$ by

$$R_i = (B_{if}/B_{bb})R_{in}.$$

Akima developed a computer subroutine to calculate output SNR in an FM system as a function of the $R_i$ parameter used to express the input SNR. Figure 7 shows this relationship for an FM system with 10-kHz peak frequency deviation. For the PEACESAT network application, we are interested only in the curve that is for the commercial telephone psophometer, IF bandwidth of 26 kHz, and no threshold extension improvement ($T_e = 0$). Using the appropriate curve, we see that output (audio) SNR in the range of 20 to 25 dB corresponds to $R_i$ in the range of 13.5 to 15.0 dB. The required $C/N_0$, then, is calculated using the expression

$$C/N_0 = R_i + 10 \log B_{bb} \qquad \text{(dB)}$$

to relate the required SNR to carrier-to-noise power density for an NBFM system that may be operating below threshold.

We conclude that the required $C/N_0$ for an NBFM system to provide marginally commercial quality telephone service is in the range of 48.3 to 49.8 dB-Hz. (We do not develop the basis for the value here, but simply observe that good commercial quality telephone service would require the $C/N_0$ to be in the range of 54 to 57 dB-Hz.)

The link budgets that have been developed using the characteristics just discussed are provided in Appendix B (using required $C/N_0$ = 50 dB). One further assumption used in these link budgets is that a PEACESAT user terminal would use a parabolic reflector antenna with 3-m (10-ft) diameter aperture. The dependent characteristic to be examined in this analysis is the required capability of the user-terminal high power amplifier (HPA).

Information from the link budgets for PEACESAT service (included in Appendix B) is summarized in Table 8. We see that the network $C/N_0$ margin certainly is excessive for the conditions of "high" signal input power and signal input power equal to noise power. The HPA power requirements to achieve these signal input powers also are very high (and expensive). The condition of "low" signal input power would allow the use of a 50-W (or 30-W, perhaps) HPA, while still providing positive network $C/N_0$ margins ranging from 6.6 to 2.1 dB (for 50 W) and 4.4 to -0.1 dB (for 30 W), depending on the number of accesses (number and type of circuits) desired.

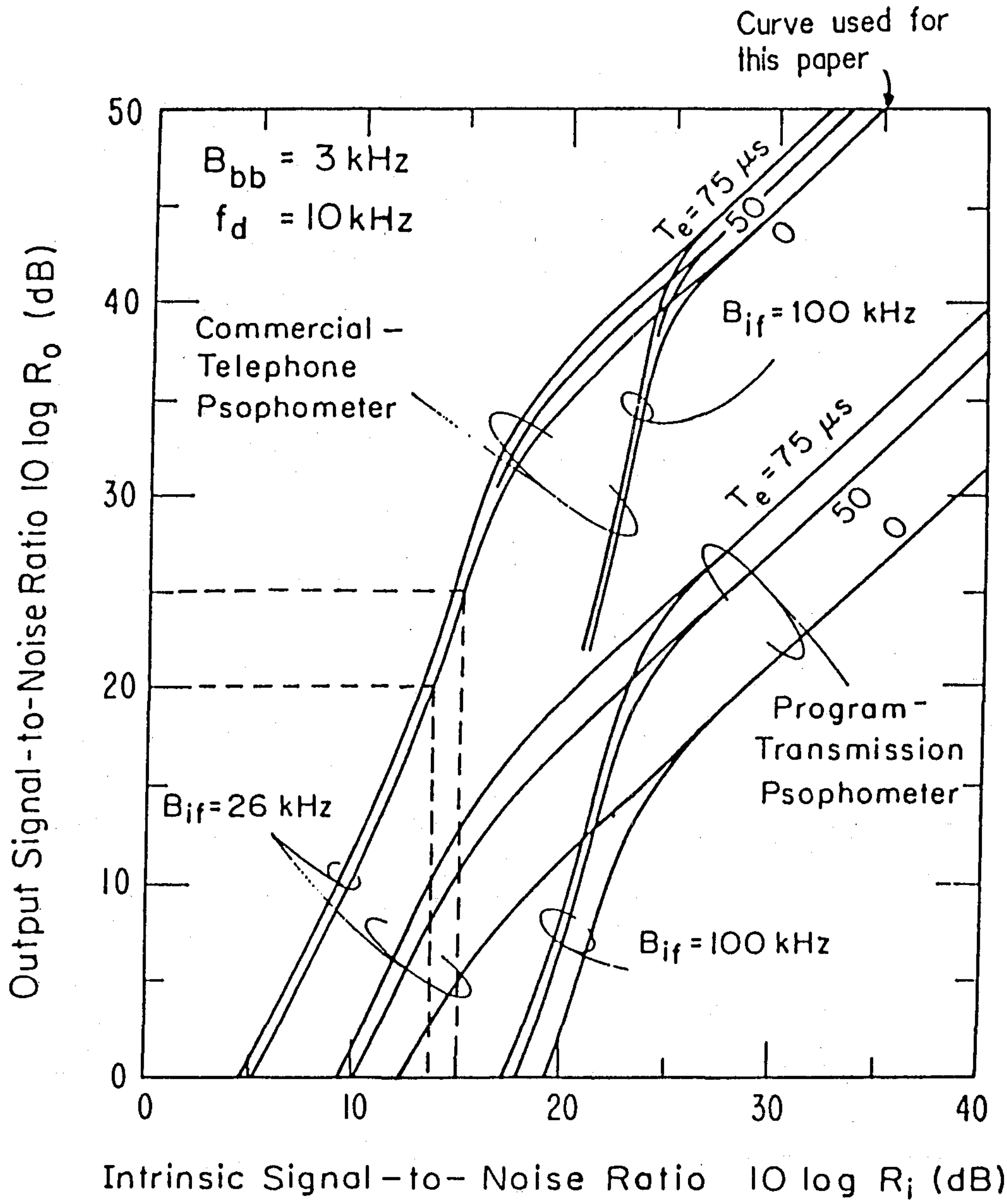


Figure 7. Output SNR's in an FM system with a 10-kHz peak frequency deviation (Akima, 1976).

Table 8. Summarized High Power Amplifier (HPA) Power Requirements and Network $C/N_0$ Margins for Marginally Commercial Voice Quality (50 dB-Hz)

| | 1 Access | 2 Accesses | 4 Accesses |
|---|---|---|---|
| For "High" Signal Input Power $[(c/n)_{up} = 10]$ | | | |
| Required HPA Power (W) | <------------ 5000 | -------------- | --------------> |
| Network $C/N_0$ Margin (dB) | 20.5 | 16.8 | 14.4 |
| For Signal Input Power Equal to Noise Power $[(c/n)_{up} = 1]$ | | | |
| Required HPA Power (W) | <------------ 500 | -------------- | --------------> |
| Network $C/N_0$ Margin (dB) | 15.6 | 12.9 | 10.5 |
| For "Low" Signal Input Power $[(c/n)_{up} = 0.1]$ | | | |
| Required HPA Power (W) | <------------ 50 | -------------- | --------------> |
| Network $C/N_0$ Margin (dB) | 6.6 | 4.3 | 2.1 |
| For "Low Signal Input Power $[(c/n)_{up} = 0.06]$ | | | |
| Required HPA Power (W) | <------------ 30 | -------------- | --------------> |
| Network $C/N_0$ Margin (dB) | 4.4 | 2.1 | -0.1 |

Further examination of the link budgets presented in Appendix B (Tables B-7, B-8, and B-9 for a 50-W HPA and Tables B-10, B-11, and B-12 for a 30-W HPA) indicates that the network (total) $C/N_0$ is slightly constrained by the uplink power for a single access, but becomes downlink (satellite) power limited for two and four accesses. This constraint is directly dependent on the power sharing loss that results when the transponder is essentially saturated on noise "seen" by the satellite. The relationship that has been used to calculate the power sharing loss (for a hard-limiting receiver) is

$$p_{out}/p_{max} = c_{in}/(c + n)_{in}.$$

This expression can be re-written as

$$p_{out} = p_{max} \{(c/n)_{in}/[(c/n)_{in} + 1]\}.$$

We draw three conclusions from this expression for the relationship between input and output signal power:

1. When the input carrier-to-noise ratio is much greater than one $[(c/n)_{in} >> 1]$, the output signal power approaches $p_{max}$. That is

$$p_{out} \approx p_{max}, \text{ for } (c/n)_{in} >> 1.$$

2. When the input carrier-to-noise ratio is unity $[(c/n)_{in} = 1]$, the output signal power is equal to the noise power. That is

$$p_{out} = p_{max} [1/(1 + 1)] = 0.5\ p_{max},\ \text{for}\ (c/n)_{in} = 1.$$

3. When the input carrier-to-noise ratio is much less than one $[(c/n)_{in} << 1]$, the output signal power is approximately equal to the ratio of input carrier power to noise power times the maximum out power. That is

$$p_{out} \approx p_{max} (c_{in}/n_{in}),\ \text{for}\ (c/n)_{in} << 1.$$

According to Jones (1963), these conclusions must be modified (for hard-limiting receivers when the input carrier-to-noise ratio is smaller than 0.1. For such very low signal levels, the output signal suppression by noise is about 1 dB more than the calculation using the above expression would indicate.

When multiple signals of roughly equal power are present at the satellite receiver input, the useful output signal power is only a fraction of the calculated output power due to intermodulation loss. Cameron (1968) shows that the useful output power is $\pi/4$ times the calculated output power, an intermodulation loss of about 1.1 dB.

The results of recent measurements of the operating characteristics of GOES-2 and GOES-3 are included in this report as Appendix C. The measurement results are summarized in Table 9 and Figures 8 and 9. These results included measurements of

- the gain transfer characteristic of each transponder (MFR) on each satellite for low input signal levels,
- the receiving-system-gain-to-system noise-temperature-ratio (G/T) for each transponder on each satellite,
- the EIRP for each transponder on each satellite,
- the S-Band command threshold,
- the S-Band telemetry EIRP, and
- the VHF command threshold.

The published S-Band characteristics (Ford, 1977) show that the satellite G/T is -25.7 dB/K; the measured values ranged from -25.7 dB/K (for GOES-2, Side 1) to -22.8 dB/K (for GOES-3, Side 2). Figure 8 shows the MFR gain transfer characteristics for each transponder of each satellite in terms of received satellite carrier power (normalized to -14.0 dBm) vs. uplink EIRP. Figure 9 shows similar information in that it presents satellite carrier EIRP vs. earth station EIRP for each transponder of each satellite. Summarized, the measurement results show that each transponder on each satellite seems to be operating satisfactorily, and the performance of each satellite is quite similar.

It is useful to compare the estimated performance (based on the link budgets discussed above and included as Appendix B) with these measured performance characteristics. Table 10 presents a comparison of estimated and measured/calculated satellite carrier EIRP's for earth station (uplink) EIRP's corresponding to HPA output powers of 30 W (the current best estimate of required HPA capability) and 50 W.

Table 9. A Summary of Some of the Measurement Results Indicating Performance for the GOES-2 and GOES-3 Satellites

| FUNCTION | GOES-2 | | GOES-3 | |
|---|---|---|---|---|
| | **Side 1** | **Side 2** | **Side 1** | **Side 2** |
| Satellite G/T (dB/K) | -25.7 | -24.6 | -24.5 | -22.8 |
| S-Band Command Threshold (Uplink EIRP) (dBm) | Between 81 - 84* | | Not measured | |
| S-Band Telemetry Threshold (Downlink EIRP) (dBm) | 31.1 | Not Measured | 37.6 | 33.2 |
| VHF Command Threshold (Transmitter Power) (dBm) | About 53** | | Not measured | |

* This uplink EIRP corresponds to about 100 W transmitter power delivered to a 3-m (10-ft) antenna.

** This transmitter power (200 W) delivered to the 16-element VHF antenna (nominal gain $\approx$ 20 dB) produces nominal uplink EIRP of about 73 dBm.

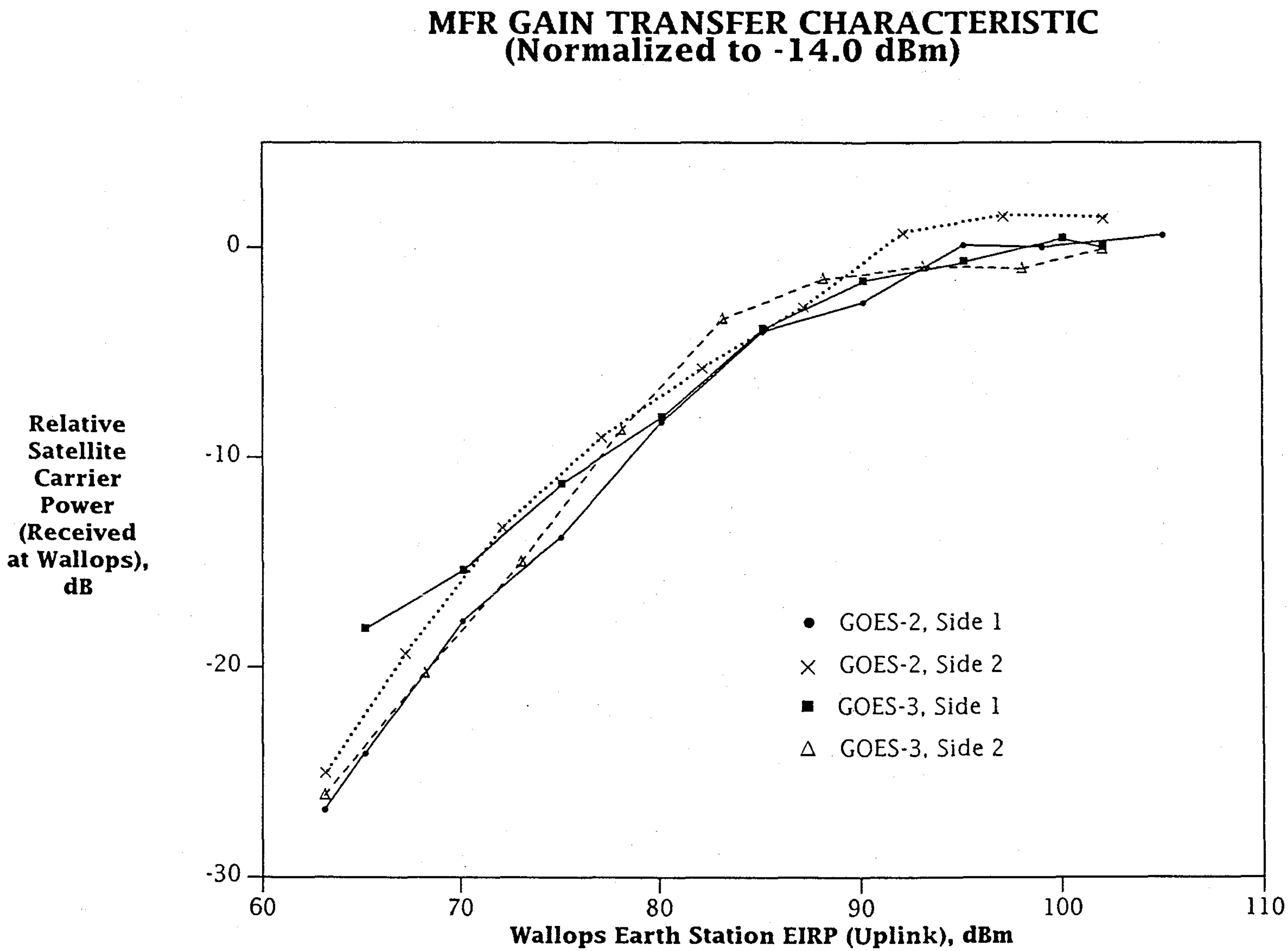


Figure 8. Multifunction repeater gain transfer characteristics for GOES-2 and GOES-3 (normalized to -14.0 dBm).

## SATELLITE CARRIER EIRP vs. EARTH STATION EIRP

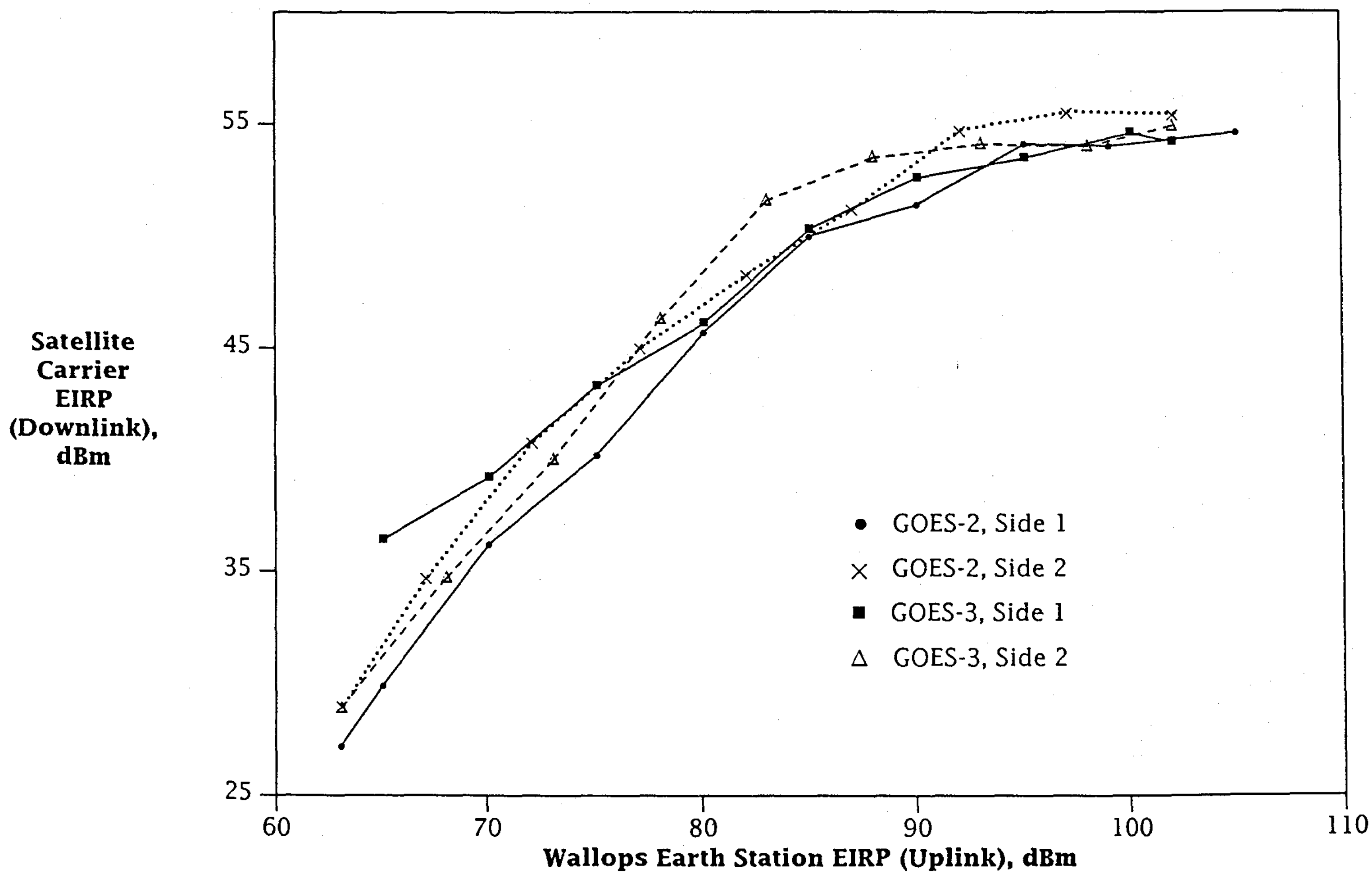


Figure 9. Satellite carrier EIRP vs. earth station EIRP for GOES-2 and GOES-3.

Table 10. A Comparison of Estimated and Measured/Calculated Satellite Carrier EIRP's for Earth Station EIRP's of 30 and 50 W

| | 1 Access | 2 Accesses | 4 Accesses |
|---|---|---|---|
| Earth Station EIRP for 30-W HPA and 3-m Antenna (dBm) | <---------------- 76.4 ----------------> | | |
| Estimated Satellite Carrier EIRP (dBm) | 43.6 | 39.5 | 36.5 |
| Measured/Calculated Satellite Carrier EIRP (dBm) | 41.8 for GOES-2, Side 1<br>44.5 for GOES-2, Side 2<br>44.1 for GOES-3, Side 1<br>44.4 for GOES-3, Side 2 | | |
| Earth Station EIRP for 50-W HPA and 3-m Antenna (dBm) | <---------------- 78.6 ----------------> | | |
| Estimated Satellite Carrier EIRP (dBm) | 45.8 | 41.7 | 38.7 |
| Measured/Calculated Satellite Carrier EIRP (dBm) | 44.2 for GOES-2, Side 1<br>45.4 for GOES-2, Side 2<br>46.2 for GOES-3, Side 1<br>47.1 for GOES-3, Side 2 | | |

### 3.4 Command and Control Station Issues

The primary command and control station for the SMS/GOES satellites is the CDA station at Wallops Station, VA. This station has both S-band and VHF command and control uplink and telemetry downlink capabilities. This station is also the primary downlink site for the stretched VISSR and DCPR signals. Telemetry and ranging data are sent from Wallops Station to the NESDIS Spacecraft Operations Control Center (SOCC) in Suitland, MD. The SOCC determines the satellite ephemeris and maneuver commands. These commands are relayed back to Wallops for transmission to the satellite. There also is limited backup command and control transmission capability at NASA's Goldstone, CA tracking station.

The basic telemetry, tracking, and control requirements to support a GOES-2 or GOES-3 operation are listed in Table 11. The Command Telemetry Processor (CTP) provides the operator interface for all transponder control and spacecraft maneuvering. The uplink command is an AM/FSK/PM signal transmitted on either the primary VHF command frequency of 148.56 MHz or the backup S-Band command frequency of 2034.2 MHz. The downlink telemetry is a 180-b/s pulse-code modulated (PCM) subcarrier of the signal received on either the primary VHF telemetry frequency of 136.38 MHz or the backup S-Band telemetry frequency of 1694.0 MHz.

Using the GOES-2 or GOES-3 for PEACESAT requires a TT&C station further west than the Wallops CDA Station. Wallops can not "see" a satellite west of 140' W; this location does not meet PEACESAT's coverage requirements. However, it has been proposed to install a CTP at the NASA's Kokee Park Geophysical Observatory on Kauai, HI. The Kauai station has VHF equipment but no S-Band capability. However, adequate spacecraft command and control can be provided via the VHF system. The Kauai station also allows the greatest flexibility in choosing an optimum satellite position.

## 4.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the Technical Options Panel study results (PEACESAT, 1988a), it was determined that the most feasible replacement options for ATS-1 would be

| | Interim Option | Long-Term Option |
|---|---|---|
| 1. | MARISAT UHF | AMSAT VHF/UHF |
| 2. | GOES S-Band | AMSAT S-Band |
| 3. | MARISAT UHF | AMSAT S-Band |

Subsequent to completion of the studies that led to these choices for replacement satellites, it has become clear that the MARISAT UHF system is not a viable interim option, and attention shifted to the second choice.

This report contains the results of engineering studies, analyses, and operational measurements that have been conducted to determine the technical feasibility of using GOES-2 or GOES-3 to provide the satellite transponder bandwidth required for interim operation of the PEACESAT network when ATS-1 is no longer useful and until a long-term transponder capability can be established. We conclude that it is feasible, from a technical viewpoint, to use either of these GOES satellites for operational telecommunications by the PEACESAT user community given the following conditions:

Table 11. TT&C Station Requirements for GOES-2 and/or GOES-3 Support

<u>Command</u>

Primary command uplink frequency at VHF (148.56 MHz) required
Backup command uplink at S-Band (2034.2 MHz) desirable

<u>Telemetry</u>

CTP primary for telemetry processing

Primary telemetry downlink at VHF (136.38 MHz)
Backup telemetry downlink at S-Band (1694.0 MHz)

Capability to quality monitor user downlink at 1683.1 MHz extremely desirable

<u>Communications</u>

Full duplex digital link to SOCC
Voice Circuit to SOCC
Single analog communication link desirable for telemetry

<u>Housekeeping Telemetry Requirements</u>

Telemetry for 1 hour, twice per week non-eclipse season
Telemetry for 1 hour daily post-eclipse during eclipse season

<u>Command Coverage Requirements</u>

Post eclipse daily for 1 hour
3 times a year CTP command for station keeping maneuvers
At SOCC request if spacecraft emergency

1. The service would be Single-Channel-Per-Carrier-Frequency-Modulated (SCPC-FM) voice, and voice-bandwidth data, at a quality defined by the CCIR as "marginally commercial quality." This quality is better than "just usable quality" (defined as 90% sentence intelligibility) but not as good as "good commercial quality."

2. The user earth terminal would incorporate a 3-m (10-ft) parabolic reflector antenna and require the high power amplifier output power to be in the range of 30 W, depending on the desired telecommunications capability. Summarized below from Appendix B (Tables B-12, B-13, and B-14), we see the margins (relative to an assumed requirement of $C/N_0$ = 50 dB) relating HPA output power capability and service capability ranging from one simplex circuit to two duplex circuits.

| | 1 Simplex Circuit | 1 Duplex Circuit | 2 Duplex Circuits |
|---|---|---|---|
| HPA Output Power Capability (W) | 10 | 20 | 30 |
| Estimated Total $C/N_0$ Margin (dB) | -0.4 | 0.3 | -0.1 |

3. The -3 dB beamwidth for a 3-m (10-ft) parabolic reflector antenna, at the GOES S-Band frequencies, is about 3°. Each of the satellites being considered has orbit north-south inclination of at least ±5°, and this inclination will increase with time. Therefore, the user terminal antennas will require pointing adjustment for extended periods of operation.

4. The operational tests indicate approximately equivalent transponder performance from GOES-2 and GOES-3. GOES-2 has more fuel than GOES-3 which would be desireable for PEACESAT network interim service. However, GOES-2 has slightly greater orbit inclination than GOES-3. In addition, it is reported by a contractor to NASA that one of the transponders on GOES-2 has exhibited intermittent performance in the past. It is our recommendation, therefore, that GOES-3 be the first-choice satellite to provide the interim network support for PEACESAT.

There are several other factors, not considered in these conclusions, that must be considered in reaching the final decision of interim use of a GOES satellite for the PEACESAT network. These other factors include

1. Market availability and cost of user earth terminal hardware.

2. Operational compatibility with other meteorological satellites.

3. Command and control of the GOES satellite used for PEACESAT. Who will do it and from where?

4. Favorable determination of a GOES satellite being available for PEACESAT.

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## APPENDIX A: AZIMUTH AND ELEVATION ANGLES FOR PEACESAT USER TERMINALS

This Appendix contains tables of aximuth and elevation angles for the PEACESAT user locations shown below (and in Table 1 of the report). These data are shown for candidate satellite locations of 150° W, 160° E, and 140° E.

1. Adelaide, South Australia
2. Apai, Western Samoa
3. Bentley, Australia
4. Canberra, New South Wales, Australia
5. Darwin, Northern Territory, Australia
6. Footscray, Australia
7. Funafuti, Tuvalu
8. Guam
9. Honiara, Solomon Islands
10. Honolulu, Hawaii
11. Kelvin Grove, Australia
12. Kosrae, F.S.M.
13. Lae, Papua-New Guinea
14. La Trobe, Australia
15. Magill, Australia
16. Majuro, Marshall Islands
17. Niue
18. Noumea, New Caledonia
19. Pago Pago, American Soma
20. Palau (Belau)
21. Perth, Western Australia
22. Pohnpei, F.S.M.
23. Rarotonga, Cook Islands
24. Suva, Fiji
25. Saipan, Northern Mariana Islands
26. Nuku 'Alofa, Tonga
27. Tarawa, Kiribati
28. Toowoomba, Queensland, Australia
29. Truk, F.S.M.
30. Vila, Vanuata
31. Wellington, New Zealand
32. Yap, F.S.M.

**AZIMUTH AND ELEVATION ANGLES FOR PEACESAT USER TERMINALS**

| | | | |
|---|---|---|---|
| Earth Radius (km): | 6378 | | |
| Height of Sat above Earth (km): | 35786 | | |
| Subsatellite Point (deg): | -150 | 160 | 140 |
| **Adelaide, South Australia** | | | |
| Latitude: | -34.9 | | |
| Longitude: | 138.5 | | |
| Distance to Sat (km): | 40969.68 | 37524.15 | 37114.95 |
| Elevation Angle: | 6.44 | 43.43 | 49.43 |
| Azimuth: | 79.16 | 34.55 | 2.62 |
| Azimuth Angle from North: | 79.16 | 34.55 | 2.62 |
| **Apia, Western Samoa** | | | |
| Latitude: | -13.83 | | |
| Longitude: | 188.5 | | |
| Distance to Sat (km): | 36504.38 | 36871.65 | 38372.22 |
| Elevation Angle: | 60.32 | 53.40 | 32.74 |
| Azimuth: | 58.75 | 66.24 | 78.06 |
| Azimuth Angle from North: | 58.75 | 293.76 | 281.94 |
| **Bentley, Australia** | Coordinate data not available | | |
| **Canberra, New South Wales, Australia** | | | |
| Latitude: | -35.25 | | |
| Longitude: | 149.1 | | |
| Distance to Sat (km): | 40060.84 | 37244.87 | 37212.69 |
| Elevation Angle: | 15.00 | 47.44 | 47.92 |
| Azimuth: | 72.19 | 18.45 | 15.51 |
| Azimuth Angle from North: | 72.19 | 18.45 | 344.49 |
| **Darwin, Northern Territory, Australia** | | | |
| Latitude: | -12.42 | | |
| Longitude: | 130.85 | | |
| Distance to Sat (km): | 41468.16 | 36874.79 | 36054.24 |
| Elevation Angle: | 1.90 | 53.35 | 71.93 |
| Azimuth: | 87.64 | 68.91 | 36.83 |
| Azimuth Angle from North: | 87.64 | 68.91 | 36.83 |
| **Footscray, Australia** | | | |
| Latitude: | -37.75 | | |
| Longitude: | 144 | | |
| Distance to Sat (km): | 40564.88 | 37545.82 | 37339.66 |
| Elevation Angle: | 10.20 | 43.13 | 46.04 |
| Azimuth: | 74.75 | 25.10 | 6.52 |
| Azimuth Angle from North: | 74.75 | 25.10 | 353.48 |

**Azimuth and Elevation Angles for PEACESAT User Terminals** (continued)

| | | | |
|---|---|---|---|
| Earth Radius (km): | 6378 | | |
| Height of Sat above Earth (km): | 35786 | | |
| Subsatellite Point (deg): | -150 | 160 | 140 |
| **Funafuti, Tuvalu** | | | |
| Latitude: | -8.8 | | |
| Longitude: | 181 | | |
| Distance to Sat (km): | 36791.44 | 36363.06 | 37647.63 |
| Elevation Angle: | 54.80 | 63.43 | 41.75 |
| Azimuth: | 74.57 | 68.27 | 80.02 |
| Azimuth Angle from North: | 74.57 | 291.73 | 279.98 |
| **Guam** | | | |
| Latitude: | 13.45 | | |
| Longitude: | 144.75 | | |
| Distance to Sat (km): | 39993.55 | 36246.50 | 36016.46 |
| Elevation Angle: | 15.65 | 66.28 | 73.25 |
| Azimuth: | 83.88 | 49.53 | 19.66 |
| Azimuth Angle from North: | 96.12 | 130.47 | 199.66 |
| **Honiara, Solomon Islands** | | | |
| Latitude: | -9.45 | | |
| Longitude: | 159.95 | | |
| Distance to Sat (km): | 38442.28 | 35887.84 | 36328.70 |
| Elevation Angle: | 31.93 | 78.88 | 64.24 |
| Azimuth: | 82.17 | 0.30 | 65.66 |
| Azimuth Angle from North: | 82.17 | 0.30 | 294.34 |
| **Honolulu, Hawaii** | | | |
| Latitude: | 21.32 | | |
| Longitude: | 202.18 | | |
| Distance to Sat (km): | 36360.76 | 38042.01 | 39807.67 |
| Elevation Angle: | 63.48 | 36.69 | 17.47 |
| Azimuth: | 20.69 | 68.14 | 79.14 |
| Azimuth Angle from North: | 159.31 | 248.14 | 259.14 |
| **Kosrae, F.S.M.** | | | |
| Latitude: | 5.4 | | |
| Longitude: | 163 | | |
| Distance to Sat (km): | 38122.18 | 35829.58 | 36408.67 |
| Elevation Angle: | 35.71 | 82.73 | 62.39 |
| Azimuth: | 84.98 | 29.11 | 77.50 |
| Azimuth Angle from North: | 95.02 | 209.11 | 257.50 |

**Azimuth and Elevation Angles for PEACESAT User Terminals** (continued)

| | | | |
|---|---|---|---|
| Earth Radius (km): | 6378 | | |
| Height of Sat above Earth (km): | 35786 | | |
| Subsatellite Point (deg): | -150 | 160 | 140 |
| **La Trobe, Australia** | | | |
| Latitude: | -41 | | |
| Longitude: | 146.25 | | |
| Distance to Sat (km): | 40483.94 | 37738.55 | 37616.20 |
| Elevation Angle: | 10.96 | 40.54 | 42.17 |
| Azimuth: | 72.07 | 20.45 | 9.48 |
| Azimuth Angle from North: | 72.07 | 20.45 | 350.52 |
| **Lae, Papua New Guinea** | | | |
| Latitude: | -6.7 | | |
| Longitude: | 147 | | |
| Distance to Sat (km): | 39698.53 | 36027.79 | 35892.79 |
| Elevation Angle: | 18.56 | 72.84 | 78.61 |
| Azimuth: | 86.60 | 63.19 | 46.46 |
| Azimuth Angle from North: | 86.60 | 63.19 | 313.54 |
| **Magill, Australia** | Coordinate data not available | | |
| **Majuro, Marshall Islands** | | | |
| Latitude: | 7.2 | | |
| Longitude: | 171 | | |
| Distance to Sat (km): | 37467.24 | 35981.70 | 36893.02 |
| Elevation Angle: | 44.22 | 74.57 | 53.04 |
| Azimuth: | 81.20 | 57.19 | 78.22 |
| Azimuth Angle from North: | 98.80 | 237.19 | 258.22 |
| **Niue** | | | |
| Latitude: | -19.03 | | |
| Longitude: | 190.1 | | |
| Distance to Sat (km): | 36611.37 | 37129.45 | 38630.78 |
| Elevation Angle: | 58.16 | 49.20 | 29.79 |
| Azimuth: | 47.99 | 60.64 | 74.75 |
| Azimuth Angle from North: | 47.99 | 299.36 | 285.25 |
| **Noumea, New Caledonia** | | | |
| Latitude: | -22.28 | | |
| Longitude: | 166.5 | | |
| Distance to Sat (km): | 38176.83 | 36386.69 | 37055.12 |
| Elevation Angle: | 35.05 | 62.88 | 50.37 |
| Azimuth: | 68.22 | 16.73 | 52.75 |
| Azimuth Angle from North: | 68.22 | 343.27 | 307.25 |

**Azimuth and Elevation Angles for PEACESAT User Terminals** (continued)

| | | | |
|---|---|---|---|
| Earth Radius (km): | 6378 | | |
| Height of Sat above Earth (km): | 35786 | | |
| Subsatellite Point (deg): | -150 | 160 | 140 |
| **Nuku 'Alofa, Tonga** | | | |
| Latitude: | -21.17 | | |
| Longitude: | 186 | | |
| Distance to Sat (km): | 36882.19 | 36982.36 | 38341.60 |
| Elevation Angle: | 53.22 | 51.55 | 33.09 |
| Azimuth: | 50.95 | 53.48 | 70.77 |
| Azimuth Angle from North: | 50.95 | 306.52 | 289.23 |
| **Pago Pago, American Samoa** | | | |
| Latitude: | -14.27 | | |
| Longitude: | 189.28 | | |
| Distance to Sat (km): | 36482.15 | 36930.04 | 38450.47 |
| Elevation Angle: | 60.79 | 52.41 | 31.83 |
| Azimuth: | 56.91 | 66.27 | 78.02 |
| Azimuth Angle from North: | 56.91 | 293.73 | 281.98 |
| **Palau (Belau)** | | | |
| Latitude: | 7.5 | | |
| Longitude: | 134.5 | | |
| Distance to Sat (km): | 41048.37 | 36567.54 | 35884.45 |
| Elevation Angle: | 5.72 | 59.03 | 79.06 |
| Azimuth: | 88.07 | 74.70 | 36.42 |
| Azimuth Angle from North: | 91.93 | 105.30 | 143.58 |
| **Perth, Western Australia** | | | |
| Latitude: | -31.95 | | |
| Longitude: | 115.87 | | |
| Distance to Sat (km): | 43027.31 | 38612.43 | 37443.19 |
| Elevation Angle: | -12.01 | 29.99 | 44.56 |
| Azimuth: | 92.19 | 61.39 | 40.25 |
| Azimuth Angle from North: | 92.19 | 61.39 | 40.25 |
| **Pohnpei, F.S.M.** | | | |
| Latitude: | 6.92 | | |
| Longitude: | 158.17 | | |
| Distance to Sat (km): | 38581.31 | 35844.50 | 36210.22 |
| Elevation Angle: | 30.34 | 81.57 | 67.24 |
| Azimuth: | 84.59 | 14.85 | 69.84 |
| Azimuth Angle from North: | 95.41 | 165.15 | 249.84 |

**Azimuth and Elevation Angles for PEACESAT User Terminals** (continued)

| | | | |
|---|---|---|---|
| Earth Radius (km): | 6378 | | |
| Height of Sat above Earth (km): | 35786 | | |
| Subsatellite Point (deg): | -150 | 160 | 140 |
| **Rarotonga, Cook Islands** | | | |
| Latitude: | -21.5 | | |
| Longitude: | 200 | | |
| Distance to Sat (km): | 36409.68 | 37883.22 | 39601.41 |
| Elevation Angle: | 62.37 | 38.68 | 19.53 |
| Azimuth: | 25.69 | 66.41 | 78.05 |
| Azimuth Angle from North: | 25.69 | 293.59 | 281.95 |
| **Saipan, Northern Mariana Islands** | | | |
| Latitude: | 15 | | |
| Longitude: | 145.6 | | |
| Distance to Sat (km): | 39925.00 | 36266.87 | 36075.53 |
| Elevation Angle: | 16.32 | 65.76 | 71.22 |
| Azimuth: | 82.93 | 44.77 | 20.75 |
| Azimuth Angle from North: | 97.07 | 135.23 | 200.75 |
| **Suva, Fiji** | | | |
| Latitude: | -18.1 | | |
| Longitude: | 178.5 | | |
| Distance to Sat (km): | 37183.16 | 36519.46 | 37661.51 |
| Elevation Angle: | 48.37 | 60.01 | 41.56 |
| Azimuth: | 63.12 | 47.12 | 68.67 |
| Azimuth Angle from North: | 63.12 | 312.88 | 291.33 |
| **Tarawa, Kiribati** | | | |
| Latitude: | 1.5 | | |
| Longitude: | 172.8 | | |
| Distance to Sat (km): | 37285.65 | 35974.76 | 36966.78 |
| Elevation Angle: | 46.83 | 74.85 | 51.80 |
| Azimuth: | 88.02 | 83.43 | 87.67 |
| Azimuth Angle from North: | 91.98 | 263.43 | 267.67 |
| **Toowoomba, Queensland, Australia** | | | |
| Latitude: | -27 | | |
| Longitude: | 152 | | |
| Distance to Sat (km): | 39554.17 | 36659.56 | 36738.69 |
| Elevation Angle: | 20.00 | 57.23 | 55.75 |
| Azimuth: | 74.16 | 17.20 | 25.09 |
| Azimuth Angle from North: | 74.16 | 17.20 | 334.91 |

**Azimuth and Elevation Angles for PEACESAT User Terminals** (continued)

| | | | |
|---|---|---|---|
| Earth Radius (km): | 6378 | | |
| Height of Sat above Earth (km): | 35786 | | |
| Subsatellite Point (deg): | -150 | 160 | 140 |
| **Truk, F.S.M.** | | | |
| Latitude: | 7.42 | | |
| Longitude: | 151.77 | | |
| Distance to Sat (km): | 39213.17 | 35925.40 | 36004.94 |
| Elevation Angle: | 23.50 | 76.98 | 73.68 |
| Azimuth: | 85.43 | 48.24 | 58.21 |
| Azimuth Angle from North: | 94.57 | 131.76 | 238.21 |
| **Vila, Vanuata** | | | |
| Latitude: | -15.6 | | |
| Longitude: | 167 | | |
| Distance to Sat (km): | 37942.30 | 36115.26 | 36836.29 |
| Elevation Angle: | 37.93 | 69.97 | 54.01 |
| Azimuth: | 73.91 | 24.54 | 62.18 |
| Azimuth Angle from North: | 73.91 | 335.46 | 297.82 |
| **Wellington, New Zealand** | | | |
| Latitude: | -49.32 | | |
| Longitude: | 174.77 | | |
| Distance to Sat (km): | 39142.16 | 38464.03 | 39121.54 |
| Elevation Angle: | 24.24 | 31.68 | 24.46 |
| Azimuth: | 42.96 | 19.17 | 42.47 |
| Azimuth Angle from North: | 42.96 | 340.83 | 317.53 |
| **Yap, F.S.M.** | | | |
| Latitude: | 9.52 | | |
| Longitude: | 138.1 | | |
| Distance to Sat (km): | 40665.56 | 36418.72 | 35893.41 |
| Elevation Angle: | 9.26 | 62.16 | 78.58 |
| Azimuth: | 86.91 | 67.64 | 11.34 |
| Azimuth Angle from North: | 93.09 | 112.36 | 168.66 |

## APPENDIX B: LINK BUDGET ANALYSES FOR POSSIBLE PEACESAT UTILIZATION OF GOES

The link budgets in this appendix have been computed to estimate the output-power capability required for the high power amplifier (HPA) in the PEACESAT Users' earth station. This earth station is assumed to use a 3-m (10-ft) parabolic reflector antenna, and the receiving system noise temperature is assumed to be 200 K[1]. Other assumptions in these link budget calculations are:

1. diplexer loss is 1 dB.
2. antenna efficiency is 0.5 (50%) to provide transmit gain of 33.2 dB and receive gain of 31.6 dB.
3. free-space (propagation) loss is calculated for a path that has an elevation angle of 30° (at the earth station).
4. pointing error for the earth station could result in gain reduction of 0.5 dB.
5. values for polarization loss, satellite antenna gain, off beam-center reduction in the satellite antenna gain, transmission line loss on the satellite, satellite receiving system noise temperature, and satellite output power are taken from reports by Ford (1977).
6. the carrier-to-noise power density ($C/N_0$) required for marginally commercial quality (defined by CCIR Recommendation 339-6) received voice, using SCPC-FM, is 50 dB-Hz.

Three operating conditions are assumed for the wide-bandwidth, hard-limiting repeater on the satellite. These are:

1. input signal power is high with respect to the noise power of the satellite receiving system, i.e., uplink carrier power to the satellite is 10 dB greater than the receiving system noise power,
2. input signal power is equal to the receiving system noise power, and
3. input signal power is low with respect to the noise power of the satellite receiving system, i.e., uplink carrier power to the satellite is 10 dB less than the receiving system noise power.

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[1]Current trade literature suggests that low noise amplifiers (LNAs) that operate in the range of 1.6 to 2.0 GHz are available with noise temperature of about 60 K. Depending on the elevation angle for the earth station and the "sky" temperature seen by the antenna, this LNA noise temperature might allow a receiving system noise temperature in the range of 100 to 150 K, if the LNA is reasonably high gain and losses between the antenna and the LNA are kept very small.

Table B-1. Link Budget for PEACESAT Utilization of GOES for Conditions of Single Access (One Simplex Circuit) and "High" Signal Input Power (HPA Output Power Equals 5 kW)

| Link Budget Step | Units | Value | Comments |
|---|---|---|---|
| | **UPLINK** | | |
| 1. ES XMTR (HPA) Power Output | (dBW) | 37.0 | About 5 kW!! Required for $(c/n)_{up}$ = 10 (10 dB) |
| 2. XMTR Line/Diplexer Loss (2030 MHz) | (dB) | 1.6 | Table 6-5, Ford (1977) |
| 3. XMT Antenna Gain (3-m parabola) | (dB) | 33.2 | Assume = 0.50 |
| 4. Uplink EIRP (2030 MHz) | (dBW) | 68.6 | |
| 5. Free-space Loss | (dB) | 190.3 | $\alpha$ = 30°, 2030 MHz |
| 6. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 7. S/C RCV Antenna Gain | (dB) | 13.8 | Table 6-5, Ford (1977) |
| 8. Off Beam-Center Reduction (8.4°) | (dB) | 2.5 | Table 6-5, Ford (1977) |
| 9. RCV Line Loss, Rotary Joint, Etc. | (dB) | 6.8 | Table 6-5, Ford (1977) |
| 10. Rec'd Power, S/C RCVR Input | (dBW) | -117.4 | $(c/n)_{up}$ = 10 (10.0 dB) |
| [Noise power, S/C RCVR Input | (dBW) | -127.4 | 8.2 MHz BW] |
| 11. S/C RCV System Noise Temp. | (dB-K) | 32.1 | 1630 K; Table 6-5, Ford (1977) |
| 12. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 13. S/C RCVR Input Noise, $N_o$ | (dBW/Hz) | -196.5 | |
| 14. Uplink $C/N_o$ | (dB-Hz) | 79.1 | |
| | **DOWNLINK** | | |
| 15. S/C XMTR Power Amp Output (Max) | (dBW) | 13.5 | 43.5 dBm; Table 6-5, Ford (1977) |
| 16. Power Sharing Loss | (dB) | --- | None for $(c/n)_{up} >> 1$ |
| 17. Intermodulation Loss | (dB) | --- | None for single access |
| 18. XMTR Line Loss, Rotary Joint, Etc | (dB) | 4.3 | Table 6-5, Ford (1977) |
| 19. S/C XMT Antenna Gain | (dB) | 17.6 | Table 6-5, Ford (1977) |
| 20. Off Beam Center Reduction(8.7°) | (dB) | 2.4 | Table 6-5, Ford (1977) |
| 21. Downlink EIRP (1688 MHz) | (dBW) | 24.4 | |
| 22. Free-space Loss | (dB) | 188.7 | $\alpha$ = 30°, 1688 MHz |
| 23. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 24. RCV Antenna Gain (3-m parabola) | (dB) | 31.6 | Assume = 0.50 |
| 25. Pointing Error Loss | (dB) | 0.5 | Assumption |
| 26. RCV Line/Diplexer Loss (1688 MHz) | (dB) | 1.0 | Assumption |
| 27. Rec'd Power, ES RCVR Input | (dBW) | -134.4 | |
| 28. ES RCV System Noise Temp. | (dB-K) | 23.0 | Assume $T_s$ = 200 K |
| 29. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 30. ES RCVR Input Noise, $N_o$ | (dBW/Hz) | -205.6 | |
| 31. Downlink $C/N_o$ | (dB-Hz) | 71.2 | |
| | **NETWORK** | | |
| 32. Total $C/N_o$ | (dB-Hz) | 70.5 | |
| 33. Required $C/N_o$ | (dB-Hz) | 50.0 | For SCPC-FM |
| 34. Margin | (dB) | 20.5 | For One Simplex Circuit |

Table B-2. Link Budget for PEACESAT Utilization of GOES for Conditions of Two Accesses (One Duplex Circuit) and "High" Signal Input Power (HPA Output Power Equals 5 kW)

| Link Budget Step | Units | Value | Comments |
|---|---|---|---|
| | **UPLINK** | | |
| 1. ES XMTR (HPA) Power Output | (dBW) | 37.0 | About 5 kW!! Required for $(c/n)_{up}$ = 10 (10 dB) |
| 2. XMTR Line/Diplexer Loss (2030 MHz) | (dB) | 1.6 | Table 6-5, Ford (1977) |
| 3. XMT Antenna Gain (3-m parabola) | (dB) | 33.2 | Assume = 0.50 |
| 4. Uplink EIRP (2030 MHz) | (dBW) | 68.6 | |
| 5. Free-space Loss | (dB) | 190.3 | $\alpha$ = 30°, 2030 MHz |
| 6. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 7. S/C RCV Antenna Gain | (dB) | 13.8 | Table 6-5, Ford (1777) |
| 8. Off Beam-Center Reduction (8.4°) | (dB) | 2.5 | Table 6-5, Ford (1977) |
| 9. RCV Line Loss, Rotary Joint, Etc. | (dB) | 6.8 | Table 6-5, Ford (1977) |
| 10. Rec'd Power, S/C RCVR Input | (dBW) | -117.4 | $(c/n)_{up}$ = 10 (10.0 dB) |
| [Noise power, S/C RCVR Input | (dBW) | -127.4 | 8.2 MHz BW] |
| 11. S/C RCV System Noise Temp. | (dB-K) | 32.1 | 1630 K; Table 6-5, Ford (1977) |
| 12. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 13. S/C RCVR Input Noise, $N_0$ | (dBW/Hz) | -196.5 | |
| 14. Uplink $C/N_0$ | (dB-Hz) | 79.1 | |
| | **DOWNLINK** | | |
| 15. S/C XMTR Power Amp Output (Max) | (dBW) | 13.5 | 43.5 dBm; Table 6-5, Ford (1977) |
| 16. Power Sharing Loss | (dB) | 3.0 | 1/2 of total output pwr |
| 17. Intermodulation Loss | (dB) | 1.1 | $\pi/4$ useful output power |
| 18. XMTR Line Loss, Rotary Joint, Etc. | (dB) | 4.3 | Table 6-5, Ford (1977) |
| 19. S/C XMT Antenna Gain | (dB) | 17.6 | Table 6-5, Ford (1977) |
| 20. Off Beam Center Reduction (8.7°) | (dB) | 2.4 | Table 6-5, Ford (1977) |
| 21. Downlink EIRP (1688 MHz) | (dBW) | 20.3 | |
| 22. Free-space Loss | (dB) | 188.7 | $\alpha$ = 30°, 1688 MHz |
| 23. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 24. RCV Antenna Gain (3-m parabola) | (dB) | 31.6 | Assume = 0.50 |
| 25. Pointing Error Loss | (dB) | 0.5 | Assumption |
| 26. RCV Line/Diplexer Loss (1688 MHz) | (dB) | 1.0 | Assumption |
| 27. Rec'd Power, ES RCVR Input | (dBW) | -138.5 | |
| 28. ES RCV System Noise Temp. | (dB-K) | 23.0 | Assume $T_s$ = 200 K |
| 29. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 30. ES RCVR Input Noise, $N_0$ | (dBW/Hz) | -205.6 | |
| 31. Downlink $C/N_0$ | (dB-Hz) | 67.1 | |
| | **NETWORK** | | |
| 32. Total $C/N_0$ | (dB-Hz) | 66.8 | |
| 33. Required $C/N_0$ | (dB-Hz) | 50.0 | For SCPC-FM |
| 34. Margin | (dB) | 16.8 | For One Duplex Circuit |

Table B-3. Link Budget for PEACESAT Utilization of GOES for Conditions of Four Accesses (Two Duplex Circuits) and "High" Signal Input Power (HPA Output Power Equals 5 kW)

| | Link Budget Step | Units | Value | Comments |
|---|---|---|---|---|
| | | **UPLINK** | | |
| 1. | ES XMTR (HPA) Power Output | (dBW) | 37.0 | About 5 kW!! Required for $(c/n)_{up}$ = 10 (10 dB) |
| 2. | XMTR Line/Diplexer Loss (2030 MHz) | (dB) | 1.6 | Table 6-5, Ford (1977) |
| 3. | XMT Antenna Gain (3-m parabola) | (dB) | 33.2 | Assume = 0.50 |
| 4. | Uplink EIRP (2030 MHz) | (dBW) | 68.6 | |
| 5. | Free-space Loss | (dB) | 190.3 | $\alpha$ = 30°, 2030 MHz |
| 6. | Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 7. | S/C RCV Antenna Gain | (dB) | 13.8 | Table 6-5, Ford (1977) |
| 8. | Off Beam-Center Reduction (8.4°) | (dB) | 2.5 | Table 6-5, Ford (1977) |
| 9. | RCV Line Loss, Rotary Joint, Etc. | (dB) | 6.8 | Table 6-5, Ford (1977) |
| 10. | Rec'd Power, S/C RCVR Input | (dBW) | -117.4 | $(c/n)_{up}$ = 10 (10.0 dB) |
| | [Noise power, S/C RCVR Input | (dBW) | -127.4 | 8.2 MHz BW] |
| 11. | S/C RCV System Noise Temp. | (dB-K) | 32.1 | 1630 K; Table 6-5, Ford (1977) |
| 12. | Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 13. | S/C RCVR Input Noise, $N_o$ | (dBW/Hz) | -196.5 | |
| 14. | Uplink $C/N_o$ | (dB-Hz) | 79.1 | |
| | | **DOWNLINK** | | |
| 15. | S/C XMTR Power Amp Output (Max) | (dBW) | 13.5 | 43.5 dBm; Table 6-5, Ford (1977) |
| 16. | Power Sharing Loss | (dB) | 6.0 | 1/4 of total output pwr |
| 17. | Intermodulation Loss | (dB) | 1.1 | $\pi/4$ useful output power |
| 18. | XMTR Line Loss, Rotary Joint, Etc. | (dB) | 4.3 | Table 6-5, Ford (1977) |
| 19. | S/C XMT Antenna Gain | (dB) | 17.6 | Table 6-5, Ford (1977) |
| 20. | Off Beam Center Reduction (8.7°) | (dB) | 2.4 | Table 6-5, Ford (1977) |
| 21. | Downlink EIRP (1688 MHz) | (dBW) | 17.3 | |
| 22. | Free-space Loss | (dB) | 188.7 | $\alpha$ = 30°, 1688 MHz |
| 23. | Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 24. | RCV Antenna Gain (3-m parabola) | (dB) | 31.6 | Assume = 0.50 |
| 25. | Pointing Error Loss | (dB) | 0.5 | Assumption |
| 26. | RCV Line/Diplexer Loss (1688 MHz) | (dB) | 1.0 | Assumption |
| 27. | Rec'd Power, ES RCVR Input | (dBW) | -141.5 | |
| 28. | ES RCV System Noise Temp. | (dB-K) | 23.0 | Assume $T_s$ = 200 K |
| 29. | Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 30. | ES RCVR Input Noise, $N_o$ | (dBW/Hz) | -205.6 | |
| 31. | Downlink $C/N_o$ | (dB-Hz) | 64.1 | |
| | | **NETWORK** | | |
| 32. | Total $C/N_o$ | (dB-Hz) | 64.0 | |
| 33. | Required $C/N_o$ | (dB-Hz) | 50.0 | For SCPC-FM |
| 34. | Margin | (dB) | 14.4 | For Two Duplex Circuits |

Table B-4. Link Budget for PEACESAT Utilization of GOES for Conditions of Single Access (One Simplex Circuit) and Equal Signal Input and Noise Powers (HPA Output Power Equals 500 W)

| Link Budget Step | Units | Value | Comments |
|---|---|---|---|
| | **UPLINK** | | |
| 1. ES XMTR (HPA) Power Output | (dBW) | 27.0 | About 500 W; Required for $(c/n)_{up}$ = 1 (0 dB) |
| 2. XMTR Line/Diplexer Loss (2030 MHz) | (dB) | 1.6 | Table 6-5, Ford (1977) |
| 3. XMT Antenna Gain (3-m parabola) | (dB) | 33.2 | Assume = 0.50 |
| 4. Uplink EIRP (2030 MHz) | (dBW) | 58.6 | |
| 5. Free-space Loss | (dB) | 190.3 | $\alpha$ = 30°, 2030 MHz |
| 6. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 7. S/C RCV Antenna Gain | (dB) | 13.8 | Table 6-5, Ford (1977) |
| 8. Off Beam-Center Reduction (8.4°) | (dB) | 2.5 | Table 6-5, Ford (1977) |
| 9. RCV Line Loss, Rotary Joint, Etc. | (dB) | 6.8 | Table 6-5, Ford (1977) |
| 10. Rec'd Power, S/C RCVR Input | (dBW) | -127.4 | $(c/n)_{up}$ = 1 (0 dB) |
| [Noise power, S/C RCVR Input | (dBW) | -127.4 | 8.2 MHz BW] |
| 11. S/C RCV System Noise Temp. | (dB-K) | 32.1 | 1630 K; Table 6-5, Ford (1977) |
| 12. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 13. S/C RCVR Input Noise, $N_0$ | (dBW/Hz) | -196.5 | |
| 14. Uplink $C/N_0$ | (dB-Hz) | 69.1 | |
| | **DOWNLINK** | | |
| 15. S/C XMTR Power Amp Output (Max) | (dBW) | 13.5 | 43.5 dBm; Table 6-5, Ford (1977) |
| 16. Power Sharing Loss | (dB) | 3.0 | 1/2 of total output pwr |
| 17. Intermodulation Loss | (dB) | --- | None for single access |
| 18. XMTR Line Loss, Rotary Joint, Etc. | (dB) | 4.3 | Table 6-5, Ford (1977) |
| 19. S/C XMT Antenna Gain | (dB) | 17.6 | Table 6-5, Ford (1977) |
| 20. Off Beam Center Reduction (8.7°) | (dB) | 2.4 | Table 6-5, Ford (1977) |
| 21. Downlink EIRP (1688 MHz) | (dBW) | 21.4 | |
| 22. Free-space Loss | (dB) | 188.7 | $\alpha$ = 30°, 1688 MHz |
| 23. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 24. RCV Antenna Gain (3-m parabola) | (dB) | 31.6 | Assume = 0.50 |
| 25. Pointing Error Loss | (dB) | 0.5 | Assumption |
| 26. RCV Line/Diplexer Loss (1688 MHz) | (dB) | 1.0 | Assumption |
| 27. Rec'd Power, ES RCVR Input | (dBW) | -137.4 | |
| 28. ES RCV System Noise Temp. | (dB-K) | 23.0 | Assume $T_s$ = 200 K |
| 29. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 30. ES RCVR Input Noise, $N_0$ | (dBW/Hz) | -205.6 | |
| 31. Downlink $C/N_0$ | (dB-Hz) | 68.2 | |
| | **NETWORK** | | |
| 32. Total $C/N_0$ | (dB-Hz) | 65.6 | |
| 33. Required $C/N_0$ | (dB-Hz) | 50.0 | For SCPC-FM |
| 34. Margin | (dB) | 15.6 | For One Simplex Circuit |

Table B-5. Link Budget for PEACESAT Utilization of GOES for Conditions of Two Accesses (One Duplex Circuit) and Equal Signal Input and Noise Powers (HPA Output Power Equals 500 W)

| Link Budget Step | Units | Value | Comments |
|---|---|---|---|
| **U P L I N K** | | | |
| 1. ES XMTR (HPA) Power Output | (dBW) | 27.0 | About 500 W; Required for $(c/n)_{up}$ = 1 (0 dB) |
| 2. XMTR Line/Diplexer Loss (2030 MHz) | (dB) | 1.6 | Table 6-5, Ford (1977) |
| 3. XMT Antenna Gain (3-m parabola) | (dB) | 33.2 | Assume = 0.50 |
| 4. Uplink EIRP (2030 MHz) | (dBW) | 58.6 | |
| 5. Free-space Loss | (dB) | 190.3 | $\alpha$ = 30°, 2030 MHz |
| 6. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 7. S/C RCV Antenna Gain | (dB) | 13.8 | Table 6-5, Ford (1977) |
| 8. Off Beam-Center Reduction (8.4°) | (dB) | 2.5 | Table 6-5, Ford (1977) |
| 9. RCV Line Loss, Rotary Joint, Etc. | (dB) | 6.8 | Table 6-5, Ford (1977) |
| 10. Rec'd Power, S/C RCVR Input | (dBW) | -127.4 | $(c/n)_{up}$ = 1 (0 dB) |
| [Noise power, S/C RCVR Input | (dBW) | -127.4 | 8.2 MHz BW] |
| 11. S/C RCV System Noise Temp. | (dB-K) | 32.1 | 1630 K; Table 6-5, Ford (1977) |
| 12. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 13. S/C RCVR Input Noise, $N_0$ | (dBW/Hz) | -196.5 | |
| 14. Uplink $C/N_0$ | (dB-Hz) | 69.1 | |
| **D O W N L I N K** | | | |
| 15. S/C XMTR (TWTA) Pwr Output (Max) | (dBW) | 13.5 | 43.5 dBm; Table 6-5, Ford (1977) |
| 16. Power Sharing Loss | (dB) | 6.0 | 1/4 of total output pwr |
| 17. Intermodulation Loss | (dB) | 1.1 | $\pi/4$ useful output power |
| 18. XMTR Line Loss, Rotary Joint, Etc. | (dB) | 4.3 | Table 6-5, Ford (1977) |
| 19. S/C XMT Antenna Gain | (dB) | 17.6 | Table 6-5, Ford (1977) |
| 20. Off Beam Center Reduction (8.7°) | (dB) | 2.4 | Table 6-5, Ford (1977) |
| 21. Downlink EIRP (1688 MHz) | (dBW) | 17.3 | |
| 22. Free-space Loss | (dB) | 188.7 | $\alpha$ = 30°, 1688 MHz |
| 23. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 24. RCV Antenna Gain (3-m parabola) | (dB) | 31.6 | Assume = 0.50 |
| 25. Pointing Error Loss | (dB) | 0.5 | Assumption |
| 26. RCV Line/Diplexer Loss (1688 MHz) | (dB) | 1.0 | Assumption |
| 27. Rec'd Power, ES RCVR Input | (dBW) | -141.5 | |
| 28. ES RCV System Noise Temp. | (dB-K) | 23.0 | Assume $T_s$ = 200 K |
| 29. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 30. ES RCVR Input Noise, $N_0$ | (dBW/Hz) | -205.6 | |
| 31. Downlink $C/N_0$ | (dB-Hz) | 64.1 | |
| **N E T W O R K** | | | |
| 32. Total $C/N_0$ | (dB-Hz) | 62.9 | |
| 33. Required $C/N_0$ | (dB-Hz) | 50.0 | For SCPC-FM |
| 34. Margin | (dB) | 12.9 | For One Duplex Circuit |

Table B-6. Link Budget for PEACESAT Utilization of GOES for Conditions of Four Accesses (Two Duplex Circuits) and Equal Signal Input and Noise Powers (HPA Output Power Equals 500 W)

| | Link Budget Step | Units | Value | Comments |
|---|---|---|---|---|
| | **UPLINK** | | | |
| 1. | ES XMTR (HPA) Power Output | (dBW) | 27.0 | About 500 W; Required for $(c/n)_{up}$ = 1 (0 dB) |
| 2. | XMTR Line/Diplexer Loss (2030 MHz) | (dB) | 1.6 | Table 6-5, Ford (1977) |
| 3. | XMT Antenna Gain (3-m parabola) | (dB) | 33.2 | Assume = 0.50 |
| 4. | Uplink EIRP (2030 MHz) | (dBW) | 58.6 | |
| 5. | Free-space Loss | (dB) | 190.3 | $\alpha$ = 30°, 2030 MHz |
| 6. | Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 7. | S/C RCV Antenna Gain | (dB) | 13.8 | Table 6-5, Ford (1977) |
| 8. | Off Beam-Center Reduction (8.4°) | (dB) | 2.5 | Table 6-5, Ford (1977) |
| 9. | RCV Line Loss, Rotary Joint, Etc. | (dB) | 6.8 | Table 6-5, Ford (1977) |
| 10. | Rec'd Power, S/C RCVR Input | (dBW) | -127.4 | $(c/n)_{up}$ = 1 (0 dB) |
| | [Noise power, S/C RCVR Input | (dBW) | -127.4 | 8.2 MHz BW] |
| 11. | S/C RCV System Noise Temp. | (dB-K) | 32.1 | 1630 K; Table 6-5, Ford (1977) |
| 12. | Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 13. | S/C RCVR Input Noise, $N_o$ | (dBW/Hz) | -196.5 | |
| 14. | Uplink $C/N_o$ | (dB-Hz) | 69.1 | |
| | **DOWNLINK** | | | |
| 15. | S/C XMTR (TWTA) Pwr Output (Max) | (dBW) | 13.5 | 43.5 dBm; Table 6-5, Ford (1977) |
| 16. | Power Sharing Loss | (dB) | 9.0 | 1/8 of total output pwr |
| 17. | Intermodulation Loss | (dB) | 1.1 | $\pi/4$ useful output power |
| 18. | XMTR Line Loss, Rotary Joint, Etc. | (dB) | 4.3 | Table 6-5, Ford (1977) |
| 19. | S/C XMT Antenna Gain | (dB) | 17.6 | Table 6-5, Ford (1977) |
| 20. | Off Beam Center Reduction (8.7°) | (dB) | 2.4 | Table 6-5, Ford (1977) |
| 21. | Downlink EIRP (1688 MHz) | (dBW) | 14.3 | |
| 22. | Free-space Loss | (dB) | 188.7 | $\alpha$ = 30°, 1688 MHz |
| 23. | Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 24. | RCV Antenna Gain (3-m parabola) | (dB) | 31.6 | Assume = 0.50 |
| 25. | Pointing Error Loss | (dB) | 0.5 | Assumption |
| 26. | RCV Line/Diplexer Loss (1688 MHz) | (dB) | 1.0 | Assumption |
| 27. | Rec'd Power, ES RCVR Input | (dBW) | -144.5 | |
| 28. | ES RCV System Noise Temp. | (dB-K) | 23.0 | Assume $T_s$ = 200 K |
| 29. | Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 30. | ES RCVR Input Noise, $N_o$ | (dBW/Hz) | -205.6 | |
| 31. | Downlink $C/N_o$ | (dB-Hz) | 61.1 | |
| | **NETWORK** | | | |
| 32. | Total $C/N_o$ | (dB-Hz) | 60.5 | |
| 33. | Required $C/N_o$ | (dB-Hz) | 50.0 | For SCPC-FM |
| 34. | Margin | (dB) | 10.5 | For Two Duplex Circuits |

Table B-7. Link Budget for PEACESAT Utilization of GOES for Conditions of Single Access (One Simplex Circuit) and "Low" Signal Input Power (HPA Output Power Equals 50 W)

| Link Budget Step | Units | Value | Comments |
|---|---|---|---|
| | **U P L I N K** | | |
| 1. ES XMTR (HPA) Power Output | (dBW) | 17.0 | About 50 W; Required for $(c/n)_{up}$ = 0.1 (-10 dB) |
| 2. XMTR Line/Diplexer Loss (2030 MHz) | (dB) | 1.6 | Table 6-5, Ford (1977) |
| 3. XMT Antenna Gain (3-m parabola) | (dB) | 33.2 | Assume = 0.50 |
| 4. Uplink EIRP (2030 MHz) | (dBW) | 48.6 | |
| 5. Free-space Loss | (dB) | 190.3 | $\alpha$ = 30°, 2030 MHz |
| 6. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 7. S/C RCV Antenna Gain | (dB) | 13.8 | Table 6-5, Ford (1977) |
| 8. Off Beam-Center Reduction (8.4°) | (dB) | 2.5 | Table 6-5, Ford (1977) |
| 9. RCV Line Loss, Rotary Joint, Etc. | (dB) | 6.8 | Table 6-5, Ford (1977) |
| 10. Rec'd Power, S/C RCVR Input | (dBW) | -137.4 | $(c/n)_{up}$ = 0.1 (-10 dB) |
| [Noise power, S/C RCVR Input | (dBW) | -127.4 | 8.2 MHz BW] |
| 11. S/C RCV System Noise Temp. | (dB-K) | 32.1 | 1630 K; Table 6-5, Ford (1977) |
| 12. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 13. S/C RCVR Input Noise, $N_0$ | (dBW/Hz) | -196.5 | |
| 14. Uplink $C/N_0$ | (dB-Hz) | 59.1 | |
| | **D O W N L I N K** | | |
| 15. S/C XMTR (TWTA) Pwr Output (Max) | (dBW) | 13.5 | 43.5 dBm; Table 6-5, Ford (1977) |
| 16. Power Sharing Loss | (dB) | 11.0 | 0.1 (10%) of total power out minus 1 dB |
| 17. Intermodulation Loss | (dB) | --- | None for single access |
| 18. XMTR Line Loss, Rotary Joint, Etc. | (dB) | 4.3 | Table 6-5, Ford (1977) |
| 19. S/C XMT Antenna Gain | (dB) | 17.6 | Table 6-5, Ford (1977) |
| 20. Off Beam Center Reduction (8.7°) | (dB) | 2.4 | Table 6-5, Ford (1977) |
| 21. Downlink EIRP (1688 MHz) | (dBW) | 13.4 | |
| 22. Free-space Loss | (dB) | 188.7 | $\alpha$ = 30°, 1688 MHz |
| 23. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 24. RCV Antenna Gain (3-m parabola) | (dB) | 31.6 | Assume = 0.50 |
| 25. Pointing Error Loss | (dB) | 0.5 | Assumption |
| 26. RCV Line/Diplexer Loss (1688 MHz) | (dB) | 1.0 | Assumption |
| 27. Rec'd Power, ES RCVR Input | (dBW) | -145.4 | |
| 28. ES RCV System Noise Temp. | (dB-K) | 23.0 | Assume $T_s$ = 200 K |
| 29. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 30. ES RCVR Input Noise, $N_0$ | (dBW/Hz) | -205.6 | |
| 31. Downlink $C/N_0$ | (dB-Hz) | 60.2 | |
| | **N E T W O R K** | | |
| 32. Total $C/N_0$ | (dB-Hz) | 56.6 | |
| 33. Required $C/N_0$ | (dB-Hz) | 50.0 | For SCPC-FM |
| 34. Margin | (dB) | 6.6 | For One Simplex Circuit |

Table B-8. Link Budget for PEACESAT Utilization of GOES for Conditions of Two Accesses (One Duplex Circuit) and "Low" Signal Input Power (HPA Output Power Equals 50 W)

| | Link Budget Step | Units | Value | Comments |
|---|---|---|---|---|
| | | **UPLINK** | | |
| 1. | ES XMTR (HPA) Power Output | (dBW) | 17.0 | About 50 W; Required for $(c/n)_{up}$ = 0.1 (-10 dB) |
| 2. | XMTR Line/Diplexer Loss (2030 MHz) | (dB) | 1.6 | Table 6-5, Ford (1977) |
| 3. | XMT Antenna Gain (3-m parabola) | (dB) | 33.2 | Assume = 0.50 |
| 4. | Uplink EIRP (2030 MHz) | (dBW) | 48.6 | |
| 5. | Free-space Loss | (dB) | 190.3 | $\alpha$ = 30°, 2030 MHz |
| 6. | Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 7. | S/C RCV Antenna Gain | (dB) | 13.8 | Table 6-5, Ford (1977) |
| 8. | Off Beam-Center Reduction (8.4°) | (dB) | 2.5 | Table 6-5, Ford (1977) |
| 9. | RCV Line Loss, Rotary Joint, Etc. | (dB) | 6.8 | Table 6-5, Ford (1977) |
| 10. | Rec'd Power, S/C RCVR Input | (dBW) | -137.4 | $(c/n)_{up}$ = 0.1 (-10 dB) |
| | [Noise power, S/C RCVR Input | (dBW) | -127.4 | 8.2 MHz BW] |
| 11. | S/C RCV System Noise Temp. | (dB-K) | 32.1 | 1630 K; Table 6-5, Ford (1977) |
| 12. | Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 13. | S/C RCVR Input Noise, $N_0$ | (dBW/Hz) | -196.5 | |
| 14. | Uplink $C/N_0$ | (dB-Hz) | 59.1 | |
| | | **DOWNLINK** | | |
| 16. | S/C XMTR (TWTA) Pwr Output (Max) | (dBW) | 13.5 | 43.5 dBm; Table 6-5, Ford (1977) |
| 17. | Power Sharing Loss | (dB) | 14.0 | 0.05 (5%) of total power out minus 1 dB |
| 18. | Intermodulation Loss | (dB) | 1.1 | $\pi/4$ useful output power |
| 19. | XMTR Line Loss, Rotary Joint, Etc. | (dB) | 4.3 | Table 6-5, Ford (1977) |
| 20. | S/C XMT Antenna Gain | (dB) | 17.6 | Table 6-5, Ford (1977) |
| 21. | Off Beam Center Reduction (8.7°) | (dB) | 2.4 | Table 6-5, Ford (1977) |
| 22. | Downlink EIRP (1688 MHz) | (dBW) | 9.3 | |
| 23. | Free-space Loss | (dB) | 188.7 | $\alpha$ = 30°, 1688 MHz |
| 24. | Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 25. | RCV Antenna Gain (3-m parabola) | (dB) | 31.6 | Assume = 0.50 |
| 26. | Pointing Error Loss | (dB) | 0.5 | Assumption |
| 27. | RCV Line/Diplexer Loss (1688 MHz) | (dB) | 1.0 | Assumption |
| 29. | Rec'd Power, ES RCVR Input | (dBW) | -149.5 | |
| 30. | ES RCV System Noise Temp. | (dB-K) | 23.0 | Assume $T_s$ = 200 K |
| 31. | Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 32. | ES RCVR Input Noise, $N_0$ | (dBW/Hz) | -205.6 | |
| 33. | Downlink $C/N_0$ | (dB-Hz) | 56.1 | |
| | | **NETWORK** | | |
| 34. | Total $C/N_0$ | (dB-Hz) | 54.3 | |
| 35. | Required $C/N_0$ | (dB-Hz) | 50.0 | For SCPC-FM |
| 36. | Margin | (dB) | 4.3 | For One Duplex Circuit |

Table B-9. Link Budget for PEACESAT Utilization of GOES for Conditions of Four Accesses (Two Duplex Circuits) and "Low" Signal Input Power (HPA Output Power Equals 50 W)

| Link Budget Step | Units | Value | Comments |
|---|---|---|---|
| | **UPLINK** | | |
| 1. ES XMTR (HPA) Power Output | (dBW) | 17.0 | About 50 W; Required for $(c/n)_{up}$ = 0.1 (-10 dB) |
| 2. XMTR Line/Diplexer Loss (2030 MHz) | (dB) | 1.6 | Table 6-5, Ford (1977) |
| 3. XMT Antenna Gain (3-m parabola) | (dB) | 33.2 | Assume = 0.50 |
| 4. Uplink EIRP (2030 MHz) | (dBW) | 48.6 | |
| 5. Free-space Loss | (dB) | 190.3 | $\alpha$ = 30°, 2030 MHz |
| 6. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 7. S/C RCV Antenna Gain | (dB) | 13.8 | Table 6-5, Ford (1977) |
| 8. Off Beam-Center Reduction (8.4°) | (dB) | 2.5 | Table 6-5, Ford (1977) |
| 9. RCV Line Loss, Rotary Joint, Etc. | (dB) | 6.8 | Table 6-5, Ford (1977) |
| 10. Rec'd Power, S/C RCVR Input | (dBW) | -137.4 | $(c/n)_{up}$ = 0.1 (-10 dB) |
| [Noise power, S/C RCVR Input | (dBW) | -127.4 | 8.2 MHz BW] |
| 11. S/C RCV System Noise Temp. | (dB-K) | 32.1 | 1630 K; Table 6-5, Ford (1977) |
| 12. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 13. S/C RCVR Input Noise, $N_o$ | (dBW/Hz) | -196.5 | |
| 14. Uplink $C/N_o$ | (dB-Hz) | 59.1 | |
| | **DOWNLINK** | | |
| 15. S/C XMTR (TWTA) Pwr Output (Max) | (dBW) | 13.5 | 43.5 dBm; Table 6-5, Ford (1977) |
| 16. Power Sharing Loss | (dB) | 17.0 | 0.025 (2.5%) of total power out minus 1 dB |
| 17. Intermodulation Loss | (dB) | 1.1 | $\pi/4$ useful output power |
| 18. XMTR Line Loss, Rotary Joint, Etc. | (dB) | 4.3 | Table 6-5, Ford (1977) |
| 19. S/C XMT Antenna Gain | (dB) | 17.6 | Table 6-5, Ford (1977) |
| 20. Off Beam Center Reduction (8.7°) | (dB) | 2.4 | Table 6-5, Ford (1977) |
| 21. Downlink EIRP (1688 MHz) | (dBW) | 6.3 | |
| 22. Free-space Loss | (dB) | 188.7 | $\alpha$ = 30°, 1688 MHz |
| 23. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 24. RCV Antenna Gain (3-m parabola) | (dB) | 31.6 | Assume = 0.50 |
| 25. Pointing Error Loss | (dB) | 0.5 | Assumption |
| 26. RCV Line/Diplexer Loss (1688 MHz) | (dB) | 1.0 | Assumption |
| 27. Rec'd Power, ES RCVR Input | (dBW) | -152.5 | |
| 28. ES RCV System Noise Temp. | (dB-K) | 23.0 | Assume $T_s$ = 200 K |
| 29. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 30. ES RCVR Input Noise, $N_o$ | (dBW/Hz) | -205.6 | |
| 31. Downlink $C/N_o$ | (dB-Hz) | 53.1 | |
| | **NETWORK** | | |
| 32. Total $C/N_o$ | (dB-Hz) | 52.1 | |
| 33. Required $C/N_o$ | (dB-Hz) | 50.0 | For SCPC-FM |
| 34. Margin | (dB) | 2.1 | For Two Duplex Circuits |

Table B-10. Link Budget for PEACESAT Utilization of GOES for Conditions of Single Access (One Simplex Circuit) and Signal Input Power Corresponding to HPA Output Power Equal to 30 W

| Link Budget Step | Units | Value | Comments |
|---|---|---|---|
| | **U P L I N K** | | |
| 1. ES XMTR (HPA) Power Output | (dBW) | 14.8 | 30-W HPA |
| 2. XMTR Line/Diplexer Loss (2030 MHz) | (dB) | 1.6 | Table 6-5, Ford (1977) |
| 3. XMT Antenna Gain (3-m parabola) | (dB) | 33.2 | Assume = 0.50 |
| 4. Uplink EIRP (2030 MHz) | (dBW) | 46.4 | (74.6 dBm) |
| 5. Free-space Loss | (dB) | 190.3 | $\alpha$ = 30°, 2030 MHz |
| 6. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 7. S/C RCV Antenna Gain | (dB) | 13.8 | Table 6-5, Ford (1977) |
| 8. Off Beam-Center Reduction (8.4° | (dB) | 2.5 | Table 6-5, Ford (1977) |
| 9. RCV Line Loss, Rotary Joint, Etc. | (dB) | 6.8 | Table 6-5, Ford (1977) |
| 10. Rec'd Power, S/C RCVR Input | (dBW) | -139.6 | $(c/n)_{up}$=0.06 (-12.2 dB) |
| [Noise power, S/C RCVR Input | (dBW) | -127.4 | 8.2 MHz BW] |
| 11. S/C RCV System Noise Temp. | (dB-K) | 32.1 | 1630 K; Table 6-5, Ford (1977) |
| 12. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 13. S/C RCVR Input Noise, $N_o$ | (dBW/Hz) | -196.5 | |
| 14. Uplink $C/N_o$ | (dB-Hz) | 56.9 | |
| | **D O W N L I N K** | | |
| 16. S/C XMTR (TWTA) Pwr Output (Max) | (dBW) | 13.5 | 43.5 dBm; Table 6-5, Ford (1977) |
| 17. Power Sharing Loss | (dB) | 13.2 | 0.06 (6%) of total power out minus 1 dB |
| 18. Intermodulation Loss | (dB) | --- | None for single access |
| 19. XMTR Line Loss, Rotary Joint, Etc. | (dB) | 4.3 | Table 6-5, Ford (1977) |
| 20. S/C XMT Antenna Gain | (dB) | 17.6 | Table 6-5, Ford (1977) |
| 21. Off Beam Center Reduction (8.7°) | (dB) | 2.4 | Table 6-5, Ford (1977) |
| 22. Downlink EIRP (1688 MHz) | (dBW) | 11.2 | |
| 23. Free-space Loss | (dB) | 188.7 | $\alpha$ = 30°, 1688 MHz |
| 24. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 25. RCV Antenna Gain (3-m parabola) | (dB) | 31.6 | Assume = 0.50 |
| 26. Pointing Error Loss | (dB) | 0.5 | Assumption |
| 27. RCV Line/Diplexer Loss (1688 MHz) | (dB) | 1.0 | Assumption |
| 29. Rec'd Power, ES RCVR Input | (dBW) | -147.6 | |
| 30. ES RCV System Noise Temp. | (dB-K) | 23.0 | Assume $T_s$ = 200 K |
| 31. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 32. ES RCVR Input Noise, $N_o$ | (dBW/Hz) | -205.6 | |
| 33. Downlink $C/N_o$ | (dB-Hz) | 58.0 | |
| | **N E T W O R K** | | |
| 34. Total $C/N_o$ | (dB-Hz) | 54.4 | |
| 35. Required $C/N_o$ | (dB-Hz) | 50.0 | For SCPC-FM |
| 36. Margin | (dB) | 4.4 | For One Simplex Circuit |

Table B-11. Link Budget for PEACESAT Utilization of GOES for Conditions of Two Accesses (One Duplex Circuit) and Signal Input Power Corresponding to HPA Output Power Equal to 30 W

| Link Budget Step | Units | Value | Comments |
|---|---|---|---|
| | **UPLINK** | | |
| 1. ES XMTR (HPA) Power Output | (dBW) | 14.8 | 30-W HPA |
| 2. XMTR Line/Diplexer Loss (2030 MHz) | (dB) | 1.6 | Table 6-5, Ford (1977) |
| 3. XMT Antenna Gain (3-m parabola) | (dB) | 33.2 | Assume = 0.50 |
| 4. Uplink EIRP (2030 MHz) | (dBW) | 46.4 | |
| 5. Free-space Loss | (dB) | 190.3 | $\alpha$ = 30°, 2030 MHz |
| 6. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 7. S/C RCV Antenna Gain | (dB) | 13.8 | Table 6-5, Ford (1977) |
| 8. Off Beam-Center Reduction (8.4°) | (dB) | 2.5 | Table 6-5, Ford (1977) |
| 9. RCV Line Loss, Rotary Joint, Etc. | (dB) | 6.8 | Table 6-5, Ford (1977) |
| 10. Rec'd Power, S/C RCVR Input | (dBW) | -139.6 | $(c/n)_{up}$=0.06 (-12.2 dB) |
| [Noise power, S/C RCVR Input | (dBW) | -127.4 | 8.2 MHz BW] |
| 11. S/C RCV System Noise Temp. | (dB-K) | 32.1 | 1630 K; Table 6-5, Ford (1977) |
| 12. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 13. S/C RCVR Input Noise, $N_o$ | (dBW/Hz) | -196.5 | |
| 14. Uplink $C/N_o$ | (dB-Hz) | 56.9 | |
| | **DOWNLINK** | | |
| 16. S/C XMTR (TWTA) Pwr Output (Max) | (dBW) | 13.5 | 43.5 dBm; Table 6-5, Ford (1977) |
| 17. Power Sharing Loss | (dB) | 16.2 | 0.03 (3%) of total power out minus 1 dB |
| 18. Intermodulation Loss | (dB) | 1.1 | $\pi/4$ useful output power |
| 19. XMTR Line Loss, Rotary Joint, Etc. | (dB) | 4.3 | Table 6-5, Ford (1977) |
| 20. S/C XMT Antenna Gain | (dB) | 17.6 | Table 6-5, Ford (1977) |
| 21. Off Beam Center Reduction (8.7°) | (dB) | 2.4 | Table 6-5, Ford (1977) |
| 22. Downlink EIRP (1688 MHz) | (dBW) | 7.1 | |
| 23. Free-space Loss | (dB) | 188.7 | $\alpha$ = 30°, 1688 MHz |
| 24. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 25. RCV Antenna Gain (3-m parabola) | (dB) | 31.6 | Assume = 0.50 |
| 26. Pointing Error Loss | (dB) | 0.5 | Assumption |
| 27. RCV Line/Diplexer Loss (1688 MHz) | (dB) | 1.0 | Assumption |
| 29. Rec'd Power, ES RCVR Input | (dBW) | -151.7 | |
| 30. ES RCV System Noise Temp. | (dB-K) | 23.0 | Assume $T_s$ = 200 K |
| 31. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 32. ES RCVR Input Noise, $N_o$ | (dBW/Hz) | -205.6 | |
| 33. Downlink $C/N_o$ | (dB-Hz) | 53.9 | |
| | **NETWORK** | | |
| 34. Total $C/N_o$ | (dB-Hz) | 52.1 | |
| 35. Required $C/N_o$ | (dB-Hz) | 50.0 | For SCPC-FM |
| 36. Margin | (dB) | 2.1 | For One Duplex Circuit |

Table B-12. Link Budget for PEACESAT Utilization of GOES for Conditions of Four Accesses (Two Duplex Circuits) and Signal Input Power Corresponding to HPA Output Power Equal to 30 W

| | Link Budget Step | Units | Value | Comments |
|---|---|---|---|---|
| | **UPLINK** | | | |
| 1. | ES XMTR (HPA) Power Output | (dBW) | 14.8 | 30-W HPA |
| 2. | XMTR Line/Diplexer Loss (2030 MHz) | (dB) | 1.6 | Table 6-5, Ford (1977) |
| 3. | XMT Antenna Gain (3-m parabola) | (dB) | 33.2 | Assume = 0.50 |
| 4. | Uplink EIRP (2030 MHz) | (dBW) | 46.4 | |
| 5. | Free-space Loss | (dB) | 190.3 | $\alpha$ = 30°, 2030 MHz |
| 6. | Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 7. | S/C RCV Antenna Gain | (dB) | 13.8 | Table 6-5, Ford (1977) |
| 8. | Off Beam-Center Reduction (8.4°) | (dB) | 2.5 | Table 6-5, Ford (1977) |
| 9. | RCV Line Loss, Rotary Joint, Etc. | (dB) | 6.8 | Table 6-5, Ford (1977) |
| 10. | Rec'd Power, S/C RCVR Input | (dBW) | -139.6 | $(c/n)_{up}$=0.06 (-12.2 dB) |
| | [Noise power, S/C RCVR Input | (dBW) | -127.4 | 8.2 MHz BW] |
| 11. | S/C RCV System Noise Temp. | (dB-K) | 32.1 | 1630 K; Table 6-5, Ford (1977) |
| 12. | Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 13. | S/C RCVR Input Noise, $N_0$ | (dBW/Hz) | -196.5 | |
| 14. | Uplink $C/N_0$ | (dB-Hz) | 56.9 | |
| | **DOWNLINK** | | | |
| 15. | S/C XMTR (TWTA) Pwr Output (Max) | (dBW) | 13.5 | 43.5 dBm; Table 6-5, Ford (1977) |
| 16. | Power Sharing Loss | (dB) | 19.2 | 0.015 (1.5%) of total power out minus 1 dB |
| 17. | Intermodulation Loss | (dB) | 1.1 | $\pi/4$ useful output power |
| 18. | XMTR Line Loss, Rotary Joint, Etc. | (dB) | 4.3 | Table 6-5, Ford (1977) |
| 19. | S/C XMT Antenna Gain | (dB) | 17.6 | Table 6-5, Ford (1977) |
| 20. | Off Beam Center Reduction (8.7°) | (dB) | 2.4 | Table 6-5, Ford (1977) |
| 21. | Downlink EIRP (1688 MHz) | (dBW) | 4.1 | |
| 22. | Free-space Loss | (dB) | 188.7 | $\alpha$ = 30°, 1688 MHz |
| 23. | Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 24. | RCV Antenna Gain (3-m parabola) | (dB) | 31.6 | Assume = 0.50 |
| 25. | Pointing Error Loss | (dB) | 0.5 | Assumption |
| 26. | RCV Line/Diplexer Loss (1688 MHz) | (dB) | 1.0 | Assumption |
| 27. | Rec'd Power, ES RCVR Input | (dBW) | -154.7 | |
| 28. | ES RCV System Noise Temp. | (dB-K) | 23.0 | Assume $T_s$ = 200 K |
| 29. | Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 30. | ES RCVR Input Noise, $N_0$ | (dBW/Hz) | -205.6 | |
| 31. | Downlink $C/N_0$ | (dB-Hz) | 50.9 | |
| | **NETWORK** | | | |
| 32. | Total $C/N_0$ | (dB-Hz) | 49.9 | |
| 33. | Required $C/N_0$ | (dB-Hz) | 50.0 | For SCPC-FM |
| 34. | Margin | (dB) | -0.1 | For Two Duplex Circuits |

Table B-13. Link Budget for PEACESAT Utilization of GOES for Conditions of Two Accesses (One Duplex Circuit) and Signal Input Power Corresponding to HPA Output Power Equal to 20 W

| Link Budget Step | Units | Value | Comments |
|---|---|---|---|
| | **UPLINK** | | |
| 1. ES XMTR (HPA) Power Output | (dBW) | 13.0 | 20-W HPA |
| 2. XMTR Line/Diplexer Loss (2030 MHz) | (dB) | 1.6 | Table 6-5, Ford (1977) |
| 3. XMT Antenna Gain (3-m parabola) | (dB) | 33.2 | Assume = 0.50 |
| 4. Uplink EIRP (2030 MHz) | (dBW) | 44.6 | |
| 5. Free-space Loss | (dB) | 190.3 | $\alpha$ = 30°, 2030 MHz |
| 6. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 7. S/C RCV Antenna Gain | (dB) | 13.8 | Table 6-5, Ford (1977) |
| 8. Off Beam-Center Reduction (8.4°) | (dB) | 2.5 | Table 6-5, Ford (1977) |
| 9. RCV Line Loss, Rotary Joint, Etc. | (dB) | 6.8 | Table 6-5, Ford (1977) |
| 10. Rec'd Power, S/C RCVR Input | (dBW) | -141.4 | $(c/n)_{up}$=0.04 (-14.0 dB) |
| [Noise power, S/C RCVR Input | (dBW) | -127.4 | 8.2 MHz BW] |
| 11. S/C RCV System Noise Temp. | (dB-K) | 32.1 | 1630 K; Table 6-5, Ford (1977) |
| 12. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 13. S/C RCVR Input Noise, $N_0$ | (dBW/Hz) | -196.5 | |
| 14. Uplink $C/N_0$ | (dB-Hz) | 55.1 | |
| | **DOWNLINK** | | |
| 16. S/C XMTR (TWTA) Pwr Output (Max) | (dBW) | 13.5 | 43.5 dBm; Table 6-5, Ford (1977) |
| 17. Power Sharing Loss | (dB) | 18.0 | 0.03 (3%) of total power out minus 1 dB |
| 18. Intermodulation Loss | (dB) | 1.1 | $\pi/4$ useful output power |
| 19. XMTR Line Loss, Rotary Joint, Etc. | (dB) | 4.3 | Table 6-5, Ford (1977) |
| 20. S/C XMT Antenna Gain | (dB) | 17.6 | Table 6-5, Ford (1977) |
| 21. Off Beam Center Reduction (8.7°) | (dB) | 2.4 | Table 6-5, Ford (1977) |
| 22. Downlink EIRP (1688 MHz) | (dBW) | 5.3 | |
| 23. Free-space Loss | (dB) | 188.7 | $\alpha$ = 30°, 1688 MHz |
| 24. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 25. RCV Antenna Gain (3-m parabola) | (dB) | 31.6 | Assume = 0.50 |
| 26. Pointing Error Loss | (dB) | 0.5 | Assumption |
| 27. RCV Line/Diplexer Loss (1688 MHz) | (dB) | 1.0 | Assumption |
| 29. Rec'd Power, ES RCVR Input | (dBW) | -153.5 | |
| 30. ES RCV System Noise Temp. | (dB-K) | 23.0 | Assume $T_s$ = 200 K |
| 31. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 32. ES RCVR Input Noise, $N_0$ | (dBW/Hz) | -205.6 | |
| 33. Downlink $C/N_0$ | (dB-Hz) | 52.1 | |
| | **NETWORK** | | |
| 34. Total $C/N_0$ | (dB-Hz) | 50.3 | |
| 35. Required $C/N_0$ | (dB-Hz) | 50.0 | For SCPC-FM |
| 36. Margin | (dB) | 0.3 | For One Duplex Circuit |

Table B-14. Link Budget for PEACESAT Utilization of GOES for Conditions of Single Access (One Simplex Circuit) and Signal Input Power Corresponding to HPA Output Power Equal to 10 W

| Link Budget Step | Units | Value | Comments |
|---|---|---|---|
| | **UPLINK** | | |
| 1. ES XMTR (HPA) Power Output | (dBW) | 10.0 | 10-W HPA |
| 2. XMTR Line/Diplexer Loss (2030 MHz) | (dB) | 1.6 | Table 6-5, Ford (1977) |
| 3. XMT Antenna Gain (3-m parabola) | (dB) | 33.2 | Assume = 0.50 |
| 4. Uplink EIRP (2030 MHz) | (dBW) | 41.6 | (74.6 dBm) |
| 5. Free-space Loss | (dB) | 190.3 | $\alpha$ = 30°, 2030 MHz |
| 6. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 7. S/C RCV Antenna Gain | (dB) | 13.8 | Table 6-5, Ford (1977) |
| 8. Off Beam-Center Reduction (8.4°) | (dB) | 2.5 | Table 6-5, Ford (1977) |
| 9. RCV Line Loss, Rotary Joint, Etc. | (dB) | 6.8 | Table 6-5, Ford (1977) |
| 10. Rec'd Power, S/C RCVR Input | (dBW) | -144.4 | $(c/n)_{up}$=0.02 (-17.0 dB) |
| [Noise power, S/C RCVR Input | (dBW) | -127.4 | 8.2 MHz BW] |
| 11. S/C RCV System Noise Temp. | (dB-K) | 32.1 | 1630 K; Table 6-5, Ford (1977) |
| 12. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 13. S/C RCVR Input Noise, $N_0$ | (dBW/Hz) | -196.5 | |
| 14. Uplink $C/N_0$ | (dB-Hz) | 52.1 | |
| | **DOWNLINK** | | |
| 16. S/C XMTR (TWTA) Pwr Output (Max) | (dBW) | 13.5 | 43.5 dBm; Table 6-5, Ford (1977) |
| 17. Power Sharing Loss | (dB) | 18.0 | 0.02 (2%) of total power out minus 1 dB |
| 18. Intermodulation Loss | (dB) | --- | None for single access |
| 19. XMTR Line Loss, Rotary Joint, Etc. | (dB) | 4.3 | Table 6-5, Ford (1977) |
| 20. S/C XMT Antenna Gain | (dB) | 17.6 | Table 6-5, Ford (1977) |
| 21. Off Beam Center Reduction (8.7°) | (dB) | 2.4 | Table 6-5, Ford (1977) |
| 22. Downlink EIRP (1688 MHz) | (dBW) | 6.4 | |
| 23. Free-space Loss | (dB) | 188.7 | $\alpha$ = 30°, 1688 MHz |
| 24. Polarization Loss | (dB) | 0.2 | Table 6-5, Ford (1977) |
| 25. RCV Antenna Gain (3-m parabola) | (dB) | 31.6 | Assume = 0.50 |
| 26. Pointing Error Loss | (dB) | 0.5 | Assumption |
| 27. RCV Line/Diplexer Loss (1688 MHz) | (dB) | 1.0 | Assumption |
| 29. Rec'd Power, ES RCVR Input | (dBW) | -152.4 | |
| 30. ES RCV System Noise Temp. | (dB-K) | 23.0 | Assume $T_s$ = 200 K |
| 31. Boltzmann's Constant | (dBW/K-Hz) | -228.6 | |
| 32. ES RCVR Input Noise, $N_0$ | (dBW/Hz) | -205.6 | |
| 33. Downlink $C/N_0$ | (dB-Hz) | 53.2 | |
| | **NETWORK** | | |
| 34. Total $C/N_0$ | (dB-Hz) | 49.6 | |
| 35. Required $C/N_0$ | (dB-Hz) | 50.0 | For SCPC-FM |
| 36. Margin | (dB) | -0.4 | For One Simplex Circuit |

## APPENDIX C: GOES-2 AND GOES-3 MEASURED PERFORMANCE

This Appendix contains some description and the results of measurements that were performed on April 18, 1989, at Wallops Station, VA on both transponders and the VHF telemetry and command frequencies of the GOES-2 and GOES-3 satellites. These measurements were performed by a representative for a NASA contractor (for support to the GOES program) and a representative from NTIA, ITS. The information contained in this Appendix was prepared by the NASA contractor. That part of the contractor's memorandum report that is concerned with the R.F. Hardline Translator Measurements at Wallops on April 19, 1989, does not pertain to the issue of interim use of a GOES satellite for the PEACESAT network.

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GOES/WEC-89-021-LH-tj

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SUBJECT: 1. GOES-2 and GOES-3 Measured Performance. April 18, 1989.

2. R.F. Hardline Translator Measurements at Wallops. April 19, 1989.

DATE: April 24, 1989

1. It was recently proposed to drift GOES-2 or GOES-3 to a location over the Pacific for the purpose of relaying voice and data for interim PEACESAT use. In order to asses the performance requirements for the user stations and for the command and control station, it is necessary to know the present performance of GOES-2 and 3. For this reason, measurements were recently made at Wallops. The 60 foot "A" system was used and the following parameters were measured on both sides of GOES-2 and 3:

- o MFR Transponder Gain Transfer Characteristic.
- o MFR Receive G/T.
- o MFR Transmit EIRP.
- o S-Band Telemetry EIRP.
- o S-Band Command Threshold.
- o VHF Command Threshold.

These are discussed in turn below.

o <u>MFR Transponder Gain Transfer Characteristic</u>

Figure 1 shows curves of relative received signal level vs uplink EIRP from Wallops. For reference, the operating point for a 10 foot dish and 10 watt P.A. is shown. The satellite P.A. is saturated on earth noise. Equal power sharing between noise and signal occurs for an uplink EIRP of some 86 dBm.

o <u>MFR Receive G/T</u>

In order to minimize compression effects, the uplink carrier power was adjusted to obtain a downlink C/N in the transponder bandwidth equal to zero dB. The applicable equation to calculate G/T is:

G/T=C/Nos-EIRP+P.L-198.6

Where: G/T is satellite receive system G/T in dB/K. C/Nos is ground received C/No, where No is adjusted to reflect transponder pedestal noise.

EIRP is ground transmitted EIRP, dBm.
P.L. is uplink path loss.

The G/T's are summarized below:

GOES-2, side 1: G/T=67.5-85.1+190.5-198.6=-25.7 dB/K
GOES-2, side 2: G/T=70.6-87.1+190.5-198.6=-24.6 dB/K

GOES-3, side 1: G/T=68.7-85.1+190.5-198.6=-24.5 dB/K
GOES-3, side 2: G/T=68.4-83.1+190.5-198.6=-22.8 dB/K

o MFR Transmit EIRP

The MFR transponder gain is such that the operating point on the gain transfer curve is well into saturation with no accessing power except that due to earth noise. The EIRP in the bandwidth is therefore constant, but the downlink signal power varies as the accessing signal power. This characteristic was measured for a range of uplink power levels. C/No was measured in the ground receive IF and the satellite EIRP was calculated according to the following relation:

EIRP=C/Nog+P.L.-G/T-198.6

Where: EIRP is satellite effective radiated carrier power in the direction of the earth station

C/Nog is ground received C/No, where No is ground station noise only.

P.L. is downlink path loss.

G/T is ground station receive G/T.

Figure 2 below gives the EIRP at beam center for both sides of GOES-2 and 3. For earth edge, from the S-Band antenna pattern measurements, the decrease in EIRP in the worst case is 2 dB. Figure 2 shows curves of satellite signal EIRP vs. ground station EIRP.

o S-Band Command Threshold

This and the following two tests are of particular interest for a command and control station located in Hawaii.

For this test, the NOP Command was transmitted using a range of uplink powers, and the number of times out of ten the command got in was noted for each uplink power level. The results are given below:

| Uplink EIRP,dBM | Number of successful commands out of 10. |
|---|---|
| 91 | 10 |
| 84 | 10 |
| 81 | 7 |
| 78 | 0 |
| 73 | 0 |

The threshold for successful commanding is between 81 and 84 dBm EIRP. This corresponds to some 100 watts into a ten foot dish. No other S-Band command tests were run.

o S-Band Telemetry EIRP

The GOES-2 and 3 telemetry EIRP was measured by widening the spectrum analyzer to include all the energy in the modulation sidebands. The following equation was used:

EIRP=C/No+P.L.-G/T-198.6

Where: EIRP is the satellite telemetry effective radiated power in the direction of the earth station.

C/No is measured in the ground receiver IF and No is with respect to ground station noise.

P.L. is downlink path loss.

G/T is the earth station receive system G/T.

The results are given below:

| Satellite | Telemetry EIRP |
|---|---|
| GOES-2 side 1 | 31.1 dBm |
| GOES-2 side 2 | Not measured |
| GOES-3 side 1 | 37.6 dBm |
| GOES-3 side 2 | 33.2 dBm |

o VHF Command Threshold

While on GOES-2 side 1, a few VHF Commands were tried at different transmitter power levels. The 16 element VHF antenna was used. The gain of this antenna is nominally 20 dB, but since it is not normally used at Wallops, some loss of gain due to deterioration is likely. The VHF command threshold is therefore subject to error in this test. It should be noted that during post launch tests in 1978, the EIRP corresponding to 100W VHF transmitter power was sufficient to assure nearly 100% command success. The present results are as follows:

| VHF XMTR Power | Number of successful commands out of 10. |
|---|---|
| 50W | 0 |
| 100W | 2 |
| 200W | 9 |

If a VHF command link is set up at Goldstone or Hawaii, trans-ionospheric effects should be taken into account when working out the VHF command link, to assure adequate margin during periods of scintillation activity.

2. R.F. Hardline Translator Measurements

Measurements were made on the E.M. S-S translator, after installation in the 60ft "A" deckhouse by Bendix. The The measurements were:

- o Absolute R.T. Delay.
- o Translator Output Level vs. Attenuator Setting.
- o Translation Frequency.
- o Spurs.
- o Phase Noise.

o Absolute Round Trip Delay Time

The absolute round trip delay time from the operations room through the translator and back was measured at 3.3 m sec, including a modulator and demodulator used in the measurement setup.

o Translator Output Level

It was of interest to measure output level for two reasons:

a. Verify that no damage to the translator or receiver pre amp would result if 500W were inadvertently switched into the translator input line.

b. Determine what translator attenuation corresponds to the anticipated GOES-I PDL received signal level. when .25W transmitter power is switched into the translator.

The Answer to (a) is that, without subjecting the Translator or Wallops receive equipment to the risk of high accessing signal power, it was verified that with 500W transmitter power, the RF amplifiers would be in compression, but no damage would result. This is true regardless of the variable attenuator settings in the translator.

The Answer to (b) is that, when .25W is switched into the translator, with variable attenuators on zero dB, the signal level out of the IF receive port is some 4 dB below the expected received PDL signal level from GOES-I. There is a manual gain adjust in the translator for the purpose of adjusting this reference level. The attenuation range is sufficient to meet the requirements of the PDR ranging cal. Also, it should be noted that for the final installation, low loss foam flex will be used for the signal line from the deckhouse to the vertex room, instead of the RG-214 used in the temporary hookup.

o <u>Translation Frequency</u>

With the automatic spectrum analyzer in the frequency measurement mode, the frequency difference between the uplink and downlink IF's was measured at 391.999940 MHz. This value includes the frequency offset in the Wallops uplink and downlink L.O.'s, and also reflects the translator internal reference mode, instead of external, which is the normal operational mode.

o <u>Spurs and Phase Noise</u>

The translated spectrum was examined for spurs and excessive phase noise. Five Spurs were found. Four of these, and the phase noise around the carrier are shown in Figure 3. The fifth spur was seen to be 7 MHz above the carrier at 35 dB down. These spurs were not seen during factory acceptance and no investigation was carried out to determine their source at Wallops. They are not anticipated to cause a problem.

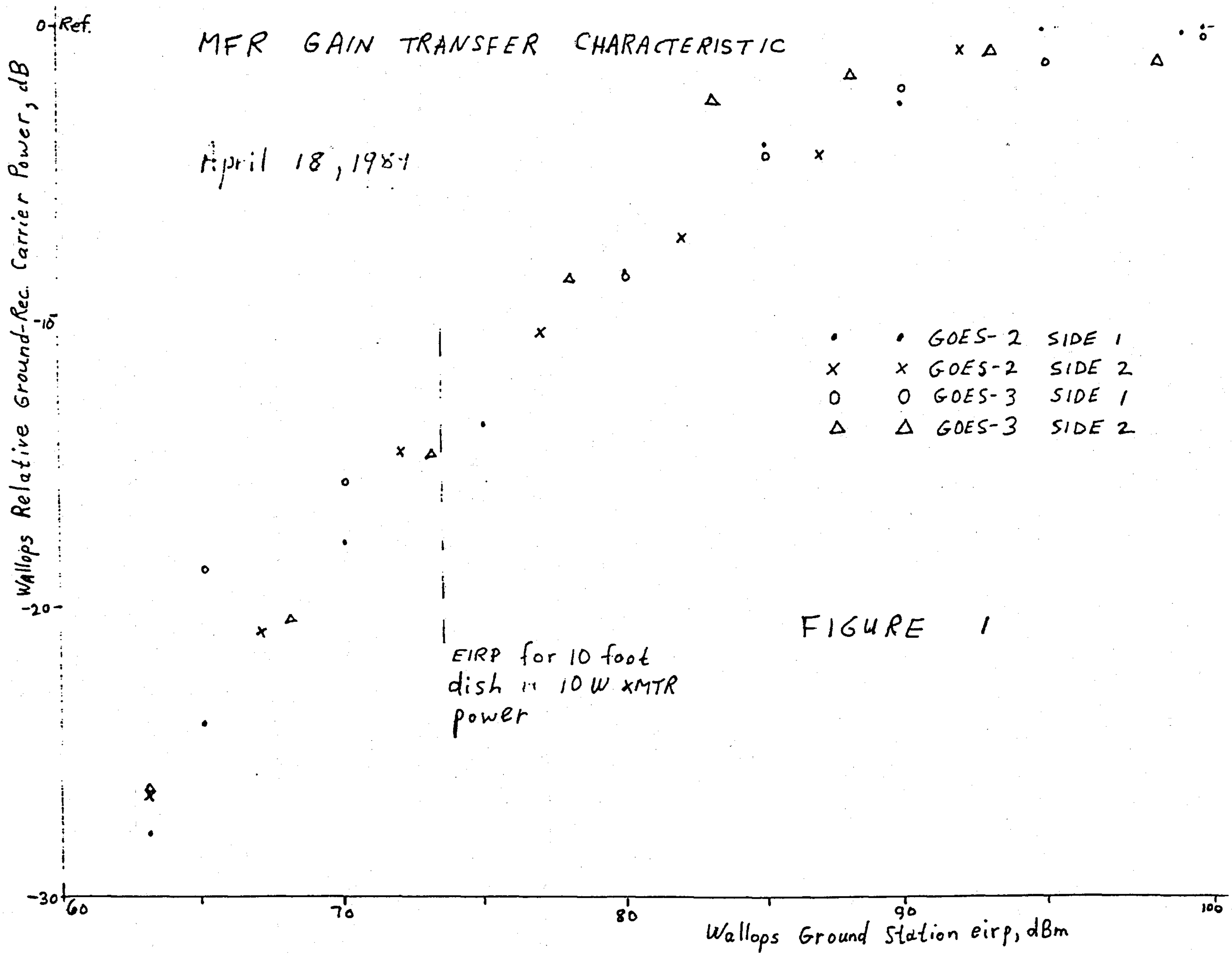
MFR GAIN TRANSFER CHARACTERISTIC
April 18, 1984
0 Ref.
-10
-20
-30
Wallops Relative Ground-Rec. Carrier Power, dB
60
70
80
90
100
Wallops Ground Station eirp, dBm
• GOES-2 SIDE 1
x GOES-2 SIDE 2
O GOES-3 SIDE 1
Δ GOES-3 SIDE 2
EIRP for 10 foot dish " 10 W XMTR power

FIGURE 1

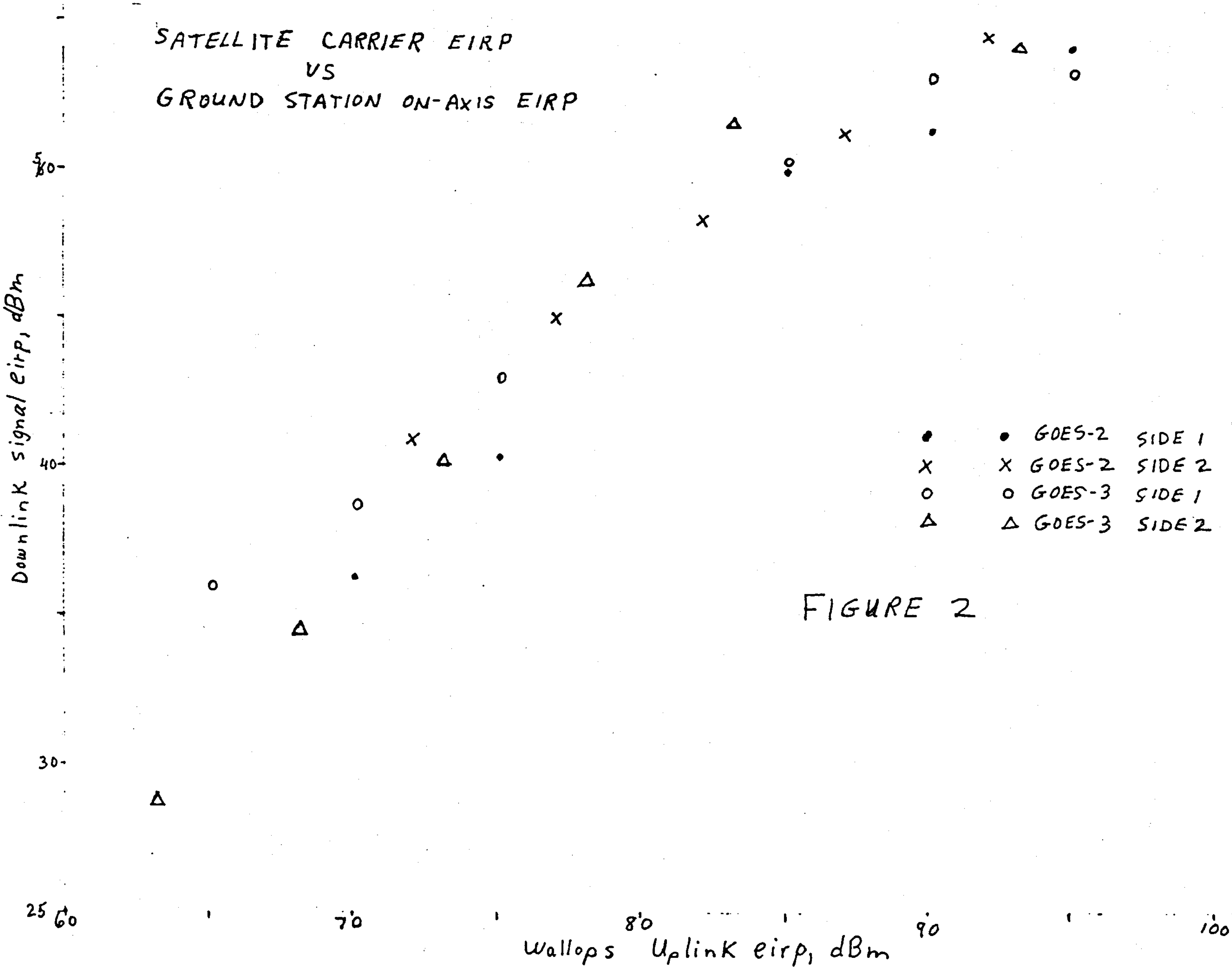
SATELLITE CARRIER EIRP
VS
GROUND STATION ON-AXIS EIRP
Downlink signal eirp, dBm
50
40
30
25
60
70
80
90
100
Wallops Uplink eirp, dBm
GOES-2 SIDE 1
GOES-2 SIDE 2
GOES-3 SIDE 1
GOES-3 SIDE 2

FIGURE 2

S-S E.M. XLATOR OUTPUT REC IF
½ watt XMTR PWR.
0 dB α in translator.

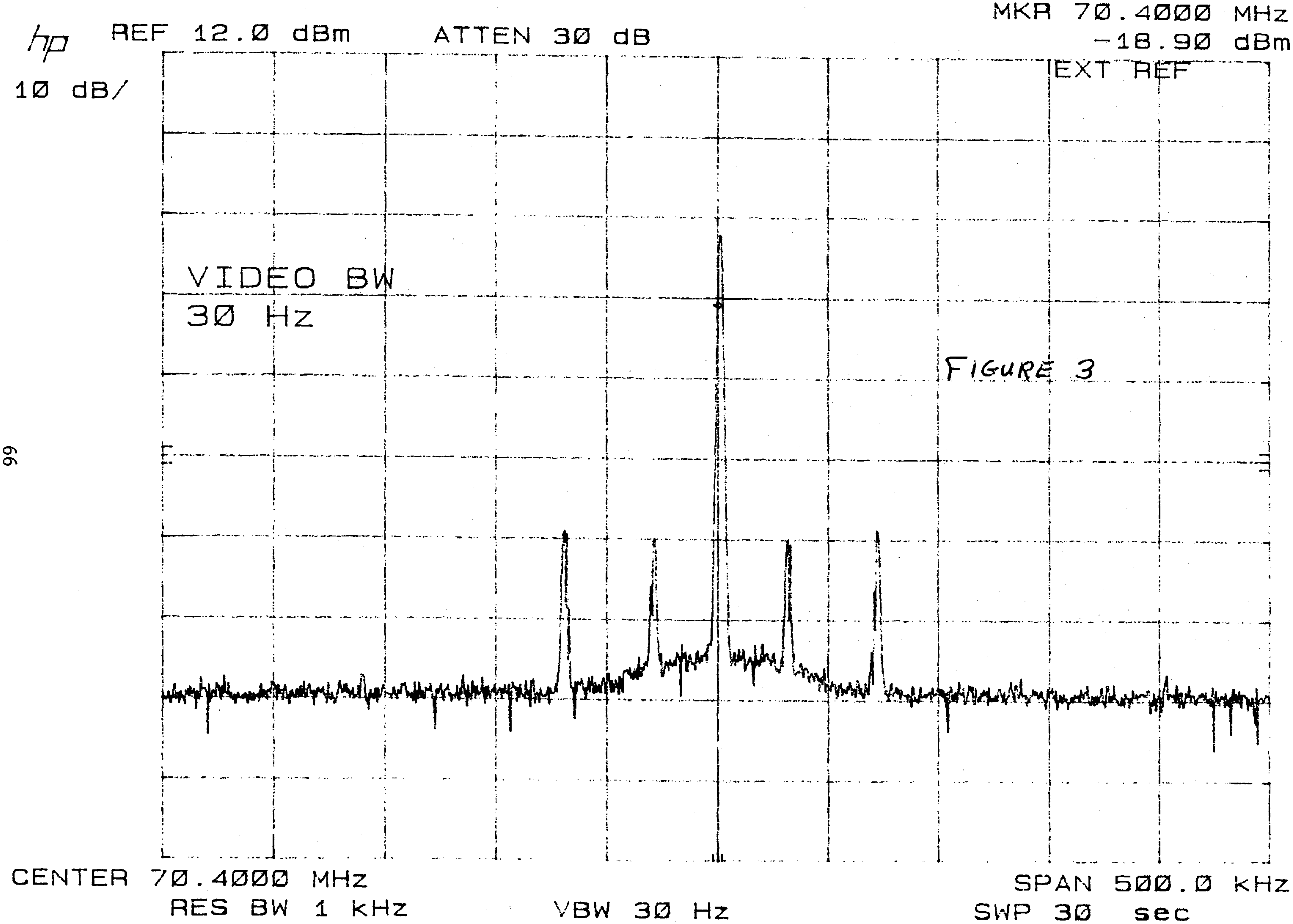


FIGURE 3

FORM **NTIA-29**
(4-80)

U.S. DEPARTMENT OF COMMERCE
NAT'L. TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION

# BIBLIOGRAPHIC DATA SHEET

| | 1. PUBLICATION NO. | 2. Gov't Accession No. | 3. Recipient's Accession No. |
|---|---|---|---|
| | | | |

**4. TITLE AND SUBTITLE**
Technical Considerations Concerning Use of a Geostationary Operationa Environmental Satellite (GOES) to Support the PEACESAT Network on an Interim Basis

**5. Publication Date**

**6. Performing Organization Code**
NTIA/ITS.N1

**7. AUTHOR(S)**
R.D. Jennings and R.D. Cass

**8. PERFORMING ORGANIZATION NAME AND ADDRESS**
National Telecommunications and Information Admin.
Institute for Telecommunications Sciences
325 Broadway
Boulder, CO 80303

**9. Project/Task/Work Unit No.**

**10. Contract/Grant No.**
Pan Pacific Educational & Cultural Experiments by Satellite (PEACESAT)

**11. Sponsoring Organization Name and Address**
National Telecommunications and Information Admin.
Herbert C. Hoover Bldg,m k4th & Constitution Ave., NW
Washington, DC 20230

**12. Type of Report and Period Covered**
Technical

**13.**

**14. SUPPLEMENTARY NOTES**

**15. ABSTRACT** *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The Institute for Telecommunication Sciences (ITS) has performed a number of technical tasks as part of the responsibilities of the National Telecommunications and Information Administration (NTIA) for re-establishing the Pan-Pacific Educational and Cultural Experiments by Satellite (PEACESAT) network and services provided by the network. This report contains a brief discussion of the PEACESAT network and services using the Applications Technology Satellite-1 (ATS-1) as background to the current work and the technical material developed at ITS in performing this work. The tasks supported by NTIA and for which this report contains material include: (1) participation in the Technical Options Panel (TOP) to define PEACESAT operational and users' requirements and the identification of possible satellite resources to replace the ATS-1 satellite, (2) a brief discussion

Continued on Reverse

**16. Key Words** *(Alphabetical order, separated by semicolons)*

Key Words: ATS-1; GOES; International PEACESAT Users' Group (IPUG); low-cost earth stations; PEACESAT; PEACESAT Impact Assessment Group (IAG); PEACESAT Technical Options Panel (TOP); satellite command and control

| 17. AVAILABILITY STATEMENT | 18. Security Class. *(This report)* | 20. Number of pages |
|---|---|---|
| ☒ UNLIMITED. | unclassified | 76 |
| ☐ FOR OFFICIAL DISTRIBUTION. | 19. Security Class. *(This page)* unclassified | 21. Price: |

☆ U.S. GOVERNMENT PRINTING OFFICE: 1990—773-002/11,041 REGION NO. 8

of the history of the Geostationary Operational Environmental Satellites (GOES) as a candidate satellite to replace ATS-1 with particular attention given to description of the GOES communication subsystem, (3) analysis of the suitability of the GOES S-Band transponder to support the PEACESAT network (as an interim solution), and (4) analysis of the technical consideration pertaining to command and control of a GOES satellite being used for PEACESAT during an interim period.